Evaluation of a shortened PSI intervention and establishing the suitability of PNF for inclusion in exercise-based falls prevention interventions

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Abstract

Risk of falling increases with age. Increasing falls incidence and associated injuries sustained by the growing older adult population contributes towards an increasing strain placed on local health services. Long-term exercise interventions have elicited significant reductions in falls incidence in community-dwelling older adults, and may be used in a preventative manner to reduce fall incidence in older adult populations. However, the effectiveness of shorter interventions is less well-known. Study One of this thesis identified that an 18-week postural stability instruction (PSI) programme is effective in reducing fall prevalence in frail older adults by 33%, and may improve health-related quality of life, confidence, and clinic-based strength and balance measures. However, gait performance and whole body lean mass remain unchanged. Study Two established that proprioceptive neuromuscular facilitation (PNF) stretching does not cause acute deficits in strength or muscle activation in the plantarflexors and is safe for use by healthy older adults as a flexibility training component of PSI interventions. Study Three found chronic strength and flexibility gains following completion of a 4-week PNF stretching intervention at the ankle in old and young adults, without any acute strength deficits. Chronic strength gains during higher velocity contractions were demonstrated in dorsiflexion in the older group, while flexibility gains demonstrated during knee flexion suggests a training effect on the soleus muscle. These findings indicate that and 18-week PSI programme reduces falls risk and prevalence, and that PNF training at the ankle may be used safely and effectively by healthy older adults to improve strength and flexibility. Refinement of individual PSI components to ensure implementation of the most effective and

age-appropriate strength, balance and flexibility training methods is warranted. Specifically there is a need for research to examine changes in falls incidence and risk factors following completion of an 18-week PSI intervention that incorporates PNF stretching.

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Contents

List of Figures

Abbreviations

A & E	Accident and Emergency
ACR	Agonist contract-relax
AHA	American Heart Association
ACSM	American College of Sports Medicine
ADL	Activities of daily living
ANOVA	Analysis of variance
AP	Anterior-posterior
ASIS	Anterior superior iliac spine
CBT	Clinic-based tests
COP	Centre of pressure
C-R	contract relax
CSA	Cross-sectional area
DXA	Dual energy X-ray absorptiometry
EMG	Electromyography
ES	Electrical stimulation
EuroQoL	European Quality of Life Instrument
EWGSOP	European Working Group on Sarcopenia in Older People

FaME	Falls Management Exercise Programme
FAEC	Balance Trial 4: Eyes closed, feet apart
FAEO	Balance Trial 3: Eyes open, feet apart
FTEC	Balance Trial 2: Eyes closed, feet together
FTEO	Balance Trial 1: Eyes open, feet together
FES	Falls Efficacy Scale
FES-I	Falls Efficacy Scale International
FP1	First force plate
FP2	Second force plate
GRF	Ground reaction forces
HAAP	Healthy Ageing Action Plan
HGD	Handgrip Dynamometry
MANOVA	Multi-variate analysis of variance
MCS	Mental Component Score
MFFRA	Multi-Factorial Falls Risk Assessment
MFFRI	Multi-Factorial Falls Risk Intervention
ML	Medio-lateral
MTU	Muscle tendon unit
MVC	Maximal voluntary contraction
NHS	National Health Service
NICE	National Institute of Clinical Excellence
NSF	National Service Framework for Older People in Wales

PARQ	Pre-activity health questionnaire
PCS	Physical Component Score
PNF	Proprioceptive neuromuscular facilitation
ProFaNE	Prevention of Falls Network Europe
PSI	Postural Stability Instruction
PTQ	Pre-test questionnaire
RCT	Randomised controlled trials
REP	Registered exercise professional
ROM	Range of motion
Romberg	Romberg's Balance Test
SD	Standard deviation
SE	Standard error
SF-12v.1	12-item Short Form Health Survey
SF-36	36-Item Short-Form Health Survey
STS	Sit-to Stand test
TGUG	Timed Get-Up-and-Go test
TTB	Time to boundary
USA	United States of America
UK	United Kingdom
WAG	Welsh Assembly Government
WHO	World Health Organisation
1RM	One-repetition maximum
3D	Three-dimensional

Part I

Chapter 1

Introduction

Longer life expectancies mean that the number of older adults is growing worldwide, and particularly in developed countries (1). In the United Kingdom (UK) life expectancy is presently 79.6 years, which is almost 13 years longer than the worldwide average (1). The risk of falling increases with age, and injuries resulting from falls are a major cause of disability in the UK (2). Injurious falls are associated with high mortality rates in older adults (3, 4), and treatment for fall-related injuries account for a high proportion of financial costs incurred by health services (5). Mobility impairments resulting from fall-related injuries, such as fractures, reduce independence (6) and quality of life (7) in older adults. Activity restriction associated with disability results in a limited capacity to perform day-to-day activities, socialise and work. The result is an overall reduction in economic and social contribution from fallers caused by increased dependence on state-provided disability allowances (8) and long-term health care (2).

Preventative interventions are needed to reduce the personal and economic costs of falling. Group- and home-based exercise programmes have been associated with reduced falls risk and incidence in older adults (9). A 36-week Postural Stability Instruction (PSI) programme has resulted in significant reductions in falls risk factors and overall falls incidence in older adults with balance impairments (10, 11). PSI targets strength, balance and flexibility, which are the three components for exercise recommended in worldwide and UK guidelines for exercise in older adult populations (12, 13, 14).

One in five of the population in Wales is aged 65 years or older (15) and, although long term health issues are more prevalent in Wales than in England, the Welsh unitary authority of Ceredigion has a longer life expectancy than the Welsh national average (16), and a lower prevalence of long term health care problems or disabilities (15). As one of the largest unitary authorities in Wales (15), providing adequate fall prevention services for Ceredigion is challenging due to the limitations to public and private transport caused by the long distances between the larger towns where health services are available (i.e.: hospitals) and the small rural communities. Due to these limitations in locations such as Ceredigion where resources are limited group classes are preferable, as they enable service delivery to larger numbers of patients using shorter outlays of time, travel and money compared to interventions delivered to individual patients.

The aim of the first study in this thesis is to examine the effects of an adapted version of the PSI programme implemented in Ceredigion, comprising of an initial 6-8 week hospital-based PSI programme, followed by a 10-12 week community-based PSI programme. Tests conducted to evaluate the effects of the programme measure changes in:

- Functional performance
- Fear of falling
- Balance and gait
- Quality of life
- Falls incidence during a six-month post-intervention follow-up period

Comparisons will also be made between laboratory- and clinic-based tests to establish whether the measures from these tests are consistent with one another.

Limited joint range of motion (ROM) is a factor that influences balance performance and may increase risk of falling in older adults (17), and consequently flexibility training is an important component of any exercise-based falls prevention interventions, including PSI. Typically static stretching methods are recommended - however, Proprioceptive Neuromuscular Facilitation (PNF) stretching methods which is an alternative flexibility training method has been shown to be equally effective in younger adults. However, so far there is little research evidence reporting the effects of PNF in older adults. The second and third studies in this thesis will evaluate the effects of PNF flexibility training in older adults and check that there is no acute or chronic detrimental effect of PNF stretching on strength in older adults. A comparison of ability to activate the muscles of the triceps surae group will also be made between old and young to inform the results of post-stretch strength-tests. The information gathered in these studies will be useful in demonstrating whether PNF stretching is effective and safe in improving ROM.

The purpose of this chapter has been to provide an introduction the research area of exercise for falls prevention, and to briefly outline the rationale for the studies within this thesis. The following chapters include a literature review in Chapter 2 which discusses the existing research evidence concerning the effects of ageing on risk of falling. The literature review will provide an overview of current statistics regarding the growth of the ageing population, and the influence this has on health service provision in the UK and worldwide. Research evidence discussed in the literature review will establish the behavioural, environmental, socio-economic, and biological falls risk factors. Also discussed are the recommended assessment tools used in falls risk assessments and current guidelines for exercise in older adults, including exercise-based falls prevention interventions and flexibility training methods. The literature review provides a background to contextualise the three research studies reported in the subsequent Chapters 3 to 5. The findings from the three studies will then be discussed in relation to the existing research evidence in Chapter 6. Conclusions regarding the implications of the most significant findings of the thesis will be made in Chapter 7, including suggestions for future research directions.

Chapter 2

Literature Review

2.1 Introduction

The purpose of this chapter is to present a review of the research literature concerning the implementation of exercise-based interventions to reduce falls incidence and risk factors in older adults. The chapter will first provide a brief overview of the older adult population in the UK, including life expectancy and falls incidence within this demographic. The chapter will then move on to discuss a number of risk factors that have been shown to be associated with a greater risk of falling, and the methods of assessment that will be implemented as part of the studies conducted later in the experimental chapters. Evidence-based recommendations made in guidelines for falls prevention in older adults will also be discussed. The review will draw attention to gaps in the research literature, and unanswered research questions will be highlighted. These research questions will inform the design of the research studies conducted in the subsequent chapters of this thesis.

2.2 Overview of Falling

2.2.1 Definition of Falling

A person who has experienced at least one fall during the last six to twelve months is defined as a faller (18), and someone who has experienced more than two falls during this period may be referred to as a recurrent faller (18). In research studies there are many definitions used for the term 'falling' (19, 20, 21, 22). Falls may also be categorised, for example, as injurious or non-injurious (23). This information is an important consideration when evaluating the causes and effects of falling in older adults, in particular when designing preventative interventions for falling. There are also notable differences in the interpretation of the term falling between different groups of people, influencing how frequently falls are reported and how effectively they are recorded. For example, researchers, health professionals and older adults have been shown to define the term of falling differently to each other (24). Older adults appear to be more focused on the details of why, when and how a fall occurs, as well as the consequences of a fall, compared to research-based definitions which tend to focus on the biomechanical events involved in a fall. The differences in definitions between researchers, health professionals and older adults may also offer an explanation as to why 'unspecified falls' are most likely to be reported in older adult fallers (2).

The number of definitions for the term falling used in research and clinical settings may be responsible for the variability in outcomes from evaluations of intervention and assessment (18, 24). A recent Cochrane Review, "Interventions for preventing falls in older people living in the community" (Review) by Gillespie et al. (9), identified the definition most commonly used in research studies to be that of Buchner et al. (19, p. 300), which defines falling as:

> "Unintentionally coming to rest on ground, floor, or other lower level; excludes coming to rest against furniture, wall, or other structure."

However, the Prevention of Falls Network Europe (ProFaNE) have made recommendations for the development of a dataset of common outcomes to be used widely in falls research, including specified definitions of terminology and research domains within falls. In line with these recommendations, the definition for falling used in this study is that recommended by ProFaNE (25, p. 1619):

> "An unexpected event in which the participants come to rest on the ground, floor, or lower level."

2.2.2 Falls in the UK

Risk of suffering from an injurious fall increases in later life (2). In the UK, injuries resulting from falls are a major cause of disability in adults over the age of 75 years and are therefore a serious health concern for older adults (2). However, many falls do not lead to injury and therefore the are not recorded. Due to this it is no possible to report the exact annual incidence of non-injurious falls. However, it is estimated that over 475,000 falls in patients over the age of 60 years are recorded by general practices in the UK annually, and falls within this age group have been found to be generally associated with higher rates of mortality and relative socio-economic deprivation (26).

Unintentional, non-fracture-related falls are the most frequently reported cause of accidental death in the UK (4). Mortality rates of recurrent fallers are double that of the general population (26) and older age is a significant factor; in England and Wales mortality rates following a fall in older adults aged 65-74 years are 8.7 per 100,000 of the population (27), and beyond the age of 75 years mortality rates increase dramatically to 57.6 (27). Generally, it is men who have a higher mortality rate following a fall than women; men aged between 65-74 years and men older than 75 years have mortality risks of 11.1 and 61.1 (per 100,000 of the population), respectively, compared to their female counterparts, whose risk is 6.6 and 54.8 (per 100,000 of the population), respectively (27). However, although the likelihood of death resulting from a fall is much greater in older men, overall they are less likely to experience a fall (28), as shown in a review of falls recorded in general practices in the UK (26). This may go some way in explaining the longer life expectancy in women compared to men.

However, fracture is one of the most common injuries sustained from falling (3). Risk of fracture increases with age, particularly at sites such as the hip, femur, vertebrae and pelvis (3), and fractures in the most common sites in later life, i.e.: the vertebrae and proximal femur, are also associated with an excess mortality rate in the five years following fracture diagnosis (3). A growing proportion of the population are living to reach an age at which they are at greater risk of sustaining a fracture (6), but recently an overall improved survival rate following hip fracture has been attributed to improved acute care (6). However, accompanying this increased survival rate is an increase in fall-related disability, resulting in reduced independence and increased proclivity to illness and longer recovery times, that requires increased provision of long-term health services (6).

Although information regarding injurious falls incidence has been investigated in the UK, there is only a limited amount of information regarding fall-related incidence available in the Welsh county of Ceredigion. As part of The Health, Social Care and Well-being Needs Assessment of 2010 (29) estimations for fall-related hospitalisations between 2008 and 2022 in east Ceredigion (Cyclch Caron) have been reported. The calculations were based on national prevalence of fall-related hospitalisations and local population growth rates. The projections estimated that there will be a 50% increase in fall-related hospitalisations in the area between 2008 and 2022 (29). In the UK, patients older than 75 years of age have been shown to be three times more likely than any other age group to attend Accident and Emergency services (A & E) following an unintentional fall, and in such cases are eleven times more likely to be hospitalised than their 60-64 year-old counterparts (2). In Ceredigion, falling is one of the most common reasons for hospital admission, alongside chronic respiratory conditions and dementia (29), and falls account for 17% of the local Ambulance Trust call-outs (29).

2.2.3 Ageing Populations

The proportion of older adults in the world population is growing, particularly in more developed countries (30). The United Nations Report “World Population Prospects: The 2010 Revision” (30) estimates that there were approximately 892,999,000 adults over the age of 60 years worldwide in 2011. Between 1950 and 2010 worldwide life expectancy increased from 47.7 to 66.8 years of age (30). However, average life expectancy in more developed countries is longer; in developed countries life expectancy is 76.9 years compared to 56.9 years in the least developed countries (30). The report also calculated the ratio of the population aged over 65 years per 100 of the population of working age (i.e.: 20-64 years), which is defined as ‘old-age dependency ratio’, and found that this increased from 10.1 to 13.4 between 1950 and 2010 (30). The data presented in Table 2.1) demonstrates how the increase in old-age dependency ratio has been much greater in more developed regions compared to less developed regions between 1950 and 2010, including in the UK (30). This data also shows how old-age dependency ratio is predicted to continue to increase worldwide between 2015 and 2100, but is expected to be most dramatic in the developed regions (Table 2.1).

	Year			
	1950	2010	2015	2100
Worldwide	10.1	13.4	14.3	21.9
Developed	14.0	25.9	28.8	62.5
Less developed	8.0	10.4	11.1	20.1
UK	17.9	27.8	30.6	63.3

Table 2.1: Estimated old-age dependency ratios (population aged over 65 years per 100 of the population of working age) worldwide between 1950 and 2100, including developed and undeveloped regions, and the UK. Data from United Nations: World Populations Prospects 2011 (30).

2.2.3.1 United Kingdom

In line with the patterns of increased life expectancies in other developed regions, the lowest ever age-standardised mortality rates England and Wales were recorded by the Office for National Statistics in 2011 (31)(Table 2.1). In the same year there were an estimated 17,182,000 adults over the age of 60 years in the United Kingdom (30), and average life expectancy was 79.6 years of age, with a difference of 4.3 years in life expectancy between men and women (30). A comparison of life expectancies of men and women in the UK, Wales, and the Welsh county of Ceredigion in 2011 is made in Table 2.2. Since 1950, life expectancy in the UK is estimated to have increased from 69.2 years in 1950 to 79.6 in 2011 (30).

There are gender differences for life expectancy in the UK; the data presented in Table 2.2 shows a longer average life expectancy for women in the UK, Wales and Ceredigion. In 1974 only 20% of all male deaths in the UK were in men aged over 80 years, compared to 44% of male deaths in 2011. However, women have generally outlived their male counterparts throughout this period, with 40% of female deaths occurring after the age of 80 years in 1974, increasing to 62% in 2010 (32). The effect of a growing older adult population in the UK has also resulted in changes in the ratio of old to young; between 1950 and 2010, old age-dependency ratio increased from 17.9 to 27.8 in the UK (30). In addition, it is predicted that this ration will increase from 30.6 in 2015 to 63.3 in 2100 - an increase that is much greater than the average for developed regions worldwide (30). This increased ratio means that greater numbers of dependent older adults will be reliant upon a smaller number of younger adults of working age in developed countries, including the UK.

	Life Expectancy (Years)	
	Men	Women
UK	77.4	81.7
Wales	77.2	81.6
Ceredigion	80.4	84.1

Table 2.2: Estimated life expectancies for the UK, Wales and the Welsh unitary authority of Ceredigion in 2011. Data from United Nations: World Populations Prospects 2011 (30) and Office for National Statistics (16).

2.2.3.2 Wales

In Wales the national life expectancy is 77.2 years for men and 81.6 years for women (16). The current mean age for inhabitants of Wales is 40.6 years (15), and almost one in five (n = 563,000) of Wales' growing 3.1 million population are aged 65 years or older (15). Despite only a marginal difference in life expectancy in Wales from the UK average, shown in Table 2.2, prevalence of long term health problems or disabilities are higher in Wales than in any region in England, and such problems affect an estimated 23% (n = 696,000) of the Welsh population (15).

Disability-free life expectancy in older adults is shorter in Wales than in England; after the age of 65 years men and women in Wales are expected to live with one or more disability for over half of their remaining life (33). Activity limitations in Wales are also greater than in any English region, with almost 12% of the Welsh population aged 16-64 years reporting that they are limited a lot, and 11% limited a little' (34). In combination with longer life expectancies, the high proportion of the Welsh population currently living with disability at a younger age helps to explain the increased incidence of disability in later life in Wales.

2.2.3.3 Ceredigion

Those living in the unitary authority of Ceredigion are expected to live longer than the national average to 80.4 years and 84.1 years for men and women, respectively, as shown in Table 2.2 (16). Furthermore, Ceredigion has one of the lowest numbers of inhabitants with reported long term health care problems or disabilities in Wales (15). However, Ceredigion is the fourth largest authority in Wales, being 178,545 hectares in area, and has the second lowest population density, with only 0.5 persons per hectare of land (15).

The 2010 Health, Social Care and Well-being Needs Assessment by Ceredigion County Council showed that the mid-year population of Ceredigion in 2007 was estimated to be 77,777 (excluding higher education students), and of this number 7,395 were over the age of 75 years (29). Based on these values it is predicted that between 2008 and 2026 the resident population of Ceredigion will increase by 8,600 people, and that 7,500 of this number will be over the age of 65 years - representing a 47% increase in the population of adults over 65 years (29). Furthermore, it is estimated that 1,500 of this older adult demographic will be over the age of 85 years, which represents a 67% increase in the number of older adults belonging to this age group (29). The older adult population is most concentrated in the more rural, southerly parts of the county, such as Cardigan (29). Therefore, improved provision of health and social care services in these rural locations are needed in order to deal with increasing needs of the growing older adult population - in particular, addressing the prevention of falls which has been highlighted as one of the most common reasons for hospital admission in the county.

2.3 Falls Management

2.3.1 Policy for Wales

In 2006 the Welsh Assembly Government launched a 'National Service Framework for Older People in Wales' (NSF) in 2006 (35). The Welsh NSF set ten national standards for healthcare provision in Wales, ensuring that health, well being and independence are maintained for as long as possible in older adult populations, with an aim to provide the highest quality treatment and support possible, including falls and fracture treatment. The ten Welsh NSF standards are (35):

- Rooting out age discrimination
- Providing person centred care
- Promoting health and well being
- Challenging dependency
- Intermediate care
- Hospital care
- Stroke
- Falls and fractures
- Mental health in older age
- Medicines and older people

The Welsh NSF standard for Falls and Fractures states the following (35):

> The NHS, working in partnership with Local Authorities and other stakeholders, takes action to prevent falls, osteoporosis, fracture and other resulting injuries, and to maintain well being in their population of older people. Older people who have fallen receive effective treatment and rehabilitation and, with their carers, receive advice on prevention through integration of falls and fracture services.

The 'Healthy Ageing Action Plan' (HAAP) (36) is a health promotion initiative set up by the Welsh Assembly Government (WAG) to complement the NSF standards. HAAP also highlights the importance of exercise in the prevention of falls, in line with recommendations made in the Welsh NSF guidelines for falls and fractures (35, 36). The key points made by HAAP concerning exercise interventions and falls prevention are as follows (36):

- Exercise can maintain or improve bone density although there is insufficient evidence for the beneficial effects of exercise as a single intervention in preventing falls.
- Interventions to reduce falls appear to be most successful when targeted at intrinsic and environmental factors.
- Prevention of falls can best be achieved by strategies aimed at both the general population and high-risk groups, incorporating multiple intervention programmes.

Action required by local authorities in response to the NSF standards include implementation of a multi-factorial falls prevention strategy, addressing risk factors in line with NICE guideline recommendations (14, 35). In addition, the key actions to be taken in response to the HAAP initiative include local strategies for older people, including evidence-based action to reduce falls through both primary prevention of falls, as well as secondary prevention, i.e.: rehabilitation from falls for those who have already fallen and therefore are at risk of recurrent falls (36).

2.3.2 Guidelines for Assessment and Intervention

2.3.2.1 Falls Risk Assessment

Multi-Factorial Falls Risk Assessments (MFFRA) are formally recommended in the NICE guidelines for falls prevention and assessment (14). MFFRAs have been introduced as standard components of NHS falls prevention services in response to increasing research evidence that shows the large number of risk factors influencing overall falls risk. MFFRAs are administered to identify the number and magnitude of risk factors affecting individuals, and thus predict and reduce their risk of falling. Multi-factorial assessments may consider a broader number of factors, such as medical, disability, physical, cognitive, and psychological measures which have varying predictive power depending on the population subgroups being assessed.

The current Welsh NSF guidelines state that local authorities in Wales must implement multi-factorial falls prevention strategies in line with NICE guideline recommendations (35). The risk factors recommended for inclusion in MFFRA by the NICE guideline 21 (14) are:

- Identification of falls history
- Assessment of gait, balance and mobility, and muscle weakness
- Assessment of osteoporosis risk
- Assessment of the older persons perceived functional ability and fear relating to falling
- Assessment of visual impairment
- Assessment of cognitive impairment and neurological examination
- Assessment of urinary incontinence
- Assessment of home hazards
- Cardiovascular examination and medication review

2.3.2.2 Falls Risk Intervention

Multi-Factorial Falls Risk Interventions (MFFRI) are implemented to reduce a number of risk factors identified during an MFFRA. On a global scale, recommendations made by the The World Health Organisation (WHO) in the WHO ‘Falls Prevention for Active Ageing’ model (37) includes an action plan for reducing the worldwide prevalence of falls in older adults through implementation of the organisation’s ‘three pillars of falls prevention’, which are:

1. Building awareness of the importance of falls prevention and treatment
2. Improving the assessment of individual, environmental, and societal factors that increase the likelihood of falls
3. For facilitating the design and implementation of culturally-appropriate, evidence-based interventions that will significantly reduce the number of falls among older persons

Under the third pillar, which concerns the identification and implementation of most effective interventions, the WHO makes specific recommendations for MF-FRI to include:

- Medical assessment
- Home safety checks and advice
- Monitoring of prescription medications
- Environmental changes
- Tailored exercise and physical activity
- Training in transfer skills and gait
- Assessment of readiness to change behaviour
- Referral of clients to health-care professionals

In Wales, the NSF guidelines (35) indicate that local authorities must provide interventions to address the risk factors listed in the criteria outlined in the NICE guideline recommendations (14), i.e.: gait, balance, mobility, muscle weakness, osteoporosis, perceived functional ability, fear of falling, visual and cognitive impairment, neurological function, urinary incontinence, medications and home hazards. In the UK, NICE guideline 21 (14, p. 11) states that:

> "Falls prevention programmes should also address potential barriers such as low self-efficacy and fear of falling".

Furthermore, the recommendations for falls prevention interventions made by the RCP (38) include commissioning of local, integrated exercise programmes through health and local authorities, as well as the voluntary sector, to ensure the long-term provision of evidence-based exercise programmes by qualified staff for reducing falls, as well as both local and national monitoring of the quality of training and delivery of exercise-based falls prevention interventions.

2.3.3 Falls Prevention Services in Ceredigion

Despite the RCP recommendations (38) and Welsh NSF standards (35) outlining the need for a multi-factorial falls preventions strategy there is no integrated falls prevention service currently in place in Ceredigion. However, a falls clinic is delivered by the general hospital in Aberystwyth in the north of the county to provide secondary intervention for patients who have recently experienced a fall. The falls clinic provides MFFRA and tailored MFFRI to older adults who have experienced one or more falls in the last six months and have subsequently been referred to the falls clinic by a health professional (i.e: general practitioner). One component available to patients as part of their tailored MFFRI is attendance at weekly exercise classes run in the falls clinic to improve their strength and balance. The classes are also delivered in two locations in community centres in Aberystwyth and Aberaeron as a follow on from the hospital classes, and to make them easier to access for self-referred participants from the community. However, there are poor public transport links to these locations and the falls clinic and exercise classes are held in the north of the county (Aberystwyth and Aberaeron). These factors are barriers to attendance, particularly for those who live in the south of Ceredigion, where a greater numbers of older adults who may benefit from this service live.

In light of the projected growth in the older adult population over the coming years, it would be beneficial to extend the number of delivery sites for the exercise classes in the south of the county so that more patients can attend. However, only a limited amount of funding is available for provision of the falls clinic and exercise classes from the local Hywel Dda National Health Service (NHS) Health Board and local branch of the Age Cymru charity. To support the argument to extend delivery of the falls prevention exercise classes to more locations it is important to establish whether the existing programme delivered from Aberystywth and Aberaeron is effective in reducing falls incidence and risk. It is also important that the exercise programme is delivered in line with the recommendations made by the NICE guidelines for falls prevention, i.e.: it must address at least one of the identified risk factors for falling, as well as potential barriers to participation, such as a fear of falling (14).

In line with the NICE 21 guideline (14) the falls clinic at Bronglais General Hospital in Aberystwyth, Ceredigion delivers tailored MFFRI to address individual falls risk factors identified in the MFFRA. If a patient presents muscle strength, balance, gait and/or mobility deficits alongside a fear of falling in their MFFRA at the falls clinic they may be referred to attend the weekly strength and balance exercise classes at either the hospital or in the community setting. This particular intervention is used to target improvements in a number of the risk factors identified by the NICE guideline, in particular: gait, balance, mobility, muscle weakness, perceived functional ability, and fear of falling. A flow diagram of the referral routes onto the exercise programme, including the individual risk factors assessed, is shown in Figure 2.3.3.These risk factors will be further discussed in Section 2.4.

Although the risk factors assessed and addressed as part of the falls clinic service and exercise classes are in line with NICE 21 guideline (14), these guidelines make no specific recommendations regarding the exact activities that must be included in the delivery of such an intervention. However, evidence-based recommendations for components and delivery of a postural stability instruction programme have been made in publication by Skelton and Dinan (39), and implemented in the Guidelines for exercise programming for the frail elderly published by the European Commission Framework and Better Ageing Project (40). It is this intervention that has been adapted and implemented in the exercise classes delivered in Ceredigion, and therefore relevant research literature will be discussed in more detail in Section 2.5.

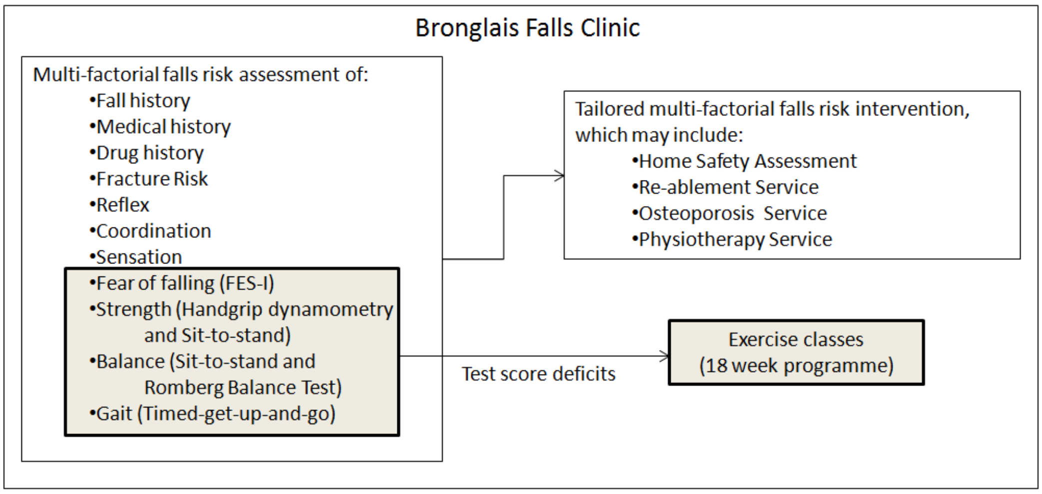


Figure 2.1: Flow diagram shows assessments conducted as part of the multi-factorial falls risk assessment, and the interventions implemented in response to these outcomes. Performance by patients in the risk factors (tests) highlighted in the darker box are used to determine patient suitability for referral on to the exercise intervention.

2.4 Falls Risk Factors

The purpose of this section is to provide an overview of a number of risk factors that will be measured as outcome variables in Studies 1, 2 and 3 of this thesis. The following risk factors are variables measured in Study 1: history of falling, fear of falling, quality of life, physical functioning, gait characteristics, postural stability and body composition - all of which are recommended for inclusion in MFFRA by the NICE guideline 21 (14). The risk factors measured as variables in Study 2 are strength and voluntary activation of the calf muscles, while Study 3 examines strength and range of motion of the calf muscles. The literature discussed in this section will include definitions of these risk factors, as well as existing research evidence concerning the relationship of each risk factor with falls incidence and other falls risk factors. In addition, evidence regarding the reliability and validity of the testing methods used in the clinic to assess each falls risk factor will be discussed.

2.4.1 History of Falling

A person's history of falling is defined by their falls incidence. For example: the definition of a faller is a person who has experienced at least one fall during the last six to twelve months (18). Once a single fall occurs the risk of subsequent falls increases - particularly if an injury was sustained in the first instance. For example, over half of all older adults who suffer a hip fracture as a result of a fall are expected to experience at least one fall during the year afterwards, while five percent will sustain another hip fracture (7). Older adults who have experienced two or more falls have been shown to accumulate a greater number of risk factors for falling alongside number of falls, including reduced visual acuity and contrast sensitivity, poor sense of vibration and proprioception, as well as impaired lower limb strength, reaction times, and balance (41). In other words, the more falls a person experiences the more risk factors they are likely to have or accumulate, and therefore they are more likely to experience further falls.

Biological impairments influence the ability to cope with functional tasks required for everyday living, for example, reduced strength associated with losses in lean muscle mass in older adults has been shown to influence performance in ability to climb stairs and perform housework (42). These mobility impairments have a known effect on behavioural risk factors, such as an increased fear of falling and reduced physical activity (43, 44). The overall effect of these behavioural changes on biological risk factors is also detrimental, and leads to further increased risk of falling, for example, a fear of falling can lead to reduced physical activity, leading to further decrements in strength. Without intervention the risk of falling continues to increase due to continued interactions between behavioural and biological risk factors, i.e.: a fall is followed by an increased fear of falling, leading to reduced physical activity in an attempt to reduce perceived exposure to risk of falling. In turn this leads to a loss of strength caused by muscle wasting, which then results in a reduced ability to perform functional tasks. Impaired mobility and decreased independence further increases fear of falling, and the cycle repeats itself.

A history of falling is a risk factor that must be managed through the adjustment of other modifiable falls risk factors. There is increasing evidence to demonstrate that exercise-based interventions targeting strength and balance can be used to reduce falls risk factors and falls incidence (39, 45, 46). Interventions that address one or more risk factor are needed to reduce risk of falling by breaking the cyclical process caused by recurrent falls.

Six-month Fall History
Six-month fall history of participants in Study 1 was examined due to the relationship between previous fall incidence and future falls risk (7). The six-month duration was chosen specifically to be in line with the definition of a faller used in this thesis, i.e.: a faller is a person who has fallen at least once during the last six months (18).

2.4.2 Fear of Falling

Fear of falling is defined by Tinetti et al. as:

> low perceived self-efficacy at avoiding falls during essential, non-hazardous activities of daily living (47, p. 239)

Women, as well as those with a history of falling, are most likely to develop a fear of falling (48, 49, 50). It is suggested that a number of predisposing factors for fear of falling are related to falls risk (50). Therefore, understandably, an intervention that seeks to reduce fear of falling may reduce overall risk of falling (51). A number of health benefits result from having a reduced fear of falling, including a better quality of life and ability to perform activities of daily living (ADL), as well as improved social functioning (43, 44). As defined by Tinetti et al. (47), fear of falling concerns a persons confidence in their own ability to avoid a fall during performance of ADL, which includes taking part in social events, for example, meeting with friends and family. ADL involve physical activity, and by reducing a person's fear of falling, thereby increasing their confidence, they are more likely to perform ADL. Increased frequency and duration of ADL performance means an overall increase in physical activity levels and social interactions. The more ADL a person is able to perform the more independently they can live, whilst benefiting from improved physical and social functioning. Therefore, the influence of the reduction of fear of falling on mental and physical quality of life are mediated by the relationship between fear of falling and ADL and social functioning.

Fear of falling is a known falls risk factor that affects up to 54% of community-dwelling older adults, and is associated with other psychological risk factors for falling, including quality of life and depression (7, 44, 49, 52, 53, 54) and reduced activity levels and independence (44, 48). Furthermore, over 44% of older adults have reported activity restriction alongside a fear of falling (50, 55). After experiencing a fall a person's perceived risk of falling again may increase, along with their concerns over the potential consequences to either their mental or physiological health as a result of a fall. In some cases this perceived risk may be greater than the actual risk. In such cases a fear of falling is formed, which disproportionately influences physical and social mobility. Most crucially, fear of falling can result in avoidance of specific activities or situations in an attempt to reduce the risk of falling.

Fear of falling may also be situational, for example, if a person experienced a fall whilst performing a particular ADL, they may become conditioned to associate falling with that activity. When performing the ADL and when exposed to associated environments anxiety symptoms develop, including increased heart rate, increased breath rate, or light-headedness. The person may continue avoiding performance of the ADL in an attempt to reduce their perceived risk of falling, and avoid experiencing the associated symptoms of anxiety. Despite still being physically capable of performing the ADL, fear of falling can result in long-term avoidance of specific behaviours and restriction of activity (56). A non-situational fear of falling results in the avoidance of a number of ADL, despite believing in their own capabilities to perform them. Both situational or non-situational fear of falling result in reduced mobility and activity restriction, and therefore result in reduced physical and mental well-being. The impact of reduced well-being is a further increase in risk of falling, and thus there is a self-perpetuating cycle of influence between increased fear of falling and activity restriction, mediated by physical and mental well-being, highlighting the need to address fear of falling as a modifiable risk factor for falling in assessments and interventions targeting falls in older adults (50, 55).

Although the term fear of falling refers specifically to a low fall-related self-efficacy, there is a lack of disparity between fear of falling and falls efficacy, and the two terms are often interchanged, despite having different meanings. The impact of this on interpretation of research findings is particularly pertinent when considering inclusion of measurement tools for falls risk assessments and design of interventions. Several tools have been developed to measure falls efficacy and fear of falling, such as the ABC scale (57) and the Survey of Activities and Fear of Falling in the Elderly (54), respectively. However, the tool developed, validated and recommended by ProFANE is the Falls Efficacy Scale-International by (58, 59, 60), which is based on a 10-item Falls Efficacy Scale (FES) by Tinetti et al. (47). The design and function of this questionnaire will be discussed later in Section 2.4.2. Although measures of fear of falling and falls efficacy using these tools have been found to reflect one another (61), a change in one measure may not necessitate the same change in the other and therefore caution should be exercised when interpreting the outcomes of these tests. A recommendation for standardisation of assessment has been made by the National Institute of Clinical Excellence (NICE) Guideline 124 for Hip Fracture (62). Further to this, although there has been some examination of reliability of tools developed to measure fear of falling in UK-based populations (58, 60), the prevalence of fear of falling in the older adult population in the UK is unknown.

A systematic review of randomised controlled trials (RCT) by Zijlstra et al. (55) highlighted a number of studies that showed significant reductions in fear of falling as a result of intervention, including community- and home-based exercise, and multi-factorial programmes. However, only three of these interventions were designed specifically to address fear of falling, despite previous evidence indicating the effectiveness of targeted interventions (43). There is also evidence suggesting that reductions in fear of falling resulting from intervention do not always reduce falls risk (43), which might be attributed to increased activity levels in response to reduced fear of falling. Although increased activity is a beneficial product of reduced fear of falling, the gains in quality of life and independence are somewhat offset by increased exposure to a greater number of falls risk factors, and it has been argued that fear of falling is independent of falls risk (63). In any case, the existing evidence does support the use of exercise-based interventions to reduced fear of falling in older adult populations (43, 55).

Falls Efficacy Scale International

The Falls Efficacy Scale International (FES-I) (58) is a popular assessment tool for the measurement of falls efficacy, and has been developed and validated by ProFANE (58, 59, 60). The original 10-item Falls Efficacy Scale (FES) was developed by Tinetti et al. (47) to expand the concept of fear of falling from dichotomous to continuous, so that the extent to which a person is fearful of falling may be quantified by their degree of falls efficacy. The FES-I is an adapted version of the FES, developed to enable standardised measurement of fear of falling in a number range of languages and cultural contexts (58). The FES-I questionnaire is made up from sixteen items assessing a person's level of concern about falling as they complete a given activity. The corresponding responses to each of the sixteen items are selected from the four point response scale, which are:

- 1 = "Not at all concerned"
- 2 = "Somewhat concerned"
- 3 = "Fairly concerned"
- 4 = "Very concerned"

A greater score is indicative of a greater fear of falling, or lower falls efficacy. Likewise, a lower score is indicative of a lesser fear of falling, or greater falls efficacy. The FES-I has demonstrated cross-cultural validity, and FES-I scores have been associated with age, sex, and falls history as predicted. A cross-sectional survey by Yardley et al. (58) of a sample of 704 community-dwelling older adults showed that the FES-I had excellent internal and testretest reliability (Cronbachs α=0.96, ICC=0.96). In fact, the FES-I demonstrated better power in discrimination between levels of concern than the original version (47, 58, 60). These results have been interpreted to indicate that the FES-I can outperform the original FES when identifying fear of falling during social activities and balance related-tasks performed outdoors in community-dwelling populations (58). Structure of both the 16-item and 7-item versions of the FES-I have shown strong internal reliability elsewhere (Cronbachs α=0.79) (59). The FES-I is administered to patients attending the falls clinic at Bronglais General Hospital as part of the MFFRA to evaluate fear of falling.

2.4.3 Quality of Life

Health-related quality of life is a commonly measured fall risk factor in clinical and medical settings, and is defined by Balboa-Castillo et al. (64, p. 47) as:

> a global indicator of health resulting from the individual's perception of the impact that diseases exert on different spheres of life (physical, mental and social)

Other psychological definitions for quality of life exist, for example, the Satisfaction with Life Scale developed by Pavot and Deiner (65) is concerned with well-being based on weighted criteria of what is important in life. However, the definition of quality of life used herein refers to health-related quality of life due to the frequency with which it is used in medical screening and assessment processes, which is particularly pertinent given that this thesis focuses on interventions prescribed by medical professionals.

Poor quality of life is a risk factor for recurrent falls in older adults (7), and is associated with a number of other falls risk factors, including fear of falling (52), reduced physical activity levels and increased sedentary behaviours (64, 66, 67). Health-related quality of life may be assessed through self-report questionnaires for the purpose of discrimination of individuals during a selection or screening process (68), or for evaluation of quality of life over a given time frame, for example: before, during and after completion of an intervention (69). ProFaNE (25) recommend the 12-item Short Form Health Survey (SF-12) (70) and European Quality of Life Instrument (EuroQoL EQ-5D) (71). However, preference has been given to the SF-12 over the EuroQoL due to the SF-12 offering broader assessment of both mental and physical health parameters - producing two individual summary scores for each (25). ProFANE (25) also argue that the SF-12 questionnaire has a better suited response format for use in older adult populations, due its structure as a descriptive response questionnaire, as opposed to scale responses which are used in other surveys.

There is a lack of evidence concerning the effectiveness of targeted exercise-based falls prevention interventions on quality of life in older adult populations. However, there is evidence to indicate that exercise-based intervention may be as effective as traditional physiotherapy treatments in improving quality of life in older adult populations. A RCT by Steadman et al. (69) compared the effects of a specialised six-week exercise intervention targeting balance versus a four-week control condition, where standard one-to-one physiotherapy treatment was prescribed. The results showed equal improvements in quality of life for both physiotherapy and exercise up to twenty-four weeks after completing the interventions (69). As the cost of delivery and time requirements for delivering a group exercise programme are smaller, the implications from this study are that exercise-based interventions offers a cost and time effective alternative to physiotherapy interventions when targeting improvements in quality of life in older adults populations at risk of falling. Fear of falling has also been shown to discriminate between those with differing levels of quality of life in community-dwelling older adults over the age of 70 years (52). There is some evidence to suggest a link between falls history and falls risk factors that are associated with quality of life, including activity restriction and functional ability (44, 48, 72). However, a direct link between falls history and quality of life has yet to be shown.

Short-Form Health Survey

The 12-item Short-Form Health Survey (SF-12v.1) (70) is an adapted version of the 36-Item Short-Form Health Survey (SF-36) (73). The SF-12v.1 questionnaire was developed to enable administration in clinical environments where time is limited, for example: to monitor self-reported health-related quality of life in large scale settings. Due to its broad outcome measures, including both mental and physical well-being, as well as the suitability of the items for administration in older adult populations, the SF-12v.1 questionnaire (70) is recommended by ProFaNE (25). The SF-12v.1 questionnaire is used in this thesis to evaluate changes in mental and physical health-related quality of life over the duration of Study 1.

The SF-12v.1 is inclusive of twelve items, each of which belongs to one of eight scales, and the responses to each of the corresponding items is used to produce two summary scores. The scales that contribute to Physical Component Score (PCS) are: physical function, role-physical function, bodily pain, and general health, while vitality, role-emotional function, social function, and mental health contribute to Mental Component Score (MCS) (70).

The SF-12v.1 questionnaire uses multiple response scales, each of which belongs to items of the same subscale. PCS and MCS are produced based on item responses using QualityMetric Health Outcomes Scoring Software 4.0. Higher scores in each or both MCS and PCS indicate a better quality of life. A previous study of general population samples from the United States of America (USA) and United Kingdom (UK) showed the test-retest reliability of PCS to be between 0.864 UK and 0.890 USA, with coefficients of 0.774 and 0.760, respectively (70). This study also reported that PCS and MCS scores were able to discriminate respondents in to groups of high and low scores consistently over a two week period, with test-retest correlations of 0.89 and 0.76 for the 12-item component scores, respectively (70).

2.4.4 Sarcopenia

Age-related declines in muscle mass and muscle function are referred to collectively as ‘sarcopenia’ (74), and recommendations of clinical tools that can be used to evaluate both muscle mass and function have been made by the European Working Group on Sarcopenia in Older People (EWGSOP) (74).

2.4.4.1 Muscle Mass

Muscle mass is known to decrease with age (75). In fact, reductions in cross-sectional area (CSA) of muscle may account for approximately 39% of age-related reductions in force production, which has been found to decrease by approximately 21% between the ages of 65-80 years (76). Reduced strength associated with losses in lean muscle mass in older adults has also been shown to influence ability to perform ADL, including stair climbing and housework (42). In addition, the likelihood of disability or functional impairment is two times greater in older men and three times greater in older women (aged over 60 years) with low skeletal muscle mass compared to older adults with normal skeletal muscle mass (77).

Age-associated replacement of muscle mass by fat and connective tissues has been demonstrated alongside change in number and area of Type I (oxidative) and Type II (glycolytic) muscle fibres (78). The increase in the proportion of non-contractile intramuscular tissues, such as fat and connective tissues, may partly explain age-related reductions in muscle quality and strength capacity (76).

There is evidence to show that muscle CSA and strength in the lower leg can be increased using resistance training programmes (79, 80). For example, a longitudinal study by Hakkinen et al. (80) investigated whether a six month resistance training intervention elicits strength gains and/or increased muscle mass in the leg extensor muscles of older and younger adults. The study compared training responses to the programme between four different groups: middle-aged men (n = 10; mean age: 42 ± 2 years), middle-aged women (n = 11; mean age: 30 ± 3 years), older men (n = 11; mean age: 72 ± 3 years), and older women (n = 10; mean age: 67 ± 3 years. The training intervention involved monthly increments in machine-based heavy and explosive resistance exercises (concentric followed by eccentric contraction) targeting the large muscle groups of the body (i.e.: upper body, trunk, and extensors and flexors of the elbow and knee). The authors found that all four groups experienced significant percentage increases isometric and dynamic strength in leg extension: isometric leg extension strength increased by 36, 36, 66, and 57%, and dynamic leg extension strength increased by 22, 21, 34 and 30% in middle-aged men, middle-aged women, older men and older women, respectively (all $P < 0.001$). Significant gains of 4.9 ($P < 0.05$), 9.7 ($P < 0.01$), and 5.8% ($P < 0.05$) were found in cross sectional area of the quadriceps femoris (leg extensor) of the middle-aged men, middle-aged women, and the older women, respectively.

The findings from Hakkinen et al. (80) indicate that resistance training may be used to increase muscle mass, and thus reduce or reverse the sarcopenic effects of ageing on muscle mass in both middle-aged and older adults. As muscle strength is a risk factor for falling, it would be beneficial for exercise interventions implemented for the purpose of reducing falls risk or incidence to increase skeletal muscle mass due to its influential relationship with muscle strength. However, it is also evident that age-related reductions in strength are not entirely proportional to age-related reductions in muscle mass (75). This means that other mechanisms must be partly accountable for the remaining strength loss. Suggested mechanisms include: contractile characteristics, motor unit functioning, and metabolism, all of which may be modifiable by changing levels of physical activity (75).

Body Composition
Dual energy X-ray absorptiometry (DXA) was used to measure changes in estimated whole body lean mass over the duration of Study 1. Although computerised tomography and magnetic resonance imaging are recommended by EWGSOP (74) as gold standard methods for estimating muscle mass in research, DXA is also recommended as a low cost, low radiation alternative for both clinical and research settings. Estimations of skeletal muscle mass made using the DXA method have been shown to be highly correlated with estimations of skeletal muscle mass made using computerised tomography and magnetic resonance imaging methods (81, 82).

2.4.4.2 Muscle Strength

According to the definition of sarcopenia by EWGSOP, muscle function is determined by two components, which are muscle strength and physical functioning

(74). Muscle strength is defined as:

> the capacity of a muscle to produce force and generate active tension (83, p. 57)

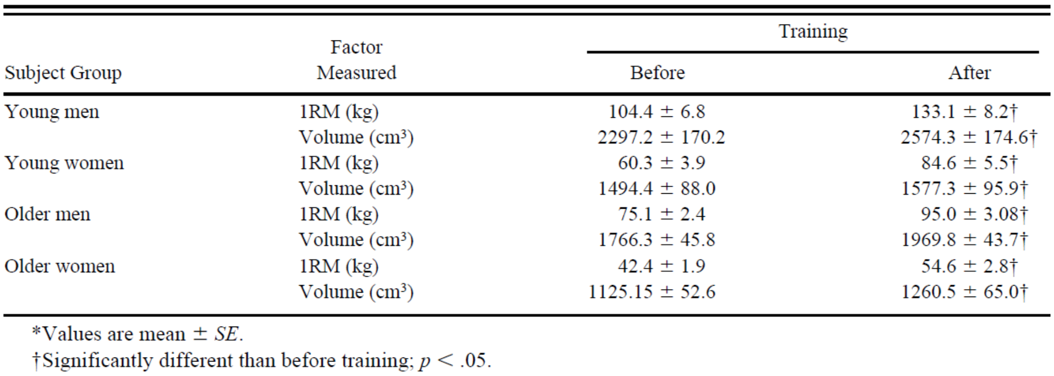
Muscle strength is known to decline with age (75), and is associated with lower extremity functional performance, particularly in the most frail portion of the older adult population (84). Strength deficits may influence performance in certain tasks, for example: age-related joint torque deficits at the ankle have been shown to impair balance performance in older adults (85). In fact, age-associated strength deficits are suggested to account for 17% of falls incidence in older adults (86).

Muscle strength may be quantified by measuring the resultant torque produced at a joint, for example: resultant torque at the ankle is the product of individual torques of the agonist and antagonist muscles around the joint, as well as the other structures crossing the joint (87, 88). Along with age and gender, muscle strength has been shown to be influenced by a number of biological structures and functions, such as muscle fibre type, muscle size, muscle strength, fascicle length, speed of contraction, tendon length, and tendon stiffness (83, 89, 90, 91).

Age-associated reductions in ankle plantar-flexor torque caused by reductions in excitation and contraction of the muscles are suggested to contribute towards a decline in balance performance in older age (85). torques and powers produced in distal lower limb joints have also been shown to reduce with age during walking (92, 93, 94, 95). More specifically, strength impairment at the ankle has been argued to be the main limiting factor in forward progression of the body during walking in older adults, particularly age-associated reductions in step length (96). Joint torques and powers produced at the ankle and knee during walking have been shown to be redistributed to the hip in older adults, and this redistribution is suggested to be a means of compensation for age-associated reductions in ankle plantar-flexor strength (95).

However, there is conflicting evidence regarding the nature of compensation at the hip for age-related reductions in ankle joint torque during walking. For example: some evidence indicates that the hip flexors are used to increase walking gait velocity in older adults (92), while other research has shown that the hip extensors are used by older adults more than younger adults during walking (95, 97). It is suggested that leg advancement is aided by an increase in joint torque produced by the hip flexors, whereas the hip extensors may either be used to assist advancement of the contralateral limb during the early stance phase, or to stabilise the trunk (96). In addition, there is also evidence to indicate that the main factor inhibiting joint torque and power produced by the ankle plantarflexors during walking is not diminished strength, but in fact a reduced ability to extend the hip caused by age-related contracture of the hip flexors (94, 97). A limited range of motion in hip extension may prevent older adults from taking on a posture during walking that enables the production of large joint torques in plantarflexion at the ankle.

However, it is possible that muscle strength may be improved by exercise-based intervention. For example, resistance training over durations as short as thirty five days have been shown to cause significantly increased muscle mass and strength in the leg extensors of younger and older adults (79, 98). A study by Ivey et al. (79) investigated the effects of a nine-week lower leg strength training intervention followed by a 31-week de-training period on muscle quality in younger men (n = 11) and younger women (n = 9) aged 20-30 years and older men (n = 11) and older women (n = 11) aged 65-75 years. Muscle quality was calculated by dividing dominant leg one-repetition maximum (1RM) performance (in kilograms or kg) divided by dominant leg muscle volume (in centimetres cubed or cm^3), and therefore muscle quality units were kg/cm^3. The results showed that although the younger men had significantly greater muscle quality than older women at baseline ($P < 0.05$) all four groups significantly improved 1RM performance and significantly increased muscle leg volume over the nine-week training programme ($P < 0.01$) - the mean values are presented in Figure 2.2. (79). As such, muscle quality was seen to be significantly improved after completion of the nine weeks of strength training (all groups $P < 0.05$). However, there was a clear effect of age and gender on these gains; to be young or a woman was associated with greater gains in muscle quality (i.e.: young women demonstrated greater gains in 1RM performance per cm^3 of muscle volume gained). All groups except for the older women maintained significantly elevated muscle quality following the de-training period when compared to baseline measures.



Subject Group	Factor Measured	Training	
		Before	After
Young men	1RM (kg)	104.4 ± 6.8	133.1 ± 8.2†
	Volume (cm³)	2297.2 ± 170.2	2574.3 ± 174.6†
Young women	1RM (kg)	60.3 ± 3.9	84.6 ± 5.5†
	Volume (cm³)	1494.4 ± 88.0	1577.3 ± 95.9†
Older men	1RM (kg)	75.1 ± 2.4	95.0 ± 3.08†
	Volume (cm³)	1766.3 ± 45.8	1969.8 ± 43.7†
Older women	1RM (kg)	42.4 ± 1.9	54.6 ± 2.8†
	Volume (cm³)	1125.15 ± 52.6	1260.5 ± 65.0†

*Values are mean ± *SE*.
†Significantly different than before training; $p < .05$.

Figure 2.2: Results from Ivey et al. (79) - One repetition maximum strength and muscle volume of quadriceps muscle groups before and after training and detraining in younger and older men and women.

Ivey et al.'s (79) findings demonstrate that resistance training over periods as short as nine weeks may be used to elicit long lasting gains in skeletal muscle mass and strength in the lower limb, therefore improving muscle quality. However, the disproportionate gains in strength compared to muscle volume demonstrated in Ivey et al.'s (79) study, particularly in the sample of young women, following strength training supports the notion that strength is not determined by muscle mass alone (83), and that other factors must be involved.

Changes in mechanical contributions of individual muscles to resultant joint torque, such as age-related declines in force produced per unit of muscle CSA may be caused by alterations in combination of muscular, tendinous and neural factors with age. Fascicle length and pennation angle are examples of muscular factors; fascicle length is bound by its intersection with superficial and deep aponeuroses and pennation angle is the angle between the path of the fascicle and the deep aponeurosis (91). Fascicle length and pennation angle are positively associated with measures of muscle strength and muscle CSA, but have been found to be

10 and 13% smaller, respectively, in older adults than younger adults (99). It is suggested that these reductions in both fascicle length and pennation angle are due to age-related losses in sarcomeres, in parallel and series, respectively (99, 100).

In terms of tendinous factors influencing joint torque at the ankle, tendon compliancy in the calf has been shown to be greater in older adults than younger adults (91). Furthermore, Achilles tendon thickness is also around 22% greater in older adults (101). These age-related changes in tendon behaviour and structure are suggested to impair magnitude of force produced at the ankle in older adults by increasing the time taken to transmit rapidly generated forces at the ankle, which is particularly important when responding to an external balance perturbation (100). The extent to which a muscle shortens during a voluntary contraction is dependent upon the compliability of the tendon, and therefore age-related changes in the structure and behaviour of the tendon are likely to cause age-related differences in muscle shortening during contraction and lengthening during stretching.

Differences in fascicle-tendon interactions between older and younger adults are suggested to account for age-related differences in mechanical contributions of the ankle plantar-flexors during walking (91). Mian et al. (91) compared length changes in muscle fascicle, tendon and muscle tendon complex of the gastrocnemius lateralis muscle between eight younger (mean age: 27 ± 7 years) and eight older adults (mean age: 77 ± 7 years) during bearfoot treadmill walking. The results showed that during walking, the lengthening and shortening of the tendinous tissues, which includes free tendons and aponeuroses, were the main contributors to lengthening and shortening of the muscle tendon complex, respectively (91). Although the muscle tendon complex length did not differ between the two age groups during walking, greater contributions were made by tendinous tissues to muscle tendon complex lengthening in older adults, while increased length of the muscle fascicle was only found to contribute to muscle tendon complex lengthening in younger adults (91). These findings indicate that the length of the gastrocnemius lateralis muscle tendon complex when stretched during walking is increasingly dependent on tendinous tissues with age. The authors suggest that the increased contribution from the tendinous tissues to muscle tendon complex length may be due to an age-related increase in compliance of the tendinous tissues in the complex, thus explaining reduced contributions from the muscle fascicle in complex lengthening, as well as maintained contributions from muscle fascicle in shortening of the muscle tendon complex in older adults (91).

However, it is possible that muscular and tendinous structures and functions may be altered by exercise interventions. A RCT by Reeves et al. (102) investigated the effects of a fourteen week leg press and leg extension resistance training programme in a sample of eighteen older adults. Nine participants were assigned to the training group (mean age: 74 ± 3.5 years) and nine to a control group (mean age: 67 ± 2 years). A number of measures were examined, including muscle fascicle length and pennation angle in the vastus lateralis during isometric maximal voluntary contraction (MVC) in knee extension. The training programme was found to significantly increase fascicle length at rest and during isometric MVC in the vastus lateralis by 8-10 and 10-18%, respectively ($P < 0.01$), and also pennation angle in the vastus lateralis significantly increased both at rest and during isometric MVC by 28-35 and 10-16%, respectively. Isometric MVC force production also increased significantly in the training group after completing the intervention by 11-35% ($P < 0.05$). The study also reported increased fascicle force development at longer fascicle lengths, which the authors attributed to a “training-induced increase in neural drive” perhaps caused by the changes in fascicle length, as well as a change in tendon mechanical properties (102, p. 686).

A RCT by Duclay et al. (103) examined the effects of a seven week eccentric resistance training programme on muscle architecture and tendon properties in a sample of 18 younger adults following completion(103). The participants were divided into a control and training group (control group n=10, mean age: 23 ± 3; training group n=10, mean age: 24 ± 3 years), and the findings at the gastrocnemius reflected similar changes to those found in the vastus lateralis by

Reeves et al. (102); after completion of the training programme the training group showed a significant increase in pennation angle in the medial gastrocnemius both at rest and during isometric MVC (103). However, although fascicle length was shown to be increased at rest following intervention, no difference in fascicle length during isometric MVC was found (103). In addition to the measures concerning muscle architecture, the results also showed that tendon elongation decreased significantly while tendon stiffness was significantly increased following completion of the training programme.

These findings suggest that is it possible to alter muscle architecture and therefore the contractile properties of muscle in younger adults using resistance training programmes. However, it is unclear from the findings of Duclay et al. (103) whether these changes are dependant on the contraction type used, i.e.: eccentric training, and if these findings will be reflected in an older adult population. On the other hand, the similar changes in muscle architecture in the knee extensors of both younger and older adult groups following concentric training reported by Reeves et al. (102) could be taken to mean that similar training responses between the age groups may be possible.

Changes in fascicle length and tendon properties resulting from resistance training are suggested to influence neural activity (102). Voluntary activation is a neural factor associated with strength (87, 104, 105, 106, 107), and represents the proportion of motor firing units activated during MVC and is defined as (108, p. 255):

> the completeness of skeletal muscle activation during voluntary contractions

There is evidence to suggest that voluntary activation of the lower limb muscles may influence performance of ADL, such as walking, for example: the ability to activate the ankle plantar-flexor muscle group has been shown to influence the falls risk factor of gait velocity, particularly forward progression during late stance phase (109, 110). However, research evidence concerning the effect of ageing on ability to voluntarily maximally activate muscle has shown varied results, and there have been a number of studies suggesting that maximal voluntary muscle activation is not altered with age, and cannot be fully accountable for age-related strength deficits (104, 105, 106, 107). In 2001 a study by Knight et al. (105) identified differences in isometric knee extensor strength between younger and older adults at baseline, as well as greater strength gains in younger adults compared to older adults after completion of a six-week resistance strength training programme despite similar muscle activation levels in both age groups (105). This supports the notion that there are a number of factors involved in determining strength in addition to the ability to voluntarily activate muscles.

There is evidence that, although influenced by age, voluntary activation may be increased by participation in strength training in both younger and older adults (87, 105, 106). For example, a randomised and controlled longitudinal study by Simoneau et al. (87) investigated the effects of a six-month strength training programme on strength and muscle activation in a sample of twenty healthy older adults. Five men and six women were allocated to a training group (mean age: 78 ± 3 years) and five men and four women to a control group (mean age: 75 ± 3 years). The strength training programme involved twice weekly supervised weight training and once weekly home-based exercise using elastic bands targeting the calf muscles. Following completion of the intervention the results showed that significant gains in isometric MVC torque of 24.5% in plantarflexion and 7.6% in dorsiflexion were demonstrated ($P < 0.001$ and 0.001, respectively), although participants who had greater isometric MVC torques at baseline demonstrated smaller strength gains at the post-training data point. Percentage voluntary activation of the plantar-flexor muscles was shown to increase significantly from a range of 66.3 to 100% at baseline to 81.2 to 100% following the intervention ($P \pm 0.007$), and these gains were also found to be significantly correlated with the strength gains demonstrated by the increased MVC torques in plantarflexion ($r \pm 0.63$, $P \pm 0.05$).

Simoneau et al. (87) suggest that their findings indicate that strength training may increase the number of active motor units or motor unit firing rates, thus increasing activation capacity of the muscles, resulting in increased strength performance. There has been evidence published more recently to support this explanation in both younger and older adult populations. For example, in 2008 a longitudinal study of younger adults (n = 8; 4 male, 4 female; age range: 1829 years) and older adults (n = 7; 6 male, 1 female; age range: 6781 years) by Knight et al. (106) found significant correlations between motor unit firing rates and gains in both muscle activation at $r= -0.062$ and isometric MVC force production at $r= -0.068$ (both $P< 0.05$) in the knee extensors over the course of a six-week strength training intervention. These findings provide further evidence of a direct relationship between voluntary activation (i.e.: motor firing rates) and joint strength in both older and younger adults, and suggest that effective strength training interventions would not result in reduced voluntary activation of the trained muscle group.

Isokinetic Dynamometry

Isometric and isokinetic strength are measured in Studies 2 and 3 of this thesis, respectively, using a commercial isokinetic dynamometer. Isometric dynamometry is used to quantify torque produced by a joint at a given angle during a single isometric MVC. Isokinetic dynamometry measures concentric torque at a given angular velocity, is recommended due to its close reflection of muscle function in day-to-day activity (74). Lower extremity strength measures obtained using isokinetic dynamometry have been shown to be independent predictors of physical function in older adults (111). Isokinetic dynamometry is more commonly used in research environments than clinical environments due to the cost of the equipment and need for trained operators. However, isometric strength can also be measured using relatively simple and low cost tests and equipment (74, 112). For example: handheld dynamometry has been shown to be a reliable and valid clinic-based tool for measurement of lower extremity isometric strength in older adult populations, particularly at the hip and knee (112).

Handgrip Dynamometry

Handgrip dynamometry is a handheld dynamometer used in clinical settings to evaluate health risks (113), which is also recommended by EWGSOP (74). Low cost equipment and simple administration means that handgrip dynamometry is both cost and time efficient, as well as mobile. Due to its correlations with other measures, including lower limb power, joint torque and cross-sectional muscle area (114), and falls risk factors such as mobility limitations (114) hand grip dynamometry is a practical alternative to more complicated measures that require more time and expensive equipment, such as isokinetic dynamometry. Handgrip dynamometry is used to quantify muscle strength as part of the MFFRA at the falls clinic at Bronglais General Hospital, and changes in these measures are analysed in Study 1.

Gait Analysis
Due to the influence of joint torque and range of motion in the lower limb on walking joint torques and joint angles at the hip, knee and ankle during walking in older adult fallers are examined in Study 1 of this thesis. These measures are calculated using ground reaction force and three-dimensional kinematic data obtained via a motion analysis system, the methods for which are described in more detail in Section 3.2.4.8.

Percentage Voluntary Activation
Voluntary activation of the plantar-flexor muscles in the calf is examined in Study 2 of this thesis. Voluntary activation is quantified by expressing the interpolated twitch (i.e.: torque generated during isometric MVC in plantarflexion with a superimposed electrical stimulus) as a percentage of evoked twitch at rest (i.e.: torque generated in plantarflexion when the calf muscles are not voluntarily contracting) (108). The calculation used in Study 2 is discussed in more detail in Section 4.2.6.

2.4.4.3 Physical Functioning

Physical functioning is defined by Painter et al. (115, p. 110) as the ability to perform activities that are “considered essential for maintaining independence, and those considered discretionary that are not required for independent living, but may have an impact on quality of life”. Physical functioning has been shown to be associated with falls incidence (116), as well as a number of falls risk factors in older adults, including history of fracture, disability and mobility limitations (116, 117, 118). Physical Functioning is known to be influenced by muscle strength, and therefore tests of physical functioning include the assessment of performance of gross motor skills such as the ability to transfer weight, balance, and walk (116, 119). Measures of physical functioning may also include tests for other physiological risk factors known to influence falling, including vision, peripheral sensation and reaction time (120), particularly given the importance of these factors in the performance of ADL, and therefore independent living in older adults.

In summary, strength and balance deficits are two indicators of sarcopenia. As part of the MFFRA in the falls clinic at Bronglais General Hospital in Aberystwyth Sit-to-Stand and Handgrip Dynamometry tests are used to evaluate strength, and the Romberg's and Timed-Get-Up-and-Go Tests are used to evaluate balance performance during standing and walking, respectively. Poor performance in these tests are taken to represent strength and balance deficits which contribute towards sarcopenia. All four tests are also examined in Study 1 of this thesis: Handgrip dynamometry was overviewed in Section 2.4.4.2, and below are brief overviews of the Sit-to-Stand, Romberg's and Timed-Get-Up-and-Go Tests.

Sit-to-Stand Test

The ability to stand up from a seated position is an important activity in day-to-day life, and the sit-to-stand test is a low cost, portable means of testing lower limb strength to evaluate functional health risk in both clinical and research settings (121, 122, 123). Sit-to-stand test performance has been shown to decline with age (124), and performance in sit-to-stand test assessment has been shown to successfully identify those with balance and gait disorders, and poor balance confidence (125). The sit-to-stand test protocol can either involve the measurement of the time taken to perform five transitions from seated to standing (125), or counting the number of transitions performed during a thirty second period (124).

The thirty second sit-to-stand test assessment method is used in the Bronglais General Hospital falls clinic, and has been found to have strong test-retest reliability (intraclass correlation coefficient = 0.84 and 0.92 for men and women, respectively) (124). It also correlates strongly with maximum weight-adjusted leg-press performance (r = 0.78 and 0.71 for men and women, respectively) in older adults, thus demonstrating validity of the test as a measure of lower body strength for older adults of both gender (124). Furthermore, performance in the sit-to-stand test has also been shown to differentiate by age group and physical activity level (124). Although often used in research as a proxy measure of lower limb strength, sit-to-stand test performance in older, community-dwelling adults is also suggested to be significantly associated with a number of risk factors aside from knee and ankle strength, including visual contrast and tactile sensitivities, lower limb proprioception, a simple foot reaction time, postural sway, body weight, pain, anxiety, and vitality (126).

Romberg's Test

Romberg's Test is a simple, clinical balance test commonly performed during neurological examinations. The test requires the subject to stand with their feet close together, and arms by their side, and a comparison of sway is made between standing in this position with their eyes open, and their eyes closed (127), and in most commonly used modified versions subjects are tested both with their feet apart and then close together (128). In a clinical environment the degree of sway is judged by the clinician or test administrator, and the test is considered to be positive if the subject demonstrates significant imbalance with their eyes closed compared to when they perform the test with their eyes open (127). Test failure is when the subject opens their eyes, moves their arms or feet to regain stability, or begins to fall or requires intervention to maintain their balance during the first 15-30 seconds of the test interval (128, 129, 130).

Force plate data can be used to objectively quantify sway during performance of the test for research purposes, particularly for research purposes (131, 132). Evidence that outcomes from modified Romberg's tests have been shown to be associated with quantitative balance measures recorded using computerized dynamic posturography (133), step width (134), and self-reported falls risk over a twelve month period (135), although concerns have been raised regarding its sensitivity in screening patients for vestibular system impairments associated with falling (136). Nonetheless, centre of pressure displacement during performance of the Romberg Balance Test has been shown to increase and to be more variable in later life (132), and a number of studies have shown that Romberg's test can be used to differentiate fallers from non-fallers in an older adult population (131). Centre of pressure displacement measures taken during performance of this test are also negatively associated with maximal torque capacity at the ankle in plantarflexion and dorsiflexion (132), which is a risk factor of falling associated with quantitative measures of postural stability (137).

In Study 1 of this thesis quantitative motion analysis methods will be used to capture ground reaction forces (GRF). This data will be used to estimate centre of pressure motion during performance of the Romberg's test, for example: sway area and sway velocity. The calculations for these measures will be described in more detail in Section 3.2.4.8.

Timed Get-Up-and-Go Test

The Timed Get-Up-and-Go Test test has been shown to identify older adults at risk of falling with 87% sensitivity (138). The test requires the subject to perform a series of actions in order, and performance is based on the time taken to perform these actions (139). The actions included in the test are: to rise from a chair and walk forward three metres, to turn around, and then walk to the chair and sit down again - all of which are vital to independence as they are components for performance of many ADL (139). As with most clinical tests, the Timed Get-Up-and-Go is low in cost and time to administer, making it ideal for field settings.

Longer time taken to complete the Timed Get-Up-and-Go test has been shown to be significantly associated with decreased physical mobility status (p <0.0001) (140). Completion of the tasks in those who are independently mobile is expected to take under ten seconds, unlike those with a history of falling, or with gait and/or balance disorders, who have been found to take significantly longer than ten seconds to complete the test (139, 141). A meta-analysis of data from twenty one studies examining Timed Get-Up-and-Go performance in healthy older adults by Bohannon (142) has shown age-related decrement in performance time within the older adult population. The mean (95% confidence interval) completion time in older adults aged over 60 years of age was 9.4 (8.99.9) seconds; however, categorisation of performance by age showed differences between age groups: mean (95% confidence interval) for 60 to 69 year olds was 8.1 (7.19.0) seconds and 9.2 (8.210.2) seconds for 70 to 79 years, while it was 11.3 (10.012.7) seconds for 80 to 99 years (142).

Performance in the Timed Get-Up-and-Go test has been shown to correlate with other functional performance measures including the Berg Balance Scale and gait speed (log-transformed scores of r = -0.81 and 0.61, respectively) and the Barthel Index of ADL (r = -0.78) (139). Timed Get-Up-and-Go performance measures have also been found to successfully differentiate older adults at risk from falling from age-matched controls (141). Furthermore, the time taken to complete the walking component of the test, which is specifically measured in an extended version of the Timed Get-Up-and-Go test, has been found to differentiate between old and young (141).

2.4.5 Range of Motion

Range of motion refers to the difference in joint angle between the end points of motion, for example, ankle plantar- and dorsi-flexion. Ankle range of motion (ROM) is known to diminish with age (143), and has been identified as an independent predictor of balance measures and falls incidence in older adults (17, 144, 145, 146). Measurement of ROM at the ankle using goniometry is an ideal clinical falls risk assessment tool, particularly due to its low cost and portability, as well as requiring only minimal time to administer, and most importantly, the predictive value of ankle ROM for falling (17, 144, 145, 146). Significant gains in ROM have been demonstrated in older adults through completion of exercise-based training targeting ROM (147). Given the predictive value of ROM for falling and the known benefits of targeted interventions on ROM, ROM has been identified as a modifiable risk factors for falling in older adults (17, 145).

Flexibility training has been shown to significantly improve ROM (148, 149), along with other measures of functional ability including strength (148), and research studies have investigated the effects of a number of different stretching methods, including static, proprioceptive neuromuscular facilitation (PNF) and self-stretch methods on muscle structure and function (150, 151, 152). Recommendations for flexibility training in older adults are discussed in more detail in Section 2.6, along with research evidence concerning the effects of PNF stretching on strength, ROM and muscle activation, which are topics investigated in Studies 2 and 3 of this thesis.

2.5 Postural Stability Instruction

Postural Stability Instruction (PSI) is a targeted exercise-based falls prevention intervention based on an initial exercise programme, called the Falls Management Exercise Programme (FaME), which was designed by Skelton et al., (39) and initially evaluated by this research group through RCT (10). The research studies to evaluate the exercise programme, referred to as the FaME trials, were conducted to address a gap in the research literature for exercise guidelines that detail specific exercises to be implemented as part of exercise-based fall prevention interventions. In particular, the authors of the FaME trials highlight their concern regarding the absence of advice for the selection and combination of exercises to be practised in exercise interventions targeting strength and balance (39), which are two of the components identified by Gillespie et al., that reduce falls rate and number of people falling (9). Until the publication of the Guidelines for exercise programming for the frail elderly by the European Commission Framework and Better Ageing Project (40) in 2005, which was based on the findings of the FaME trials (10, 39), the only other exercise-based falls prevention intervention that had been shown to reduce falls incidence through RCT and to specifically recommend intensity, duration, frequency, or increments of progression along with baseline and outcome measures was OEP (153).

A number of research studies have been conducted to evaluate the effectiveness off the PSI programme (10, 11, 154), and it has been shown to positively influence a number of falls risk factors in older adults, which include maintenance bone mineral density (11), and improved physical functioning (154), as well as reducing falls incidence and fall-related injuries (10). The PSI programme has also been included in a number of systematic reviews of research literature examining the effectiveness of exercise-based falls prevention programmes as single- and multi-factorial interventions, the main findings from each of which have supported the use of exercise to reduce rate and risk of falling (9, 46, 155, 156, 157).

A recent report produced by Aberystwyth University assessed changes of physical functioning, and quantitative and qualitative psychological variables, that included well-being, fear of falling and attitudes towards exercise in a sample of older adults who were participating in a 32-week community-based PSI programmes in the rural town of Tywyn, Gwynedd, North Wales (154). The report, which was a product of a collaborative project between Gwynedd County council, Aberystwyth University, and the National Exercise Referral Scheme, showed that the patients who participated in the programme benefited from significant improvements in performance of a number of functional tests associated with ability to perform ADL and measures of physical function, including the sit-to-stand and Timed Get-Up-and-Go tests over the duration of the 32-week PSI programme ($p < 0.001$) and FR test over the first eleven weeks of the programme ($p < 0.001$) (154). Non-significant, but desirable, changes in well-being and fear of falling were also shown in measures of well-being and fear of falling, through improved scores from the SF-12 and FES-I questionnaires (154).

Core recommendations from the Tywyn report were that the 32-week PSI programme can result in improvements in functional test performance and psychological predictors of health and falls risks in older adults with a history of falling (154). It was suggested that provision of PSI programmes might be expanded to provide for those who are at risk of falling but have yet to experience a fall in order to manage healthcare costs incurred from falling in the first instance. The report also suggests that the long term benefits to quality of life and performance in functional tests justify the implementation of longer PSI programmes based in the community, rather than shorter, hospital-based PSI programmes (154). However, a small sample size was used for this study which may have influenced the power of the data, and no control was used for comparison, which means that the data may not reflect the effect of the PSI intervention on the greater older adult population. This study also did not monitor falls incidence over the duration of the intervention, and therefore the effect of the 32-week PSI intervention on the relationship between falls incidence and the other outcomes measured has not been investigated. Further RCTs in a number of centres using larger sample sizes are needed to establish the effectiveness of the programme in reducing risk factors, and in particular falls incidence and its relationship with risk factors, including motivation, well-being, fear of falling and physical functioning.

2.6 Flexibility Training

2.6.1 Recommendations for Older Adults

Flexibility is a known risk factor for falling, and NICE guideline 21 recommends the use of flexibility training to increase range of motion in older adults to reduce risk of falling (14). The ‘Guidelines for the collaborative rehabilitative management of elderly people who have fallen’ published by the The Chartered Society of Physiotherapy and the College of Occupational Therapists also recommend interventions that will increase flexibility in the trunk and lower limbs in order to reduce falls risk (158). The two most accepted (159) and commonly researched flexibility training methods are static stretching (147, 150, 160, 161, 162, 163), and the PNF technique (148, 149, 150, 151, 152, 164, 165, 166, 167, 168). Interest in the effects of individual stretching techniques on the musculoskeletal system has increased in recent years, and a number of studies have been conducted to examine ROM and the effects of flexibility training in older adult populations (85, 147, 169).

Although the guidelines from the WHO and NICE recommend flexibility training, they do not make specific recommendations regarding the nature of the training activities (14, 37)(i.e.: intensity, frequency or duration). However, the Guidelines for Exercise Programming for the frail elderly by the Better Ageing Project (40), the ACSM Position Stand for Exercise and Physical Activity for Older Adults (13) and the combined ACSM and AHA recommendations for falls prevention in older adults (170) all make recommendations that static stretching methods should be used to target the larger muscle groups at least twice a week. The Guidelines for Exercise Programming for the frail elderly by the Better Ageing Project (40) specifically recommends that muscle groups in the lower limb influencing knee extension and flexion, ankle plantar- and dorsi-flexion, as well as hip adductors should be targeted (40). The combined ACSM and AHA recommendations for falls prevention in older adults (170) also provide more detailed recommendations regarding duration and intensity of repetitions, suggesting that stretches are to be held for between ten and thirty seconds, and to be performed in sets of three to four repetitions.

These recommendations demonstrate a general consensus between the guidelines that flexibility training for older adults should be performed two or more times a week, and involve stretching of the major muscles groups. However, it has been difficult to formulate evidence-based guidelines for flexibility training specifically for older adults at risk of falling due to conflicting research evidence. The ACSM Position Stand for Exercise and physical activity for older adults firmly recommends preference for the use of static stretching over more dynamic (ballistic) stretching techniques (13). Static stretching is also recommended by the American College of Sports Medicine and the American Heart Association combined recommendations for 'Physical Activity and Public Health in Older Adults' (12). Static stretching is described as the most traditional and common type of stretching involves passively or actively holding a specific joint position, with the muscle that is being stretched on tension to the point where a stretching sensation is experienced (159). Static stretching has been shown to positively influence joint range of motion in older adults, which is one of the main parameters for targeted exercise-based falls prevention interventions outlined by the ACSM (13).

However, research evidence concerning the effects of static stretching on a broad range of measures of functional performance is conflicting (160, 162, 171, 172, 173, 174), including guidelines directed towards other segments of the population. For example, The European College of Sports Sciences Position statement: ‘The role of stretching exercises in sports’ advised against the use of stretching techniques, stating:

> “There is no evidence that muscle strength or jump performance will improve with an acute bout stretching. In fact, there is firm evidence that muscle strength and jump performance is diminished immediately after stretching.” (171, p. 89)

However, due to the rate of production of new evidence these guidelines quickly become outdated. A recent review of literature has indicated that this statement is not necessarily in line with current research evidence (160). The review by Kay et al. (160), highlighted that a number of other systematic reviews have found the studies used to inform the European College of Sports Sciences Position statement (171) did not adequately apply controls or consider reliability of research methods (160). More recent research studies considering a broader range of stretching techniques (i.e.: static, ballistic and PNF) have found equivocal acute and chronic effects (160).

Nonetheless, although the evidence on which The European College of Sports Sciences Position statement (171) is based concerns younger adults who perform stretches before and after intense physical activity, mainly sports, the statement itself reflects concerns regarding the influence of stretching on functional performance. In older adult populations, for whom strength losses attributed to sarcopenia have been shown to have significant detrimental effects on functional performance in ADL, any further reduction in strength poses an additional threat to independence in those at risk of falling. Due to the vulnerability of this portion of the population any recommendation of stretching techniques must be based on the most up-to-date, accurate, and reliable research evidence, and knowledge of any detrimental acute or chronic effects of specific stretching techniques on strength.

The recommendations made by the ACSM in favour of static stretching techniques are supported by the outcomes of a recent systematic literature review examining the effects of static stretching on maximal muscle strength in 106 studies (160). The review found that methods where a static stretch was held for less than 60 seconds had no detrimental effect on maximal muscle strength (160). This review (160) examined a much larger number of studies than previous reviews, including those that had been used to inform The European College of Sports Sciences Position statement (171), in which static stretching was suggested to be detrimental to strength performance (172, 173) or equivocal (162, 174). It has also been highlighted that static stretching protocols most commonly investigated examine the effects of a stretch held for a much longer duration than is used in real-life settings, thus the outcomes from such studies are not applicable in the majority of settings where static stretching is generally used (174).

In summary, although current literature does not suggest strength deficits will be caused by short duration static stretch protocols, caution must be exercised when administering static stretching techniques as the effects on fall risk factors, such as strength, have still not been fully evaluated. It is apparent that more research evidence establishing the effects of static stretching and as well as investigation of the effects of alternative flexibility training methods on falls risk factors in older adults populations is required so that recommendations made in guidelines are adequately informed.

2.6.2 PNF Stretching

Proprioceptive neuromuscular facilitation or PNF is an alternative flexibility training method to static stretching. PNF involves a pre-stretch contraction of the muscle used, or its antagonist. Two of the most common types of PNF stretch are: “contract relax” (C-R) and “agonist contract-relax” (ACR) (159, 165, 175, 176). The muscle contracted during the C-R method is that which is to be stretched, while the ACR method involves contraction of the antagonist muscle to which the stretch will be applied. In both PNF modalities, the contraction is at 75-100% of an individuals maximal voluntary effort and is held for around ten seconds, and then followed by a period of rest (159). Some studies have reported the greatest gains in lower limb ROM through use of the ACR PNF technique (165, 176, 176). However, PNF stretching has also been shown to cause acute reductions in strength at the knee and ankle in younger adults (163, 177).

Preference for the use of static stretching techniques in older populations over more dynamic stretching methods is outlined by the ACSM in their Position Stand for Exercise and physical activity for older adults (13). However, there is a general absence of recommendations regarding the use of PNF stretching in exercise guidelines for older adults, i.e.: whether or not it should be used at all, and in particular in older adults who are at greatest risk of falling. This is mostly due to an insufficient amount of evidence regarding the effectiveness and safety of administering this stretch technique in this populations; the majority of studies that have been conducted to evaluate the effect of PNF stretching on muscle function have produced findings that are applicable to younger populations (149, 150, 151, 152, 163, 165, 166, 167, 168, 170, 177) and only a much smaller amount of evidence exists regarding the effect of PNF stretching on lower limb ROM in older adults (147, 175, 176).

There is evidence indicating that PNF may be used in older adult populations to acutely increase joint range of motion in the knee extensors. For example, Ferber et al. (176) compared three stretch techniques on ROM at the knee in extension. The effects of static stretching, C-R PNF and ACR PNF stretching were compared in a sample of 24 older adults aged between 50 and 75 years, and the results showed that ACR PNF stretching induced the greatest gains in ROM of all stretching methods (176) - a response that had previously been demonstrated in a younger sample (165). Ferber et al.'s (176) findings support the use of all three stretching methods (i.e.: static stretching, C-R PNF and ACR PNF stretching) in older adult populations as a means to increase ROM in knee extension.

Ferber et al.'s (176) evidence is also in line with the findings of an RCT by Feland et al. (175), which compared effects of static stretching and a C-R PNF stretch on knee extension ROM in ninety-seven active, healthy older adults with a mean age of 65 years (range: 55-79 years). The results showed that both interventions resulted in significant gains in knee extension ROM. However, when analysed based on gender and age, the results showed that the male participants benefited from the C-R PNF stretch technique more than women, as did participants under the age of 65 years compared with those aged over 65 years, in comparison to the static stretching technique (175). However, the control group from Feland et al.'s study (175) also demonstrated gains in ROM, the cause of which was difficult to explain given that no intervention was administered in this group, which suggests uncontrolled influence of extraneous variables.

The findings of Feland et al. and Ferber et al. (175, 176) only demonstrate the immediate effect of PNF on ROM at the knee in extension. However, the mechanisms responsible for these changes in ROM, such as muscle or tendon properties and characteristics, are not fully understood. As such, concerns about the risk of this stretching method increasing vulnerability to muscular soreness and/or injury in older adult populations have been raised (176). In addition, given the important role of ankle in forward progression during walking it is important that any flexibility training methods used by older adults do not have a detrimental short- or long-term effect on plantar-flexor strength at the ankle, particularly those who are frail and most likely to fall. Although evidence obtained from younger groups indicates that PNF stretching has a detrimental effect on ankle plantar-flexor strength (163, 177), there is a paucity of research evidence available to explain the mechanisms responsible for the effect of PNF on joint torque and power, such as structural, behavioural and neural changes in tissues, particularly at the ankle. In particular, the acute and chronic effects of PNF on these mechanisms at the ankle has not been researched in older adults.

Given the conflicting findings of existing research evidence concerning the effects of PNF muscle strength in older adults, and the absence of knowledge regarding the effects of PNF on ankle strength in older adults, it is important to determine how PNF influences the mechanisms responsible for age-associated losses in muscle strength, such as voluntary activation (105, 106). However, so far there has been no research conducted to investigate the effect of PNF stretching on voluntary activation at the ankle in younger or older adults, even though this information can be used to establish whether PNF is suitable for safe use in older adult populations as an alternative to static stretching at the ankle.

However, an RCT by Rees et al. (178) examined the effect of a four-week PNF stretching programme (applied to the plantar-flexors) on ankle ROM in dorsiflexion, peak force and rate of force development during isometric MVC in plantarflexion, as well as muscle-tendon unit stiffness and stretch tolerance, in a sample of twenty healthy young women (mean age: 20 ± 2 years) belonging to a control group (n = 10) or a training group (n = 10). After completion of the PNF stretching programme the training group demonstrated significant increases in ROM in dorsiflexion and muscle-tendon unit stiffness of 7.8 and 8.5% were found, respectively (both $P < 0.001$), which were also concurrent with one another (178). Peak force and rate of force development during isometric MVC in plantarflexion were also found to be significantly increased after completion of the PNF stretching programme by 26 and 25%, respectively ($P < 0.001$), and were also concurrent with one another (178). In addition, stretch tolerance was also found to be significantly increased, by 231% after completion of the four-week PNF stretching programme ($P < 0.001$) (178).

The findings of Rees et al. (178) indicate that long-term PNF stretching programmes may be an effective and safe training method for increasing flexibility at the ankle, and although PNF stretching is predominantly used to enhance flexibility, the chronic enhancement of isometric force production reported in the findings of Rees et al. (178) suggests that PNF stretching methods may also be used to enhance strength. However, these findings are only applicable to younger adult populations, and conflicting evidence exists (163, 177). In addition, although increased tendon stiffness is associated with increase joint torque production was achieved by PNF in Rees et al.'s (178) study, the underlying mechanisms responsible for these desirable changes in tendinous properties are still to be made clear. However, there is some evidence to indicate that gains in ROM in ankle dorsiflexion may not be attributable to tendon stiffness (167). Given the changes in muscle, tendon and neural characteristics with age, it is important that further evidence pertaining to the effects of PNF on these characteristics is conducted so that the suitability of PNF for use in older adult populations can be established, and recommendations can be made where necessary.

2.7 Recommendations for Research Outcomes

In response to a referral from the Department of Health and Welsh Assembly Government, the National Collaborating Centre for Nursing and Supportive Care was commissioned by the National Institute for Clinical Excellence (NICE) to develop the NICE Clinical practice guideline for the assessment and prevention of falls in older people, otherwise known as NICE guideline 21 (14). The guideline identifies the most commonly evaluated falls risk factors in the research literature and makes clinical and research recommendations based on gaps in the research evidence (14). The review of literature was conducted by the National Collaborating Centre for Nursing and Supportive Care, which focused on systematic reviews and prospective cohort studies investigating falls incidence and falls risk factors, and a multidisciplinary Guideline Development Group produced the guidelines (14).

Eight recommendations for falls prevention research were made in the NICE guidelines (14), five of which were prioritised based on clinical need for evidence. By addressing these key points through research, it will be possible to design and implement more effective, multi-factorial, multi-agency falls risk assessments and interventions, that are both time and cost efficient to health service providers and inform new or updated guidelines for falls prevention services. One of the recommendations highlighted was the need to evaluate multi-agency falls prevention programmes that target falls incidence and injury. Study One of this thesis aims to address this research recommendation by evaluating the exercise-based intervention component of the MFFRI offered by the falls clinic delivered at Bronglais General Hospital (Hywel Dda NHS Health Board) in Aberystwyth, Wales.

The quality of evidence reviewed as part of the development for NICE guideline 21 (14) was evaluated based on several factors, including: sample size, percentage of participants at follow-up and methods used for measurement of baseline and outcome measures as well as adjustment. Those studies with sample sizes of over 200 participants, over eighty percent participation at follow-up (at least six months), use of falls diaries and clear methodologies for outcome and baseline measurements, as well as appropriate adjustments for all factor considered, were recognised by reviewers as producing the highest quality of data (14). Also, the guideline only included research studies investigating risk factors that are conceptually relevant; the guideline review of literature identified the falls risk factors with the strongest predictive value to be falls history, gait deficit, balance deficit, mobility impairment, fear, visual impairment, cognitive impairment, urinary incontinence and home hazards (14). Therefore, in order to be eligible for inclusion in future NICE guideline literature reviews it is necessary for future research studies conducted in response to the NICE research recommendations and to be designed to meet the selection criteria (14). Study 1 will evaluate four of the strongest predictive values for falling: falls history, gait deficit, balance deficit, and mobility impairment.

Elsewhere, recommendations for longitudinal study design have been made over cross-sectional design for research investigating age-associated changes in falls risk factors (75). A study by Hughes et al. (75) compared cross-sectional and longitudinal changes in measures of isokinetic strength of knee and elbow extensors and flexors, alongside muscle mass, physical activity, and health in a sample of 120 healthy subjects (aged between 46 and 78 years). The results showed that age-associated reductions in muscle strength measured in longitudinal studies are up to 60% greater that those reported in cross-sectional data (75). Due to this apparent discrepancy in outcomes the authors recommended that measurement of age-related changes in muscle strength and mass using longitudinal study design are implemented, rather than cross-sectional study design (75). A longitudinal design has therefore been implemented in Study 1 to enable measurement of training responses in one sample over the duration of the intervention that is being evaluated.

2.8 Research Rationale

2.8.1 Summary of Evidence

Risk of falling increases with age, and with an ageing population the costs incurred for treatment of fall-related injuries sustained by UK health services are also increasing (2). There are a wide range of risk factors for falling, and many of which are modifiable by intervention (23, 179, 180). Effective management of modifiable risk factors through falls prevention interventions are necessary to reduce the burden on health services. Exercise-based interventions targeting strength, balance, and flexibility, such as PSI (10, 11, 39, 46, 154, 155, 156, 157) have been shown to be highly effective in reducing falls risk and falls incidence in older adults. Exercise-based interventions targeting strength, balance and flexibility are recommended by a number of guidelines, including the ACSM Position Stand for Exercise and Physical Activity for Older Adults (13), the Guidelines for exercise programming for the frail elderly by the European Commission Framework and Better Ageing Project (40) and NICE Guideline 21 (14). However, there are still unanswered questions regarding the overall effectiveness of these programmes - in particular, the newer and less researched PSI programme.

2.8.2 Gaps in Research

Research into falls prevention is listed as one of the high research priorities in Wales by the Welsh Assembly Government in ‘The Strategy for Older People in Wales 2008-2013’ (36), which aims to improve policies and strategies affecting older adults in Wales. The WHO ‘Global Report on Falls Prevention in Older Age’ (37) identifies that there is a need to integrate falls prevention strategies into health and social care agendas through the development and adherence to policies and procedures that are based on the growing evidence-base. The report also highlights the urgent need for more research covering all areas of falls prevention so that a better understanding of both worldwide and location or population specific strategies can be developed to improve health and well-being of older adults on a global scale (37).

Evidence-based research recommendations made by the NICE 21 Guideline (14) recognise the need for more research-based evaluations of the effectiveness of falls risk assessments and interventions used in the older adult population. Of the eight research recommendations highlighted by the NICE 21 Guideline (14), the two research recommendations addressed in this thesis are (14, p. 79):

- Evaluation of multi-agency falls prevention programmes to measure the impact of these programmes on reducing falls, injurious falls and fractures in older people.
- Falls prevention trials with a focus on injury reduction, such as fracture outcomes and fall related outcomes.

More detailed recommendations for research into exercise-specific falls prevention interventions are also a recent report by the Royal College of Physicians (38, p.61), which identifies two key gaps in the research literature specifically concerning this area of falls prevention:

- Implementation of evidence-based exercise interventions by healthcare providers is incomplete and varies widely across participating sites.
- There is a lack of long term follow-up classes for reducing falls in the community.

This particular set of recommendations reflect the calls made in the research literature itself for further investigation into the effects of targeted exercise-based fall prevention interventions (157, 181, 182, 183, 184, 185). Study 1 of this thesis is an evaluation of a community-based follow-up exercise-based intervention delivered in a rural community for older adults at risk of falling, and therefore directly addresses both of the gaps identified by the Royal College of Physicians (38).

Although flexibility is a known modifiable risk factor for falling, no consensus has been reached regarding which training methods are most suitable for older adults at risk of falling. Despite evidence-based recommendations against the use of dynamic stretching techniques (13), research evidence regarding the suitability of the active stretching method of PNF stretching in older adult populations is lacking, particularly concerning those at greatest risk of falling. Information regarding the effect of PNF stretching on muscles affecting ankle joint motion, i.e.: ankle plantar- and dorsi-flexors, is especially relevant to those at risk of falling, due to their role in maintenance of balance and gait which is known to influence ability to perform ADL. Further investigation into the effects of PNF stretching is needed regarding its effect on muscle function and functional performance measures in older adults, and in particular the mechanisms responsible for changes in ankle ROM and strength. These research gaps are addressed in Studies 2 and 3 of this thesis.

2.8.3 Purpose of research thesis

2.8.3.1 Study One

In general, this study is designed to meet the recommendations made in 'Older peoples experiences of therapeutic exercise as part of a falls prevention service patient and public involvement', by the Royal College of Physicians which indicates that the "quality of training and delivery of exercise programmes for reducing falls needs to be monitored locally and nationally against the evidence base for delivering effective exercise programmes to reduce falls" (38, p. 61). The study is also designed to address the following research recommendation made by the NICE 21 Guidelines (14, p. 79):

1. Falls prevention trials with a focus on injury reduction, such as fracture outcomes and fall related outcomes.

In keeping with these recommendations the main purpose of this study is to establish whether a short eighteen-week adapted community-based PSI programme can reduce falls risk factors, as well as falls incidence, including injurious and non-injurious falls. The research location is a rural community setting in Mid-Wales, where there is no existing evidence-base concerning the effectiveness of falls prevention interventions in this local area, and transport and rurality are barriers to participation. The pre-established version of the PSI programme has been shortened in duration by the local falls prevention service (Hywel Dda NHS Health Board) to meet their individual cost, resource and time allowances. In line with research recommendations the outcomes of this study include falls incidence, fall-related injuries, psychological consequences of falling, i.e.: fear of falling, and quality of life using the SF-12 questionnaire, as well as monitoring effects of exercise intervention after a follow-up period (25) will be made. This study will also compare outcomes in measures of gait, strength and balance performance using both laboratory-based and clinic-based measurement techniques to evaluate the effectiveness of the intervention. The results from this study will be used to determine the effectiveness of the adapted PSI implementation in reducing falls risk and incidence in a rural Mid-Wales setting over a reduced delivery duration of 18-weeks.

2.8.3.2 Study Two

The purpose of this study is to investigate the suitability of PNF stretching as a means of improving flexibility at the ankle joint in older adults by evaluating whether PNF stretching techniques acutely affect strength and/or voluntary activation of the plantar-flexor muscles. Flexibility training is one of the recommended components of exercise-based falls prevention interventions in guidelines, and is also low in cost and easy to deliver as part of a home-based multifactorial intervention. However, few studies have been conducted to investigate the effect of PNF stretching techniques in older adult populations, and even less is known about the effects of PNF exercises on falls risk factors. Ankle strength and flexibility, and the ability to voluntarily recruit the muscles responsible for plantarflexion during performance of functional tasks (i.e.: balance maintenance) play important roles in the avoidance of falls, but are known to change with age. To date, there are no evidence-based guidelines that adequately outline the effectiveness of joint-specific flexibility training techniques for use in the older adult population, and in particular there are no recommendations regarding the suitability of the increasingly popular PNF stretching techniques for use in older adult populations. Given the emphasis assigned to flexibility training components in guidelines for exercise-based falls prevention interventions and the effects of ageing on muscle function the purpose of this study is to compare the acute effects of PNF stretching on plantar- and dorsi-flexor muscle strength and activation in healthy older adults with healthy younger adults.

The outcomes of the study will include measurement of peak joint torque during isometric MVC in plantarflexion. The interpolated twitch technique will be used to establish the acute effect of the PNF method on ability to voluntarily activate the plantar-flexor muscles. It is hoped that the findings from this study will help to identify whether PNF stretching techniques can be used by older adults compromising measures of strength and muscle activation that may increase risk of falling by impairing balance performance.

2.8.3.3 Study Three

The purpose of this study is to compare the effectiveness of a four-week PNF stretch training programme on ankle flexibility and isokinetic strength in plantar- and dorsi-flexion between healthy older and younger adults. Although the mechanisms responsible for significant acute and chronic ROM gains caused by PNF stretching are unclear, this method of stretching has been shown to cause chronic strength gains in younger adults. Such beneficial training responses would reduce risk of falling in older adults, however, it has not been confirmed whether these ROM and strength gains are replicated in older adults.

The outcomes of this study will include weekly measurement of ankle ROM and isokinetic MVCs in plantar- and dorsi-flexion over a four-week PNF stretch training programme, including measures taken immediately before and after the administration of the PNF stretch to evaluate acute effects on ROM and strength. The findings from this study will present new information concerning the effects of PNF stretching techniques in older adult populations, and assist in the identification of safe and effective flexibility training interventions for those at the greatest risk of falling.

Part II

Chapter 3

Study One

Effects of a community-based 18-week Postural Stability Instruction Programme on fall incidence and risk factors for falling in frail older adults

3.1 Introduction

Health services are under increasing pressure to provide for a growing ageing population (37). There is increasing evidence to support the use of targeted exercise interventions to reduce fall incidence and injury in older adults (9, 10, 45, 69, 186, 187, 188). Falls risk factors, such as fear of falling (154, 189), quality of life (154), and cognitive (190) and physical functioning associated with performance of activities of daily living (ADLs) (154, 187) have also been reduced through targeted exercise interventions. Group-based tailored exercise interventions, such as the Postural Stability Instruction (PSI) intervention used in the Falls Management Exercise (FaME) trials (10, 39), require a minimum outlay of time and resources to deliver when compared to traditional one-to-one physiotherapy intervention.

A three-year randomised controlled trial by Skelton et al. (10) investigated the effects of a 36-week tailored PSI intervention on fall rates and injuries in older adults. The PSI intervention was delivered in a group-based class by registered exercise professionals (REP), with participants undertaking additional home-based activities in their own time between the weekly group-based classes.

The PSI intervention incorporates targeted strengthening exercises, combined with functional floor-based activities and challenging balance exercises adapted from Tai Chi. The results from Skelton et al.'s (10) study showed that fall rates decreased by 31% ($p = 0.029$), and there was reduction in injuries from falling that approached significance ($p = 0.08$) (10) over the duration of the intervention period. Skelton et al.'s (10) findings demonstrate that a 36-week group PSI intervention delivered by an appropriately qualified REP alongside home-based exercises is effective in reducing falls incidence in older adults.

Shorter exercise interventions lasting between four and twelve weeks (69, 184, 191) have been shown to improve some risk factors for falling, including measures of lower extremity strength (191), walking ability (69, 191) and confidence (69), balance performance (69), functional ability (69, 191) and self-reported falls risk (184, 191). For example, a randomised controlled trial by Steadman et al. (69) compared the effects of two six week training interventions: a conventional physiotherapy treatment versus an enhanced balance treatment. The physiotherapy treatment was comprised of four weeks of twice weekly sessions of non-progressive practice of functional activities, including sit-to-stand and walking, followed by two weekly follow-up calls by the physiotherapist providing treatment. The enhanced balance treatment was identical to the conventional treatment, but also included additional targeted progressive exercises aimed at improving balance. The complexity of these additional exercises was increased by decreasing the base of support, increasing the number of repetitions performed at each session and reducing the time taken to perform the exercises. Follow-up measures were recorded at 12 and 24 weeks after the intervention began for the Ten-meter timed walk test, Berg Balance Scale, Frenchay Activities Index (FAI), Falls Handicap Inventory and the European Quality of Life questionnaire (Euroqol). All measures significantly improved for both treatments ($p < 0.05$) except for TWT and Euroqol in the physiotherapy treatment group ($P > 0.05$). These results suggest that balance training programmes as short as six weeks in duration may be as effective in reducing falls risk factors as longer interventions, such as physiotherapy and targeted strength and balance training interventions (10, 45, 187, 192, 193, 194).

The findings of Skelton et al. (10) demonstrate that a 36-week PSI intervention can be used to significantly reduce fall incidence in older adult fallers. However, although there is evidence that shorter targeted strength and balance training interventions may be used to significantly reduce risk factors for falling, it still remains unclear whether a shortened PSI training intervention can effectively reduce falls incidence or individual risk factors for falling. In particular, it is important to establish the effects of PSI on risk factors recommended for inclusion in multifactorial falls risk assessment and intervention by the NICE 21 Guidelines (14), for example: gait, balance and mobility deficits, muscle weakness, perceived functional ability and fear of falling. This information will enable recommendations to be made regarding the use of PSI as part of multifactorial falls prevention interventions.

A shortened 18-week version of the Skelton et al. (10) PSI programme was implemented by a local falls preventions service in rural Mid-Wales, as this was the longest duration that could be funded given the number of weekly referrals made onto the programme. The primary purpose of this observational study was to identify whether this shortened 18-week PSI programme adapted from the 36-week FaME intervention (10) offered by the local rural falls clinic in Mid-Wales is long enough in duration to reduce the number of falls experienced by falls clinic patients. The primary outcome for this study was falls incidence over the course of the six month follow-up after completion of the 18-week PSI programme, as a faller is defined as someone who has fallen once or more in the last 6 months (18). The secondary purpose of this study was to investigate the effects of the intervention on falls risk factors. Therefore, the secondary outcome for this study was change in measures of strength, gait, and balance performance and fear of falling over the first six weeks of the intervention using clinic-based tests administered as part of the established falls clinic screening and monitoring process. Laboratory-based measures of health-related quality of life as well as gait and balance performance were also repeated after completion of the sixth and eighteenth week of the intervention, and percentage lean mass was measured before and after completion of the 18-week PSI intervention.

3.1.1 Hypotheses

The primary hypothesis for this study is that the number of falls experienced by participants will be reduced in the six month period following completion of the 18-week PSI intervention. The secondary hypothesis is that improvements in clinic-based measures of falls efficacy, strength, balance and gait will improve following completion of the first six weeks of the PSI intervention, along with improved laboratory-based measures for health-related quality of life, balance during quiet standing and joint torques and angles during walking. There will also be further improvements in these laboratory-based measures, along with an increased percentage of lean mass demonstrated over the 18-week intervention duration.

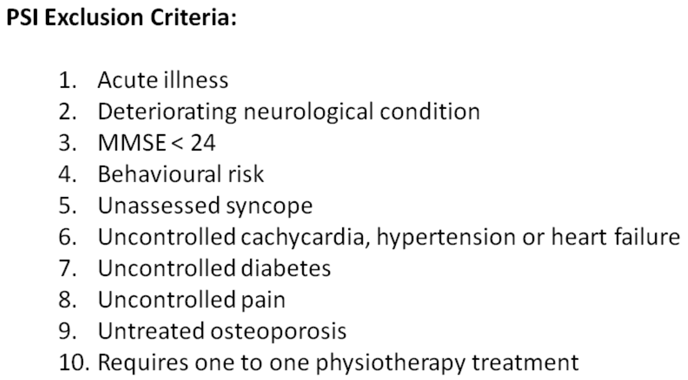
3.2 Method

3.2.1 Recruitment

Participants in this study were patients recruited from the weekly falls clinic held at Bronglais National Health Service (NHS) General Hospital (Hywel Dda Health Board), Aberystwyth, Wales UK. All participants had experienced one or more falls in the preceding six months, and were therefore classified as 'fallers'. Patients attending the falls clinic were assessed by multi-factorial fall risk assessment (MFFRA), which included a full medical examination and reviews of prescribed medications and medical history (all examinations and tests carried out are listed in Appendix A.1). All risk factors identified during the MFFRA were addressed individually, for example: by adjusting treatment or medications, or referral to appropriate clinics or health services, such as the osteoporosis clinic and scheduling a home hazard assessment.

The MFFRA also included completion of five clinic-based tests which were used to assess fear of falling, strength and balance performance. Once all other identified risk factors had been addressed those patients who did not present with any of the exclusion criteria (See Figure 3.1), but demonstrated strength and balance deficits and high levels of fear of falling, were referred to attend the

18-week PSI intervention by the falls clinic. Patients were only referred to attend the PSI programme if it was thought that they were likely to benefit from it (i.e.: they would be able to complete the exercises, and medications would not interfere with strength gains).



PSI Exclusion Criteria:

1. Acute illness
2. Deteriorating neurological condition
3. MMSE < 24
4. Behavioural risk
5. Unassessed syncope
6. Uncontrolled cachycardia, hypertension or heart failure
7. Uncontrolled diabetes
8. Uncontrolled pain
9. Untreated osteoporosis
10. Requires one to one physiotherapy treatment

Figure 3.1: Exclusion criteria for patients referred from falls clinic onto the PSI intervention.

All participants investigated in this study had been referred to attend the PSI intervention and each gave their full informed consent (See Appendix A.3). Prior to undertaking any gait and balance assessments in the university laboratory all participants underwent hip and spine DXA scans which were used in the bone health screening assessment to evaluate eligibility for testing procedures based on their bone health (See Appendix A.2). The experimental design and procedures were approved by Aberystwyth University Ethics Committee and the local NHS research ethics committee (Ref. No.: 10/WMW01/3) before commencement of the recruitment process. All studies were conducted in accordance with the Declaration of Helsinki (1964) (195).

3.2.2 Intervention Design

All participants completed an 18-week PSI intervention that comprised of six weekly hospital-based PSI classes followed by twelve weekly community-based classes. All exercise classes were supervised by a trained REP. In addition to attending the exercise classes, participants were also required to complete home-based exercises prescribed to them by the exercise instructor 2-3 times per week. The content delivered in the PSI intervention was identical to that of the 36-week intervention used in the FaME trials (10), with the only modification being that it was delivered over a shorter duration of 18 weeks.

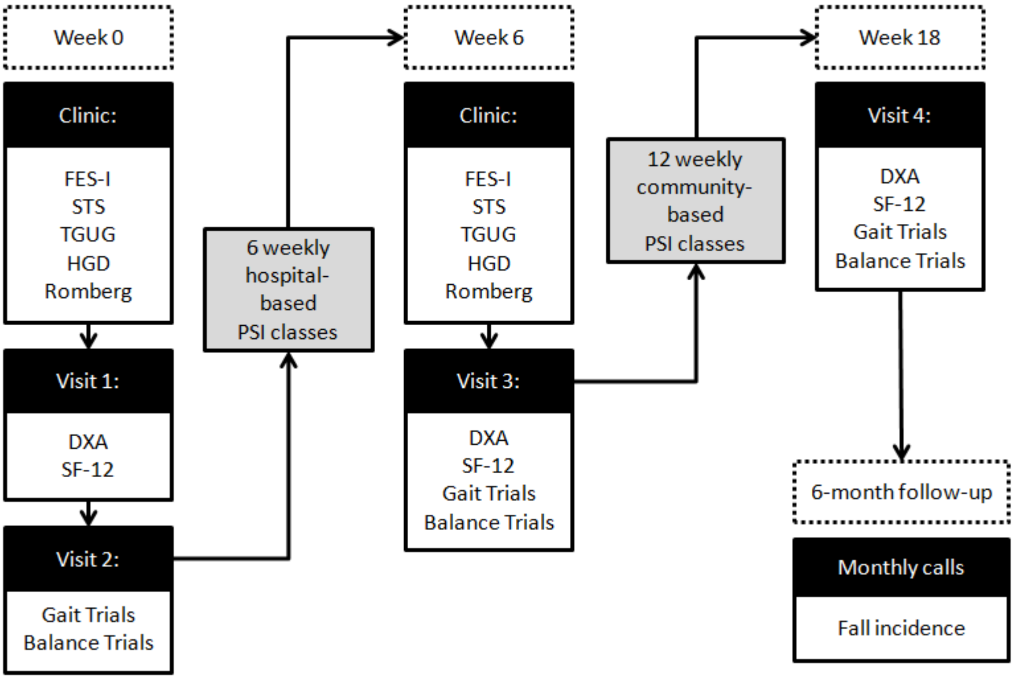


Figure 3.2: Flow diagram demonstrating the data collection points at which each testing procedure was performed by participants, including Falls Efficacy Scale International questionnaire (FES-I), Timed-Get-Up-and-Go Test (TGUG), thirty second Sit-to-Stand Test (STS), Romberg's Balance Test (Romberg) and bilateral Handgrip Dynamometry measurements (HGD).

3.2.3 Experimental Design

This was a longitudinal study: following attendance at the falls clinic (where clinic-based tests were administered) each participant was required to visit the university laboratories on four separate occasions over the intervention period to enable assessment of falls risk factors, which was followed by six monthly follow-up telephone interviews. Figure 3.2 shows the time points at which each testing procedure was completed by participants. The first and second laboratory visits took place within one week of the falls clinic MFFRA and before starting the intervention (week 0), before participants attended their first PSI class. The third (week 6) and fourth (week 18) visits were arranged to take place after participants had completed their sixth and eighteenth weekly PSI classes, respectively. Monthly follow-up telephone calls were made to each participant by the investigator for six months following completion of their eighteenth PSI class to obtain information regarding monthly falls incidence, and health and medication changes.

3.2.4 Experimental Procedures

All tests were conducted at the university labs within the Department of Sport and Exercise Science, Aberystwyth University, Wales, with the exception of the clinic-based tests, which were administered by the REP during week 0 at the fall clinic as part of the MFFRA and at week 6 after completion of the sixth PSI class. These tests were the FES-I questionnaire, the Timed Get-Up-and-Go Test, thirty second Sit-to-stand Test, Romberg's Balance Test and bilateral Handgrip Dynamometry test. Participants completed whole body composition scan to measure baseline lean and fat mass at week 0 and week 18. Participants also completed the laboratory-based gait and balance tests, as well as the Short-form Health Survey (SF-12v.1) questionnaire which is a measure of health-related quality of life at weeks 0, 6 and 18. Fall incidence and fall-related injury was reported by participants during monthly phone calls made during the six months following completion of the 18-week PSI intervention.

3.2.4.1 Fall Incidence

The investigator made six monthly telephone calls to each participant upon completion of the eighteenth PSI class (i.e.: one call per month for six months). The participants were asked to record any falls that occurred during this follow-up period, including the date, any injuries sustained (i.e.: fractures or bruising) and whether any medical assistance was sought, including GP visits, hospital admissions, and emergency service provision.

3.2.4.2 Clinic-based tests

The clinic-based tests were administered by the REP at week 0 and week 6, prior to the first and immediately following completion of the sixth weekly hospital-based PSI class.

Falls Efficacy Scale International

The FES-I questionnaire is a tool for use in clinical settings to evaluate a person's fear of falling, and was developed and validated by ProFaNE (58, 59, 60). It is comprised of sixteen items, each assessing level of concern about falling as they complete an activity. There are four possible responses to each item: 1 = "Not at all concerned", 2 = "Somewhat concerned", 3 = "Fairly concerned", and 4 = "Very concerned". The sum of all scores is used to indicate level of fear, and there is a possible score range = 16 (no concern about falling) to 64 (severe concern about falling; a greater score indicates a greater fear of falling, while a lower score indicates a lesser fear of falling.

Timed Get-Up-and-Go Test

The Timed Get-Up-and-Go Test involved the participants to rise from a chair and walk forward three metres, turn around, and then walk to the chair and sit down again. Performance in this test was based on the time taken to perform the tasks in order, which was recorded by the REP. A reduced time to complete the Timed-up-and-go Test is desirable, as a shorter time to complete the test reflects faster walking speed and better mobility when compared to slower completion times (140). Completion of the test in under ten seconds is taken to reflect independent mobility, unlike those with a history of falling, and/or with gait or balance disorders who are expected to take longer (139, 141). Performance in this test has been shown to correlate with other functional performance measures including the Berg Balance Scale and gait speed (log-transformed scores of r = -0.81 and 0.61, respectively) and the Barthel Index of ADL (r = -0.78) (139), and to successfully differentiate older adults at high risk of falling from age-matched controls (141).

Sit-to-Stand Test

The 30-second Sit-to-Stand Test test was administered by counting the number of transitions from a seated to a standing position and back to a seated position during a 30-second period timed by the REP using a stopwatch. This test has been shown to have strong test-retest reliability and validity as a measure of lower body strength for older adults of both gender, as well as demonstrating use in differentiation of age groups and physical activity levels (124).

Romberg's Balance Test

Romberg's Balance Test is comprised of four test conditions (128); the test conditions are shown in Figure 3.3. Performance in each of these test conditions was assessed by the REP, who graded degree of sway during each condition on a scale of 1 representing "no sway", to 4 representing "test failure due to a loss of balance", with scores in between of 2, 3, 4 representing "mild", "moderate" and "vigorous sway", respectively. Romberg's Balance Test is a popular clinical tool used to assess balance with and without visual input, and there is evidence that performance scores in the Romberg's Balance Test can differentiate fallers from non-fallers in an older adult population (131).

Handgrip Dynamometry

Handgrip Dynamometry is recommended by EWGSOP for evaluation of strength in clinical settings due to the low cost of equipment and short time taken to administer the testing procedures (74). Strength measures obtained using Handgrip Dynamometry has been shown to be positively correlated with other measures, including lower limb power, joint torque and cross-sectional muscle area (114), as well as falls risk factors such as mobility limitations (114), and therefore greater forces produced during isometric handgrip MVC represent greater upper and lower body strength.

3.2.4.3 Whole Body Lean Mass

Whole body composition scans were carried out at week 0 and 18 to identify any changes in absolute and percentage lean mass following the PSI intervention. All

Figure 3.3: Romberg Balance Test - four test conditions. Trial 1: Eyes open, feet together (FTEO). Trial 2: Eyes closed, feet together (FTEC). Trial 3: Eyes open, feet apart (FAEO). Trial 4: Eyes closed, feet apart (FAEC).

DXA scans were conducted by a trained operator at the university laboratories in line with the manufacturer's recommendations (Hologic Discovery A and Image Pro software: Vertec Scientific SA Limited, South Africa). The absolute lean mass, and lean mass as a percentage of whole body mass were evaluated for the whole body, and arm and leg segment data are reported as the average of left and right sides.

3.2.4.4 Health-related Quality of Life

Participants completed the SF-12v.1 (73) at visits weeks 0, 6 and 18. After explaining the item-response scale to the participant, the investigator would read the items out and mark the participant's response on the form. A copy of the questionnaire can be found in Appendix A..5. It should be noted that the number of possible responses for item 12 used in this version of the SF-12v.1 is less than the number available in the standardised questionnaire, as it does not include the response option for "A good bit of the time". Patient summary scores for MCS and PCS of the SF-12v.1 were generated from item-responses using QualityMetric Health Outcomes Scoring Software 4.0 (QualityMetric Inc, Lincoln, RI, USA).

3.2.4.5 Motion Capture System

A motion analysis system comprising of an eight-camera Eagle Digital Real Time Camera System (Motion Analysis, Santa Rosa, USA), and two sunken horizontal AMTI BP400600 force plates (AMTI, Watertown, USA) was used to capture video and ground reaction force (GRF) data during laboratory-based balance and gait trials. Ground reaction force (GRF) and three-dimensional (3D) kinematic data obtained during motion analysis of balance and gait trials were collected at a sample rate of 2 kHz and 100 Hz, respectively.

The two force plates each measured (width x length x height) 400 x 600 x 83 cm, and were configured so that the length of each force plate was aligned with the z axis, the width aligned with the x axis and height with the y axis of the global reference system. The force plates were positioned side-by side lengthways along the z axis. However, to enable measurement of GRF data during consecutive steps the force plates were staggered, with the first force plate (FP1) was positioned at 0 mm along the z axis and 0 mm along the x axis, while the second force plate (FP2) was at 600 mm along the z axis and 200 mm along the x axis. A whole body markerset comprised of 61 retro-reflective passive markers were attached using hypoallergenic tape to participants' skin and clothes. Where necessary, clothing was secured with Coban^{TM} elasticated tape (3M Inc., St Paul, MN, USA) to reduce excess motion of the passive markers and increase marker visibility during testing (See Appendix A.4).

All data collected through motion analysis (i.e.: video and ground reaction force data) was handled using Cortex software Version 2.0 or 3.0 (Motion Analysis, Santa Rosa, USA). All gait and balance trials were performed by participants without any walking or balance aids, or support from the investigator. However, all participants were offered the use of a safety harness to reduce the risk of injury from falling during testing procedures in the laboratory.

3.2.4.6 Balance Trials

The four conditions of the Romberg's Balance Test described in Section 3.2.4.2 were repeated with the participant by the investigator under laboratory conditions during visits 2, 3 and 4 (at weeks 0, 6 and 18). Each condition was recorded as a trial lasting 20 seconds using the motion capture system described in Section 3.2.4.5 - participants stood with both feet on FP1 in the appropriate positioning during each trial. No practice attempts were allowed, although practical demonstration was given to each participant prior to each trial.

3.2.4.7 Gait Analysis Trials

During visits 2, 3 and 4 (at weeks 0, 6 and 18) participants performed up to five practice trials prior to completing three trials where data was captured using the motion capture system (See Section 3.2.4.5). During each trial participants were required to walk forwards a distance of 3 metres along a set path over the FP1 and FP2, before turning 180 ° and walking back again over FP2 then FP1 to the starting point. Participants were encouraged to walk as normally as possible, and the duration of each trial was determined by the time taken for each participant to complete return to their starting position. Starting foot position was adjusted so that only one foot was in contact with each force plate at any one time without the participants having to break stride. All procedures involved in the gait analysis trials were demonstrated to participants by the investigator prior to their practice trials.

3.2.4.8 Post-processing for Motion Capture Data

A 4th order zero-lag Butterworth filter with a 5 Hz cut-off was applied to the kinematic data. A 4th order zero-lag Butterworth filter with a low pass cut off frequency of 40Hz was applied to GRF data.

Markerset
During gait and balance trials in the laboratory three markers were placed on each body segment for segment position and orientation tracking. Fifteen segments were defined, and the marker set for the lower body was based on Collins

et al. (196). The joint centres for the knee, ankle, forefoot, shoulder, elbow and wrist joints were defined using markers placed medially and laterally of each joint, and the following equation was then used to identify the joint centre:

$$C = L_m + p\,(M_m - L_m) \tag{3.1}$$

Where:

C = the location of the joint centre

L_m = represents the lateral joint marker

M_m = is the medial joint marker

p = the percentage offset between the lateral and medial joint markers which was 50% for these joints.

Once the positions of these joint centres were identified using lateral and medial markers, the position of the joint centre relative to the tracking markers could then be identified, allowing the medial markers to be removed for the balance and gait trials. The static joint centre for the hip was defined using the method of Bell et al. (197), which uses the distance between the pelvis anterior superior iliac spines (ASIS) as a reference distance. The hip joint centre was then defined as a position 64% of the inter-ASIS distance laterally, 44% posteriorly, and 68% inferiorly from the relevant ASIS marker. Fifteen segments were defined between using these joint centres Local reference frames were defined for each of the 15 segments with the Z axis along the bone, the X axis was defined using one of the lateral joint markers, and the Y axis was defined as the anterior-posterior axis for each segment (See Appendix A.4 for further details).

Gait Analysis: Joint torques and Angles

An inverse dynamics procedure was applied to the GRF and kinematic segment data to compute the resultant joint torques and angles at the ankle, knee and hip during the walking trials. The minimum and maximum torques during one complete gait cycle were computed in order to determine the peak torques and angles in each direction (i.e.: peak plantarflexion and dorsiflexion torques and angles at the ankle, peak extension and flexion torques and angles at the knee and hip).

Balance Trials: Postural Stability

GRF data and kinematic data from the balance trials were imported into MATLAB 2009b (The Mathworks Inc., MA, USA) to compute the following measures of postural stability: centre of pressure (COP) path length; COP mean velocity (mean V_{COP}), the area of the 95% best fitting ellipse (area), and the standard deviation of the COP (COP SD) in the medio-lateral (ML) and anterior-posterior (AP) directions, as well as time to boundary (TTB).

COP path length was computed by applying Pythagoras' Theorum to the change in X and Y co-ordinates of the COP position for sequential frames and then adding the interframe path length over all frames. The 95% best fitting ellipse was calculated by iteratively fitting ellipses that encompassed 95% of the COP position over the trial and then selecting the ellipse with the smallest area. TTB is the estimated time is would take for the COP to reach the boundary of the base of support if it were to continue travelling at its instantaneous velocity and trajectory. TTB in the ML and AP directions (TTB ML and TTB AP, respectively) were computed by modelling the feet as a rectangular base of support which was defined by the area within the lateral, anterior and posterior edges of both feet (198).

The base of support was comprised of separate AP and ML components, and instantaneous COP position and velocity were used to calculate TTB for each COP data point. If COP was moving medially (COP ML) then TTB ML would be computed by calculating the distance between COP ML and the medial border (d_{ML}), and then dividing by the corresponding velocity ($V_{COP\,ML}$; See Equation 3.2, adapted from (198, 199)). When COP ML moved laterally TTB ML was computed by dividing the distance between COP ML and the lateral border of the base of support by the corresponding velocity (See Equation 3.2). For calculation of TTB in the AP direction (TTB AP), when COP moved towards the anterior or posterior borders (COP AP) the distance between the COP AP and the anterior or posterior border of the feet, respectively, was divided by the corresponding instantaneous velocity ($V_{COP\,AP}$).

$$\mathrm{TTB\,ML} = \frac{d_{ML}}{V_{COP\,ML}} \tag{3.2}$$

Mean TTB was calculated by calculating the average of all TTB data points in ML and AP directions combined, and mean minimum TTB (mean TTB_{min}) was computed by identifying all TTB minima (i.e.: TTB when COP is closest to the boundary of the base of support) and then computing the average of all TTB minima in ML and AP directions combined (198, 199).

3.2.5 Statistical Analyses

Descriptive data was processed using Microsoft Excel 2010 (Excel; Microsoft Corporation, Redmond, WA), including mean values for participant age, as well as falls incidence and attendance in the 6-month follow-up period. All other statistical analyses were performed using Minitab 16 Statistical Software and Matlab 2008a. Assumptions of normality, homogeneity of variance and sphericity were tested where appropriate and met for each variable included in statistical analyses. Paired t-tests were run to compare differences in whole body and segment lean mass and lean mass percent values obtained by DXA scan between weeks 0 and 18, as well as scores in each of the clinic-based tests between weeks 0 and 6. Individual one-way repeated-measures analysis of variance (ANOVA) were conducted for MCS and PCS of the SF-12 to investigate the differences between weeks 0, 6 and 18. Multi-variate analysis of variance (MANOVA), and ANOVA were followed up with Post-hoc Tukey tests to investigate the effect of week on measures of postural stability during balance trials. One-way repeated-measures ANOVAs of the peak angles and torques at the hip, knee and ankle during walking gait trials at weeks 0, 6 and 18 were also conducted.

3.3 Results

3.3.1 Participants

A total of 51 patients were identified as suitable for inclusion in the study, and were provided with information packs at the falls clinic over the 15-month recruitment period. Twenty six participants took part in the study and data from 22 participants who had attended two or more of the laboratory visits was included in the analyses (mean ± SD: age, 77.1 ± 7.2 years; weight, 72.4 ± 8.7 kg; height, 161.4 ± 8.5 cm). The numbers of participants who completed or dropped-out at each data collection point is presented in Figure 3.4. Table 3.1 presents the number of participants who undertook each component of the testing procedures at each data collection point over the duration of the study. Twenty one of the sample were included in the analysis of the clinic-based test data, 13 in analysis of changes in body composition, and 17 in analyses of laboratory-based measures of balance and gait. All 22 participants were included in the analysis of SF-12 questionnaire data, and data from all 15 participants who participated in follow-up data collection during the 6 monthly calls are reported. Two of the 4 females who dropped out of the study prior to week 6 dropped out due to illness, one due to transport-related issues and another for unknown reasons. Another 7 participants dropped-out prior to testing at week 18; 4 for unknown reasons, one patient was referred for specialist physiotherapy treatment, another was advised to stop attendance due to arthritic knee joint pain, and another was hospitalised due to fall-related injuries.

Week	DXA	SF-12	CBT	Gait	Balance	Fall incidence
Week 0	26	26	26	22	22	-
Week 6	-	22	26	18	18	-
Week 18	14	15	26	12	12	-
6-months	-	-	-	-	-	15

Table 3.1: Number of participants who completed tests for whole body lean mass (DXA), Short-form Health Survey (SF-12), Clinic-based tests (CBT), Gait Analysis (Gait), Balance Trials (Balance) and Fall Incidence at each data collection point.

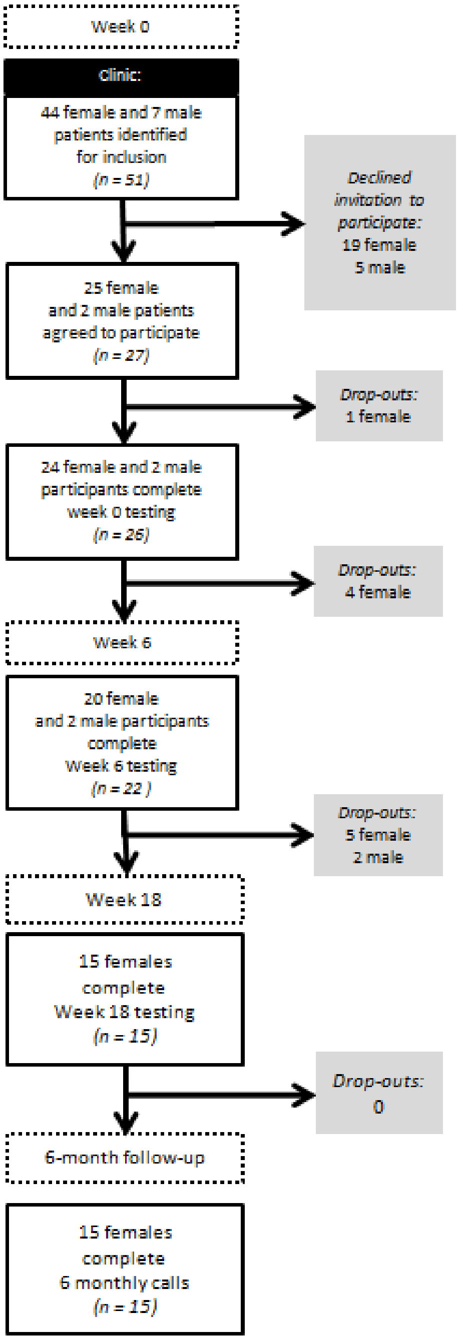


Figure 3.4: Flow diagram showing the number of participants that completed and dropped-out of the testing process at each data collection point.

3.3.2 Fall Incidence

Fall incidence

Fifteen participants completed the six monthly follow-up calls. Table 3.2) shows the total number of falls and the number of participants who fell each month during the 6-month follow-up period. A total of 41 falls were recorded during the 6-month follow-up period among 10 of the 15 participants, and 5 participants experienced no falls during the follow-up period.

Month	n	Falls	Fallers
1	15	7	4
2	15	8	2
3	15	6	5
4	15	7	5
5	15	4	3
6	15	9	6
Total:	15	41	10

Table 3.2: Total number of falls each month and number of participants who fell (fallers) each month during 6-month follow-up period (n = 15).

Injuries and NHS treatments

The monthly and total numbers of injurious falls is presented in Figure 3.5, along with the number of falls where NHS treatment was or was not required. A total of 21 injurious falls were experienced in the 6-month follow-up period, with 8 requiring NHS treatment - a monthly breakdown of soft tissue injuries and fractures, as well as the frequency of overnight stays and use of emergency services due to falling is presented in Table 3.3.

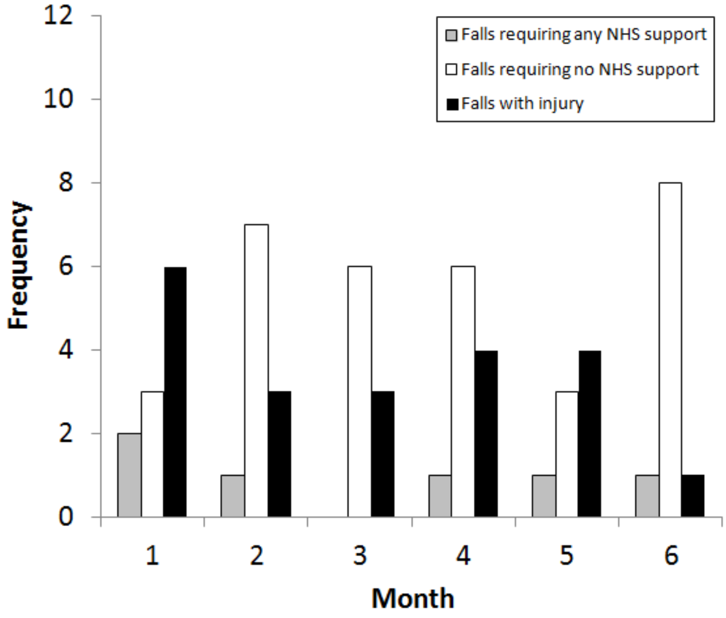


Figure 3.5: Total monthly injurious falls, and falls requiring and not requiring NHS treatment during 6-month follow-up period (n = 15).

Month	ST	Fractures	Overnight	Emergency
1	4	2	2	2
2	2	1	0	1
3	3	0	0	0
4	4	0	0	1
5	4	0	0	1
6	1	0	0	1
Total:	18	3	2	6

Table 3.3: Total monthly injurious falls, and falls requiring and not requiring NHS treatment during 6-month follow-up period (n = 15).

3.3.3 Clinic-based Tests

Paired t-tests from the data of 21 participants showed significant improvements between weeks 0 to 6 in all clinic-based tests ($p < 0.05$), except for Timed Get-

Up-and-Go Test which showed no significant change ($p > 0.05$). Table 3.4 shows the mean changes (with SD) in scores for each of the clinic-based tests between weeks 0 and 6.

	Week 0		Week 6	
	Mean	SD	Mean	SD
FES-I	42.2	12.3	34.9*	9.1
STS	5.7	2.5	8.5†	2.9
HGD-R	18.1	8.5	19.5*	7.2
HGD-L	16.5	7.8	18.6*	6.6
TGUG	23.7	12.1	18.6	9.9
Romberg	2.8	.9	1.3†	.6

Table 3.4: Mean performance scores at weeks 0 and 6 with standard deviation (SD) for the Falls Efficacy Scale International (FES-I), Sit-to-Stand (STS), Handgrip Dynamometry for right and left hand (HGD-R and HGD-L, respectively), Timed-Get-Up-and-Go (TGUG), and Romberg's Balance Tests. Significant difference to week 0 denoted by: * where $p < 0.01$ and † where $p < 0.001$.

Falls Efficacy Scale International

The significant reduction in FES-I score from 42.2 to 34.9 ($p < 0.01$) indicated a reduced fear of falling (possible score range = 16 (no concern about falling) to 64 (severe concern about falling) (See Table 3.4)).

Sit-to-Stand test

A significantly increased number of transitions from 5.7 seated to standing position in the Sit-to-Stand test in week) to 8.5 transitions in week 6 ($p < 0.001$) indicated an improvement in lower limb strength and balance (See Table 3.4).

Timed-Get-Up-and-Go Test

Although non-significant ($p > 0.05$), there was a reduction in the time taken to complete the Timed-up-and-go Test from 23.7 to 18.6 seconds between week 0 and week 6 (See Table 3.4), which suggests that participants demonstrated an increase in walking speed between Week 0 and Week 6. However, the mean completion duration remained over 10 seconds long at week 6, which is taken to represent gait and/or balance deficits, rather than independent mobility (139, 141).

Handgrip Dynamometry

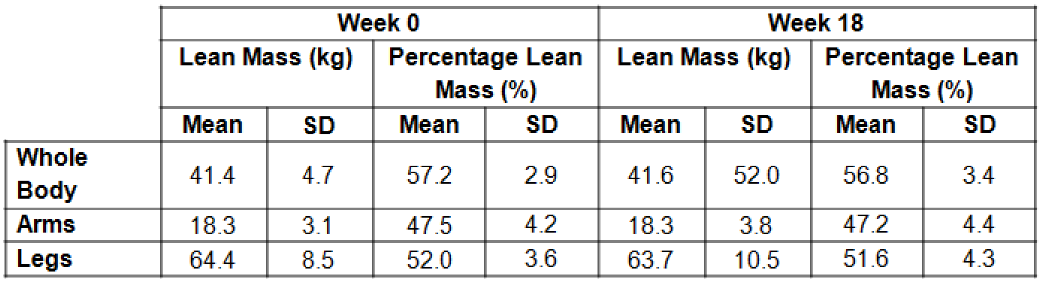
The significant increases in measures of Handgrip Dynamometry in the left (18.1 to 19.5 Newtons) and right hand (16.5 to 18.6 Newtons; both $p > 0.05$) between week 0 and 6 represent increased upper body strength (See Table 3.4).

Romberg's Balance Test

The decrease in Romberg's Balance Test score from 1.8 to 1.3 ($p > 0.001$) indicated improved balance performance - with the scoring scale of 1 representing no sway to 4 representing test failure due to a loss of balance, and scores in between of 2, 3, 4 representing mild, moderate and vigorous sway, respectively (See Table 3.4).

3.3.4 Whole Body Lean Mass

Paired t-tests of the lean mass DXA data of 13 participants showed no significant changes in whole body percentage and absolute values for lean mass between week 0 and 18 ($p > 0.05$). Details of lean mass as a percentage of whole body mass are presented in Table 3.6.



	Week 0				**Week 18**			
	Lean Mass (kg)		**Percentage Lean Mass (%)**		**Lean Mass (kg)**		**Percentage Lean Mass (%)**	
	Mean	**SD**	**Mean**	**SD**	**Mean**	**SD**	**Mean**	**SD**
Whole Body	41.4	4.7	57.2	2.9	41.6	52.0	56.8	3.4
Arms	18.3	3.1	47.5	4.2	18.3	3.8	47.2	4.4
Legs	64.4	8.5	52.0	3.6	63.7	10.5	51.6	4.3

Figure 3.6: Whole body lean mass and lean mass for arms and legs at week 0 and 18 are reported as a percentage of whole body mass (n = 13).

3.3.5 Health-related Quality of Life

Fifteen participants completed SF-12 questionnaires at weeks 0, 6 and 18. One-way repeated-measures ANOVA of data at weeks 0, 6 and 18 showed a significant main effect for time for MCS ($p = 0.025$), but not PCS ($p > 0.05$). Tukey pairwise comparisons showed significant improvements in MCS between week 0 and 18 ($p = 0.02$), but not between week 0 and 6 or between week 6 and 18 ($p > 0.05$). Mean scores at weeks 0, 6 and 18 are plotted in Figure 3.7.

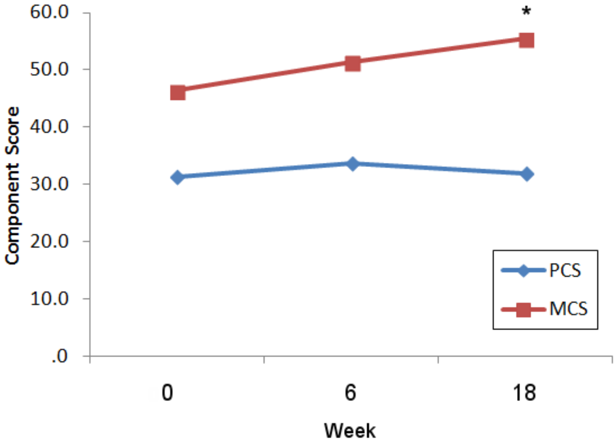


Figure 3.7: SF-12 mean scores for PCS and MCS plotted at week 0, 6 and 18 (n = 22, 22, and 15, respectively); * indicates a significant difference to MCS at week 0.

3.3.6 Balance Trials

MANOVA showed a significant effect for week across all four balance tests for mean TTB (Wilks Lamda = 0.393; $p = 0.028$) and mean TTB_{min} (Wilks' Lamda = 0.416; $p = 0.040$). Follow up one-way repeated measures ANOVAs showed a significant effect for week for mean TTB and mean TTB_{min} for the balance conditions FAEC, FTEO and FTEC, individually.

Balance condition FTEC was the most challenging of the four balance trials, and Post-hoc Tukey tests showed a significant change between week 0 to 18 only (p

= 0.017, 0.019). The week effect was not significant for balance condition FAEO, which was the easiest balance test to perform. Significant changes were found between weeks 0 and 18 in both mean TTB and mean TTB$_{min}$ in Trial FAEC (p = 0.034, 0.049) and balance condition FTEO (p = 0.009, 0.019). Significant changes were also shown in mean TTB and mean TTB$_{min}$ between weeks 6 to 18 in balance condition FTEO (p = 0.021, 0.030). A significant change in mean TTB in Trial FAEC between week 6 and 18 was also found (p = 0.042). Mean TTB and mean TTB$_{min}$ are presented in Figures 3.8 and 3.9.

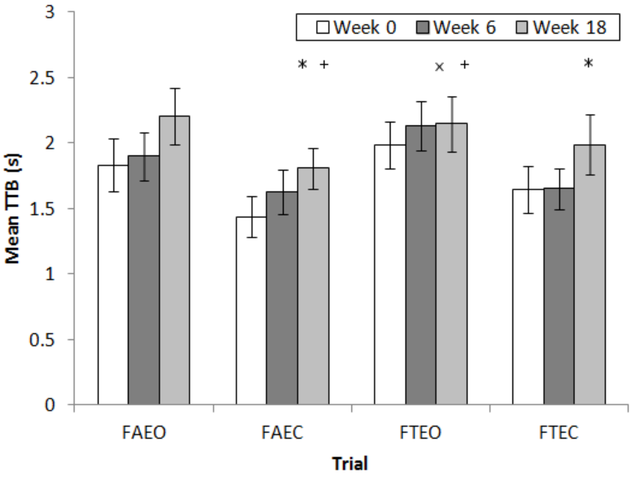


Figure 3.8: Mean time to boundary for each balance trial at weeks 0, 6 and 18. Significant differences to week 0 denoted by * where $p < 0.05$ and $^\times$ where $p < 0.001$, and significant differences to week 6 denoted by $^+$ where $p < 0.05$ (n = 16, Week 0-6; n = 11, Week 18). Error bars show ±1 SE.

There were no significant week effects for any other time to boundary measures calculated, which were the standard deviation of the TTB (SD TTB) and the standard deviation of the minimum TTB (SD TTB$_{min}$). This means that the typical temporal margin to the boundary of support, and the typical smallest temporal margin to the boundary of support both increase over the course of the PSI programme, but the variability in these margins do not change. There were no significant effects for week for any other of the COP measures, including path length and the area of the 95% best fitting ellipse.

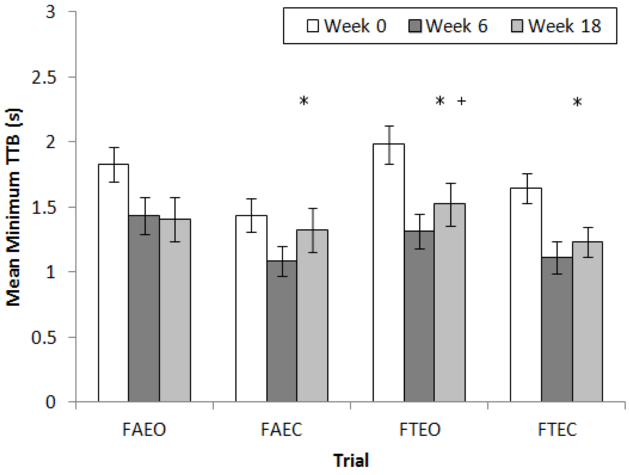


Figure 3.9: Mean minimum time to boundary for each balance trial at weeks 0, 6 and 18. Significant differences to week 0 denoted by * where $p < 0.05$ and significant differences to week 6 denoted by $^+$ where $p < 0.05$ (n = 16, Week 0-6; n = 11, Week 18). Error bars show ±1 SE.

3.3.7 Gait Analysis

Peak angles

One-way repeated-measures ANOVAs of the peak angles at the hip, knee and ankle during gait trials at weeks 0, 6 and 18 (conducted in Minitab) showed a significant increase in peak angle of the left knee in extension between week 0 to 18 ($p = 0.028$) and at weeks 6 to 18 ($p = 0.041$). No significant changes in peak angle were found for extension of the right knee, flexion of either knee, flexion and extension of the hip, or plantar- and dorsi-flexion of the ankle (all $p > 0.05$).

Peak torques

One-way repeated-measures ANOVAs of peak torques showed no significant changes in peak torque at left or right hip, knee or ankle joints (all $p > 0.05$). Figures 3.10, 3.11 and 3.12 show the peak extension for the hip and knee, and peak plantarflexion torque at the ankle. These are shown as they collectively represent lower limb support torque.

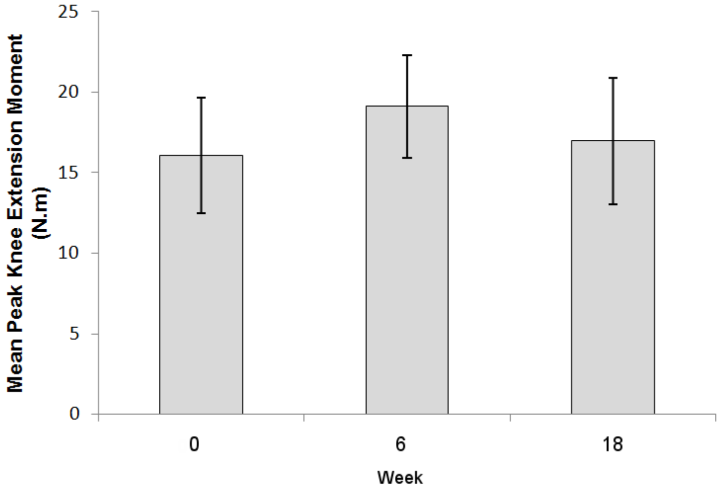


Figure 3.10: Mean torque for knee extension at week 0, 6 and 18. Error bars show ±1 SE.

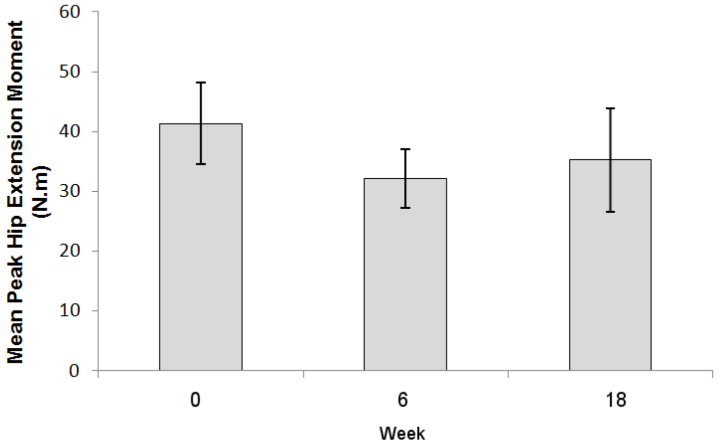


Figure 3.11: Mean torque for hip extension at week 0, 6 and 18. Error bars show ±1 SE.

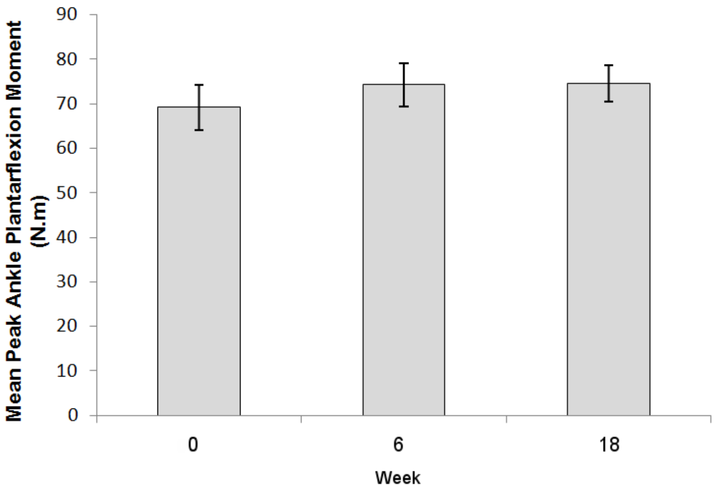


Figure 3.12: Mean torque for ankle plantarflexion at week 0, 6 and 18. Error bars show ±1 SE.

3.4 Discussion

The primary hypothesis for this study was that the number of falls experienced by participants would be reduced in the six month period following completion of the 18-week PSI intervention. All participants had experienced one or more falls during the 6-month period prior to commencing their participation in the study. The results showed that 5 of the 15 participants reported no falls following completion of the 18-week PSI intervention. This means that although falls still occurred, fall prevalence was reduced by 33% in the 6-months following the intervention. The secondary hypothesis was that improvements in clinic-based measures of falls efficacy, strength, balance and gait would improve following completion of the first six weeks of the PSI intervention, along with improved laboratory-based measures for health-related quality of life, balance during quiet standing and joint torques and angles during walking. There was also a prediction of further improvements in these laboratory-based measures, along with an increased percentage (%) of lean mass over the 18-week intervention duration. The results showed improvements in MCS over the 18-week duration of the PSI intervention. Clinic-based measures of fear of falling (FES-I), strength and balance (HGD, STS, Romberg's Balance Test) also improved significantly over the first six-weeks of PSI training. However, no significant changes in percentage lean mass or improvements in physiological health-related quality of life were reported over the 18-week PSI intervention. Clinic-based measures of gait (Timed Get-Up-and-Go Test) and laboratory-based measures of balance and gait also remained unchanged throughout the intervention, except for TTB measures.

The results here are important as they indicate that a shortened PSI intervention lasting 18 weeks is long enough in duration to elicit a marked reduction in fall prevalence among older adults who have a history of falling. The findings reported here support the findings of Skelton et al. (10), who reported a 70% reduction in a sample of 40 participants with a history of falling following completion of the 36-week PSI training intervention. Although the reduction in falls prevalence demonstrated in this study was not as large as that of Skelton et al. (10) the results reported here demonstrate that the positive effects of PSI training on falls incidence can be observed within the first half of the original 36-week PSI intervention duration. In fact, this evidence contradicts Sherrington et al. (156), who made recommendations that interventions must deliver a dosage of at least two hours per week for at least 6 months to prevent falls in older adults based on a review of evidence from 54 randomised controlled studies investigating the effects of exercise as a single falls prevention intervention (156).

However, it should be noted that a high number of falls reported in the study here were by the same 4 participants. It is likely that this is due to extraneous variables that were not managed by the PSI intervention, (i.e.: risk factors such as: culprit medication, multiple prescription drugs, or co-morbidities, such as heart disease). The application of exclusion criteria and implementation of MFFRA at the point of recruitment in the falls clinic was intended to limit the influence of these extraneous factors, but the MFFRA was not repeated after initial recruitment and therefore the effectiveness of any other measures implemented as part of the MFFRI by the falls clinic to control other falls risk factors is not accounted for. Nonetheless, the reduction in falls reported here are important to consider given the positive correlations that have been found between fallers and other health complications and risk factors for health, such as disability, mortality and socio-economic deprivation (2, 26). It is particularly encouraging to see that there was a reduction in injurious falls and falls requiring NHS treatment, which indicates that the PSI intervention could be used to reduced the burden on local health services regarding emergency call-outs, treatments and overnight hospital stays associated with falling.

The findings from this study support existing evidence indicating that fear of falling may be reduced as a result of community- and home-based exercise interventions (55, 154). Although there has been no research published in peer-reviewed journals specifically presenting data regarding the effects of PSI intervention on health-related quality of life and fear of falling, a recent report in 2012 by Aberystwyth University for Betsi Cadwaladr University Health Board (NHS) evaluated the effects of a community-based 32-week adapted version of the PSI intervention in North Wales on a range of psychological and functional measures (154). The report found a significant reduction in fear of falling of 19% ($P < 0.05$) in the frail older adult patients, which was quantified using the FES-I, after completion of the 32-week PSI intervention (154). However, this report only showed significant reductions in fear of falling from baseline measures after 32 weeks of PSI, with no significant changes demonstrated at assessments conducted at weeks 11 and 22. There were also no significant changes in mental or physical health-related quality of life, which was measured using the SF-12v.1 questionnaire at baseline and repeated during weeks 11, 22 and 32 (154).

In contrast to the findings reported by Hudson et al. (154), the results here indicate that just six weeks of PSI training is long enough to elicit significant improvements in perceived psychological health-related quality of life (i.e.: MCS) alongside significant reductions in fear of falling, but not physiological health-related quality of life (i.e.: PCS). Although the concurrent reductions in fear of falling and improved psychological quality of life may be argued to be a desirable effect of exercise (43, 55), without adequate and proportionate improvements in both psychological and physiological risk factors for falling, for example: reduced fear of falling alongside improved strength and balance, there will be a discrepancy between perceived and actual ability to avoid falls (59). However, the results presented here and the findings of Hudson et al. (154) both demonstrate concurrent improvements in clinic-based tests of strength and balance alongside reduced fear of falling (i.e.: improved FES-I scores). For example, Hudson et al. (154) found significantly improved performance scores in 30-second Sit-to-Stand and Timed-Get-Up-and-Go tests after completion of 11, 22 and 32 weeks of PSI training (39% improvement in 30-second Sit-to-Stand and 24% improvement in Timed-Get-Up-and-Go test scores; all $P < 0.001$). Similarly, the findings reported here in this study also show significant improvements in performance scores Sit-to-Stand, Handgrip Dynamometry, and Romberg's Balance tests over six weeks of PSI intervention. These findings both indicate that PSI training enables commensurate reductions in both perceived and actual risk factors for falling over durations between 6 and 32 weeks, which is further supported by the reduced fall prevalence in the findings reported here.

Age-associated strength deficits are a known risk factor for falling (200), and handgrip strength has been shown to be positively correlated with lower limb joint powers and torques, and cross-sectional muscle area, as well as being negatively associated with mobility limitations (114). However, the results from this study showed no significant changes in lean mass (DXA data), gait speed (TGUG) or lower limb joint torques during walking (gait analysis trials) over the whole 18-week PSI intervention duration. This means that the strength gains demonstrated in the clinic-based tests for strength (HGD and STS) in the first six weeks more likely to be attributed to factors other than changes in the lean mass, and that the gains in whole body strength demonstrated by increase handgrip strength do not necessarily result in the redistribution of joint torques during walking tasks. However, regardless of the causes for strength gains, improved whole body strength represented by increased handgrip strength may be influential to balance given the concurrent improvements in performance of STS and Romberg's balance tests implemented in the laboratory and clinic.

Increments in strength in the absence of increased lean mass has been reported to indicate that other factors are influential in determining muscle strength, such as neurological adaptations. For example, randomised controlled study by Taaffe et al. (201) compared the effects of 24 weeks of once, twice and three times weekly resistance training (80% 1RM) of the upper and lower body on muscle strength and lean mass in a sample of 46 community dwelling older adults (age range 65 to 79 years). The results from the isotonic strength tests showed that all variations of the intervention resulted in significant mean strength gains of around 40% compared to the control condition ($p < 0.01$). However, whole body DXA scans showed no significant changes in lean mass and therefore the reported strength gains must be attributed to neurological adaptations.

An example of neurological adaptation associated with strength gains is the ability to voluntarily activate muscle. A positive relationship between lower limb strength and voluntary activation has been demonstrated in both older and younger adults, and the effects of resistance-based exercise training on voluntary activation has also been investigated (87, 105, 106). Voluntary activation is determined by the number of active motor units, and it has been suggested that this may explain strength gains in the absence of change in lean mass (87, 105, 106). Therefore, it is possible that the improved performance in the clinic-based tests (i.e.: Handgrip Dynamometry and Sit-to-Stand tests) reported in the findings of this study may be due to an increased capacity to activate the muscles, particularly in the absence of any changes in whole body lean mass.

Only a limited number of improvements in laboratory-based measures of postural stability were demonstrated in the Balance Trials. Mean TTB and mean TTB_{min} were shown to have greater sensitivity in detecting changes in postural control over the course of the 18-week PSI intervention than the traditional measures of postural stability (i.e.: 95% ellipse area and COP path length). This was particularly apparent during completion of the most complex of the four balance conditions of the Romberg's Balance test (i.e.: where base of support was reduced and/or visual feedback was removed). The improvements in these measures alongside reduced fall incidence reported here also support previous findings that have shown reductions of 48 and 57% in risk of falling in frail older adults following completion of targeted balance and resistance training interventions, respectively (190). In addition, given the significant improvements in performance of the same conditions in the clinic-based test (Romberg's Balance Test), these findings reinforce those of Hertel et al. (198, 199) who have also reported a greater sensitivity of TTB compared with traditional measures in differentiating ankle instability in younger adults during quiet standing in single leg stance.

However, there is contrasting evidence to suggest that strength training alone does not result in adequate balance improvements in older adults (202). A review of literature by Orr et al. (202) examined the findings of 29 randomised controlled studies of progressive resistance training in older adults aged over 50 years, and found that only 14 of the studies reported significant improvements in measures of balance performance. The authors recommended further research into resistance training interventions targeting neuromuscular adaptation in the muscles that influence postural control, as this approach may be more effective in improving balance performance in older adults than general strength training programmes.

The results also indicate that a number of high priority risk factors for falling can be significantly reduced alongside fall incidence as a result of completion of only 18 weeks of PSI training. All but one of the clinic-based tests (i.e.: FES-I, HGD, STS, and Romberg's Balance Test) showed significant improvements, thus demonstrating a reduced fear of falling and increased whole body strength and improved standing balance. The outcomes of the SF-12v.1 MCS also show an improvement in perceived mental health-related quality of life. However, the 18-week PSI intervention was not found to cause any significant gains in whole body lean muscle mass, and therefore it is likely that the changes detected in the performance of the clinic-based tests of strength and balance, as well as the laboratory-based Balance Trials, are more likely to be due to neurological adaptation than physiological adaptation.

Interestingly, static stretching which is a training component incorporated into the PSI intervention has been shown to result in acute strength (160, 163, 203) and activation (203, 204) deficits in the ankle plantar-flexors. As such, there is a need for future research to establish the effects of individual components of PSI on falls risk factors, and to investigate alternative resistance-type exercises that target neuromuscular adaptations in the lower limbs - particularly in the muscles that contribute towards the maintenance of postural stability. For example, PNF stretching incorporates isometric contractions alongside static stretching and has been shown to result in chronic increases in ROM (151, 168, 175, 176, 205) and strength (167, 178). However, the mechanisms for significant changes in ROM and strength following PNF is still unclear, although an increased stretch tolerance has been indicated (167, 206).

A major limitation of this study was the rate at which participants dropped out of the intervention between weeks 0 and 18 (n = 11). Many of the drop-outs were due to issues with transport, which were compounded by the rurality of the Mid-Wales region, where participants were required to travel for up to an hour to reach the community-based classes. The frailty and age of participants also meant that a large proportion of the drop-outs from the PSI intervention were due to illness and fall-related injuries. These specific issues may be addressed by intervening to reduce falls risk early (i.e.: before advancement of strength and balance deficits).

3.5 Conclusion

Demand for a rapid reduction in falls incidence is great, especially given the financial and social costs associated with fall-related injuries in older adults. Therefore, it is important that exercise-based falls prevention interventions are effective in reducing falls risk and incidence over short durations. Previous investigations have shown that fall incidence can be reduced after completion of a 36-weeks PSI intervention (10), while falls risk factors can be reduced over as little as 11 weeks of PSI training (154). However, this study presents new information that fall prevalence and falls risk factors may both be reduced following completion of an 18-week PSI intervention, and that it is possible to see improvements in psychological measures of fear of falling, and performance in established clinic-based tests for functional balance and strength within only six weeks of commencement of the PSI training programme. Despite the absence of muscle hypertrophy, this 18-week PSI intervention results in significant reductions in psychological and physiological risk factors for falling, and although the original 36-week PSI programme (10) produced a greater percentage reduction in fall incidence, this shorter intervention has shown that PSI can be used over half the duration of the original to reduce fall prevalence in frail older adults. Further research into the individual training components of the PSI intervention are needed to establish which are the most effective, and whether more effective alternatives exist.

Part III

Chapter 4

Study Two

Acute effects of proprioceptive neuromuscular facilitation stretching on percentage voluntary activation of the gastrocnemius in older and younger adults

4.1 Introduction

Limited range of motion at the ankle is linked to poor balance performance (169) and an increased risk of falling in older adults (145). The ankle plantar-flexors modulate centre of mass accelerations to contribute towards vertical support and forward progression during walking (109), and the ability to generate ankle joint torques in response to external balance perturbations is vital for restoring and maintaining balance. Worldwide and UK guidelines make evidence-based recommendations that exercise-based falls prevention interventions for older adults must target improvements in lower limb flexibility alongside strength and balance (14, 37, 158). In line with evidence-based exercise recommendations for older adult fallers by the American College of Sports Medicine (ACSM) and American Heart Association (AHA) (12, 13) Postural Stability Instruction (PSI) (10) incorporates static stretching methods to improve flexibility in the lower limb. However, alternative flexibility training methods such as PNF stretching have been found to produce similar acute ROM gains in the lower limb (151, 168, 175, 176, 205), with potential for additional chronic strength gains

(167, 178).

Acute bouts of static stretching have been shown to cause acute ROM gains at the knee of up to 12 ° in older adults aged between 45 and 79 years (175, 176, 205). The mechanical and behavioural properties of the muscle tendon unit that are suggested to be responsible for acute gains in ROM following a static stretch of a joint include reduced muscle tendon unit (MTU) stiffness and increased muscle and tendon length (207, 208), as well as increased MTU stretch tolerance (167, 206). However, in young adults static stretching has been shown to cause significant acute reductions in ankle plantar-flexor joint torques (163, 203), particularly when stretch durations last longer than 60 seconds (160). In addition, these acute reductions in plantar-flexor joint torque production following static stretching have been shown to be linked to decreased central drive, which have been demonstrated by an acute reduction in the ability to voluntarily activate the plantar-flexor muscles (203, 204).

PNF stretching is an alternative flexibility training method that combines both static stretching and resistance training principles. Despite evidence-based recommendations made against the use of flexibility training methods other than static stretching (12, 13) there is increasing evidence to suggest that PNF stretching may elicit acute gains in ROM at the hip, knee and ankle that are equal to or greater than those resulting from traditional static stretching methods (151, 168). A number of studies directly comparing static and PNF stretching of the knee flexors in middle-aged and older adults (aged between 45 and 79 years) have found acute gains in knee extension ROM of up to 16 ° (175, 176, 205), which is around 34% greater than the ROM gains demonstrated following static stretching (176).

PNF stretching has also been shown to have a beneficial chronic training effect on measures of ROM and strength in the planatar-flexors. A study by Rees et al. (178) of 22 healthy young adults aged between 18 and 22 years showed that PNF stretching of the ankle plantar-flexors over a training period of 4 weeks can elicit chronic gains in maximal isometric plantar-flexor strength and ankle ROM in dorsiflexion of 26 and 7.8%, respectively. This evidence is also supported by similar findings of ROM gains of 6 ° in ankle dorsiflexion in healthy young adults aged between 20 and 24 years following completion of a 4-week PNF stretching of the plantar-flexors by Mahieu et al. (167).

Despite evidence of acute and chronic gains in ROM and chronic strength gains in the plantar-flexors following PNF stretching, the explanations for these changes are still not agreed upon. Chronic and acute ROM gains observed following PNF are suggested to be caused by an increased stretch tolerance in the trained muscles by Mahieu et al. (167) and Chalmers et al. (206). However, the authors of Rees et al. (178) measured and reported significant chronic increases in rate of force development (25%), maximal isometric strength (26%) and MTU stiffness (8%) ($P < 0.001$) alongside ROM gains following 4 weeks of PNF stretching, and therefore suggest that the changes in MTU stiffness and ROM occur independently. Rees et al. (178) propose that the isometric contractions that form part of the PNF stretch are responsible for an increased MTU stiffness, resulting in improved storage and release of elastic energy in the MTU, which was demonstrated in their results by a reduced contraction time (i.e.: the increased rate of force development).

However, a number of studies have identified acute strength deficits immediately following the administration of PNF stretches at the hip, knee and ankle in younger adults (151, 163, 168, 177), and the mechanisms responsible for acute ROM gains following PNF are not yet clear. As such, the suitability of PNF stretching for increasing joint flexibility in young adults remains under question (165). Age-related reductions in ankle joint torque in older adults are associated with balance deficits (209), and have been shown to be influenced by a reduced ability to voluntarily activate the ankle plantar-flexors (i.e.: a reduced motor unit firing rate or reduced number of active motor units) (210). Although evidence from a number of studies suggests that maximal voluntary muscle activation is not altered with age and therefore is not fully accountable for age-related strength deficits (104, 105, 106, 107), reductions in the ability to voluntarily activate the plantar-flexor muscles in older adults may be detrimental to balance performance (85), and caution should be used when administering stretches at the ankle in this age group.

Although voluntary activation of the plantar-flexor muscles has been suggested to be partly accountable for age-associated reductions in ankle joint torque (210), and acute reductions in voluntary activation following static stretching at the ankle have been demonstrated (203, 204), there have been no studies conducted to investigate the effects of PNF stretching on the ability to voluntarily activate the plantar-flexors. Furthermore, the existing evidence regarding the acute effects of PNF stretching on joint torque and muscle activation has limited applicability to older adults as most studies have used younger adult samples. Due to the role of lower limb strength for balance during walking and standing, and the age-associated strength and balance deficits that increase risk of falling in older adults, it is important to establish whether or not PNF stretching has an acute detrimental effect on ankle joint torque production, and to identify the mechanisms responsible in older adults so that age-appropriate recommendations can be made regarding its use of PNF stretching in this portion of the population.

In order to establish whether PNF stretching is suitable for use in older adult populations it is imperative that there are no acute detrimental effects on voluntary activation of the calf muscles that might impair strength and thus increase risk of falling. The primary purpose of this study is to compare acute changes in percentage voluntary activation of the plantar-flexor muscles in the calf in response to PNF stretching exercises with a control condition. This was assessed by examination of torque data recorded during isometric MVCs with superimposed twitch stimulation. The secondary purpose of this study is to compare the acute effects of PNF and control conditions between younger and older adults, to establish whether acute activation responses to PNF stretching in voluntary activation are age-dependent.

4.1.1 Hypotheses

The primary hypothesis for this study is that voluntary activation will be lower following completion of the PNF condition compared to the control condition.

The secondary hypothesis is that the older adults will demonstrate a greater decrement in activation of the calf muscles compared with the younger adults following completion of the PNF condition.

4.2 Method

4.2.1 Participants

Nineteen volunteers belonging to one of two age categories (younger adults and older adults, aged 18-30 and 60-70 years, respectively) were recruited from the local community and university. Volunteers who gave one or more positive responses to any of the exclusion criteria in the pre-test questionnaire and items 3-13 of the pre-activity health questionnaire (See Appendices .9 and .8) were excluded from participation in the study. Two participants were excluded from the study: one older woman who presented positive responses to the pre-activity questionnaire, and one younger woman who experienced discomfort during the testing procedures. In total 17 participants completed all testing procedures; 3 females and 5 males belonged to the older group (mean ± SD: age, 63 ± 2 years; height, 1721 ± 85 mm; weight, 74 ± 10 kg) and 5 females and 4 males belonged to the younger group (mean ± SD: age, 26 ± 2 years; height, 1746 ± 86 mm; weight, 45 ± 13 kg). None of the participants had taken part in a PNF stretch training programme during the six months prior to their participation in the study. All participants gave their written informed consent and ethical approval was gained from the Research Ethics Committee at Aberystwyth University.

4.2.2 Experimental Design

A cross-sectional design was used to evaluate the effects of age and the two test conditions on outcome measures. The participants visited the laboratory on three separate occasions over a period of 10-14 days. The first visit was used to familiarise the subjects to the equipment and experimental procedures. During all three visits to the laboratory all subjects completed isometric maximal voluntary contractions (MVCs) of the plantar-flexor muscles with a superimposed twitch generated by electrical stimulation (ES; See Section 4.2.4.1). During the first visit (familiarisation) participants practised isometric MVCs to familiarise themselves with the strength testing protocol, after which two experimental conditions were demonstrated by the investigator and performed by the participants. In the two subsequent laboratory visits the participants performed one of the two experimental conditions during each visit immediately before performing the isometric MVC trials. The order in which the experimental conditions were performed was randomly assigned (See Figure 4.1).

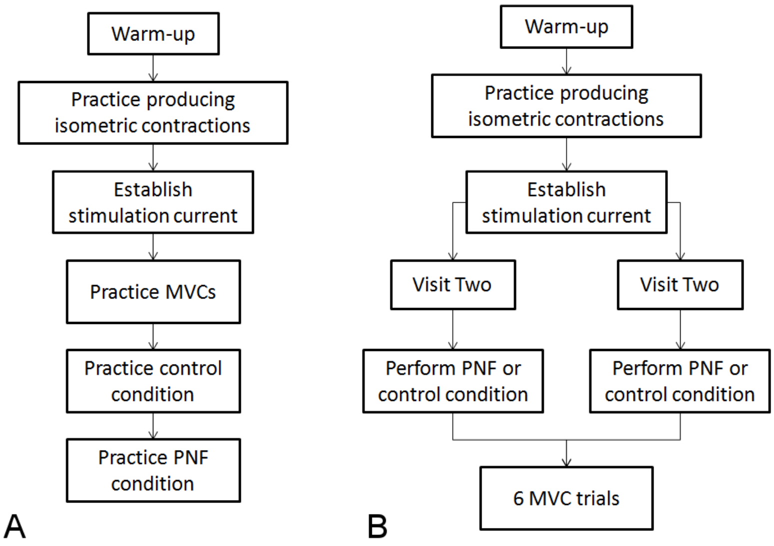


Figure 4.1: Flow diagrams representing the order of procedures during (A) familiarisation and (B) visits one and two (PNF = proprioceptive neuromuscular facilitation; MVC = isometric maximal voluntary contraction).

The order in which preparation and testing procedures were carried out during the familiarisation and visits one and two are presented in Figure 4.1. During each visit the participants were allowed a cycle ergometer warm up, followed by the placement of ES electrodes, and performance of a number of practice submaximal isometric contractions to adjust to the strength testing equipment. An optimum ES current required to elicit maximal doublet response from the gastrocnemius was established for each participant at the familiarisation, and was checked at the beginning of each testing session by gradually increasing the current over several twitches (See Section 4.2.4.1). At this point during visits 1 and 2 the appropriate experimental condition was applied, followed immediately by six MVC trials, with each trial alternating between MVC with superimposed ES, and MVC without superimposed ES. During each trial isometric torque data was collected. At the end of the familiarisation visit the experimental conditions were demonstrated to the participant; however, participants were instructed not to repeat the conditions outside of the laboratory between visits to avoid any training effects that might influence the results of the study.

4.2.3 Experimental Set-up

4.2.3.1 Electrode Placement

A pair of self-adhesive PALS Platinum Electrodes (width 90mm x height 50mm; Axelgaard Manufacturing Co., Ltd., Fallbrook CA, USA) were used for delivery of the electrical stimuli. During electrode placement participants lay in the prone position on an assessment couch, and the areas where the electrodes were to be placed were cleansed (and shaved if required). The electrodes were applied to the skin over the proximal third of the calf, and positioning of these electrodes is shown in Figure 4.2.

4.2.3.2 Subject Positioning

The participants were seated in the chair of the Biodex III dynamometer (Biodex Medical Systems, Shirley, NY) with their right leg positioned to perform the practice submaximal contractions. The right hip angle was 85 ° in flexion and knee angle at 0 ° flexion, if 0 ° flexion is defined as full extension at the knee and hip. The ankle was always in the neutral position at the start of each testing procedure, i.e.: so that the angle between the plantar surface of the foot and the tibia and fibula was 90 °. The dynamometer axis was aligned with the ankle joint axis, and all bolts and moving parts on the dynamometer were checked and tightened. Restraining straps were used around the mid-calf, thigh, waist, and

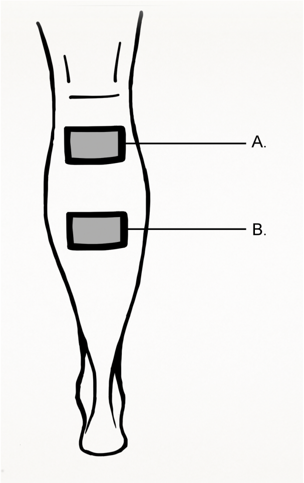


Figure 4.2: Posterior aspect of the lower leg showing electrode placement for superimposed ES: one electrode was placed proximally to knee joint over motor point of gastrocnemius (A), and another just above Achilles tendon (B).

chest to prevent any compensatory motion of the trunk which could influence force measures taken at the ankle.

4.2.4 Testing Procedures

4.2.4.1 Electrostimulation Protocol

Initially, the stimuli to the gastrocnemius were delivered manually though the DSAH7 trigger control in single pulse widths of 100 μs. The current started at 10 mA, and increased in steps of 10 mA until a muscle activation response was produced and could be seen through a graphical representation of force output at the ankle obtained by the Biodex. Following this the stimuli were then triggered using a Labview (National Instruments Inc. Austin, TX, USA) interface that delivered two pulse widths of 100 μs with a 10 millisecond (ms) interpulse interval (II) and a total stimulation time of 0.0102 s (referred to herein after as doublets). The 10 mA increments in current were repeated until no change in force output was detectable or the subject indicated that the highest current they were willing to tolerate had been reached. The desired muscle response was to be elicited without discomfort, and these procedures were in accordance with manufacturer recommendations. There were six trials in total, during each of which participants performed one isometric MVC lasting 3 s. During the first, third and fifth trials only, two electrical stimuli were delivered in doublets to the gastrocnemius; the first was administered 1.5 s into the MVC (active) and the second 5 s after completion of the MVC (resting). The current used for this was the 110% of the optimum current established in each session. Participants had a rest period of at least one minute between MVCs. Participants were provided with visual feedback during all MVCs.

4.2.5 Experimental Conditions

The experimental conditions were a Proprioceptive Neuromuscular Facilitation (PNF) stretching intervention and a control condition. Participants practised the conditions during the familiarisation, before performing the conditions immediately before strength testing during visits 1 and 2. The experimental conditions were applied to both legs. When performing each of the experimental condition participants were seated in the Biodex chair to ensure strength testing took place as soon as possible after the conditions were administered.

4.2.5.1 PNF Stretch Procedures

The PNF stretch used in this experiment is an adapted version of the partner-assisted and self-administered gastrocnemius stretches described by McAtee and Charland (211). The PNF stretch was administered with the leg fully extended at the knee, and the uninvolved knee would remain at approximately 90 ° flexion (see Figure 4.3.A). The investigator supported the heel in one hand, while the palm of their other hand was placed vertically against the proximal half of the plantar surface of the foot (see Figure 4.3.B). The participant was then instructed to take a breath in and then exhale as they dorsiflexed their ankle as far as possible. As they did so the investigator kept their palm positioned against the proximal half of the plantar surface of the foot. When the participant had reached the end of their range of motion this position was held for five seconds (see Figure 4.3.C). This was followed by a 10-second voluntary isometric contraction of the plantar-flexor muscles with $\sim$65% of the participant's maximal force against the investigator's matching resistance (see Figure 4.3.D). Finally, the participant relaxed for 5-10 seconds before repeating the stretch. These actions were repeated three times in the same order on each leg to complete one full set of the PNF stretch protocol.

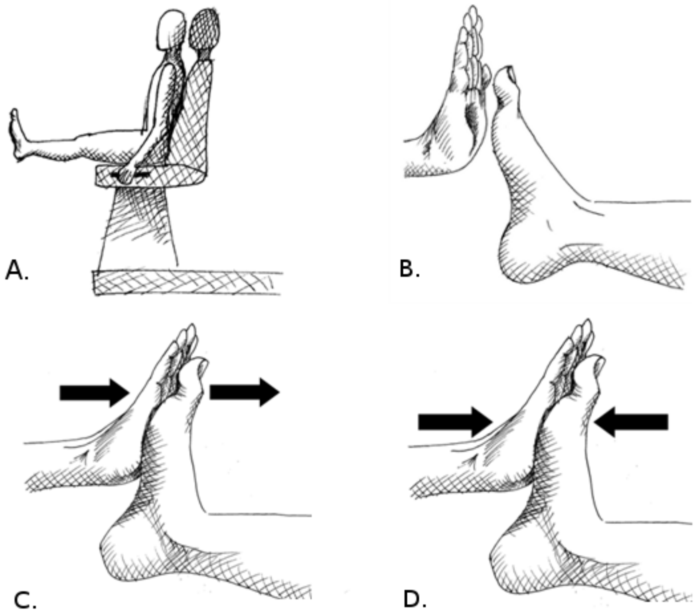


Figure 4.3: PNF Stretch: (A) Participant in seated position with hip in 85 ° flexion and left knee fully extended. (B) The palm of the investigator's hand was placed vertically against the proximal half of the plantar surface of the participant's foot. (C) Participant actively moves their ankle in dorsiflexion to the end of its range of motion. (D) Participant isometrically contracts their plantar-flexors with 65% of their maximum effort

4.2.5.2 Control Condition

During the experimental condition the participant was seated with the hips at an angle of 85 ° flexion, and the involved leg partially extended at the knee to ensure clearance of the foot from any testing equipment throughout performance of the control condition. The involved ankle started in the neutral position. The uninvolved knee was positioned at an angle of 85 ° flexion and the uninvolved ankle remained in the neutral position throughout performance of the control condition by the involved leg. Participants were instructed to mirror the actions of the investigator; holding each ankle at the end of their active range of motion (ROM) in eversion, inversion, plantarflexion and dorsiflexion for seven seconds (see Figure 4.4). Following this, the participants were instructed to circle their ankles seven times in a clockwise direction, and then seven times in an anti-clockwise direction.

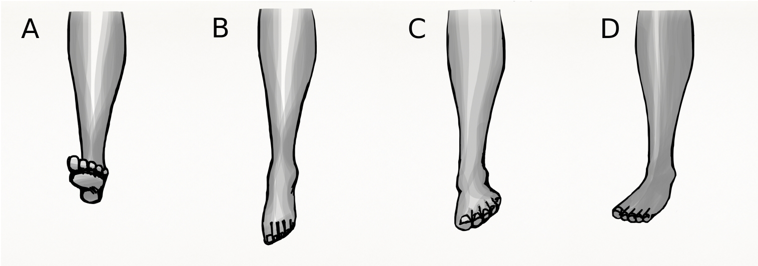


Figure 4.4: Control condition - Participants held their ankle at the end of ROM for seven seconds in A. Dorsiflexion, B. Plantarflexion, C. Eversion and D. Inversion, before circling their ankles seven times in clockwise and then anti-clockwise directions.

4.2.6 Data Acquisition and Analysis

Isometric torque data were acquired from the peripheral devices using BNC cables connected to a National Instruments BNC 2110 connector block (National Instruments), and saved to a personal computer. The sampling rate for torque data acquisition was 1 kHz, and a 4th order low-pass Butterworth filter with a cut-off of 40-Hz was applied to the torque signal. Isometric torque data was exported to Matlab R2008a (The MathWorks) for further processing. Percentage muscle activation (%) in the gastrocnemius during MVC was computed for each subject in each condition.

In this study voluntary activation was assessed using ES - a method that has been used in a number of research studies examining voluntary activation in the muscles of the lower limb (85, 87, 106, 203). Percentage voluntary activation (Activation (%)) was calculated using Equation 4.1 (212) - where the superimposed doublet was torque measured during the MVC, and the potentiated doublet was torque measured at rest following MVC.

$$Activation\,(\%) = \frac{1 - superimposed\,doublet}{potentiated\,doublet} \times 100 \tag{4.1}$$

4.2.7 Statistical Analyses

Dependent variables analysed in this study were peak joint torque and percentage voluntary activation of the gastrocnemius during isometric MVC in plantarflexion at the ankle joint. A three-way repeated measures analysis of variance (ANOVA) was used to identify differences between age groups and experimental conditions for each of the dependent variables. Therefore the main factors were: age group, condition and subject. 'Subject' was a random blocking factor nested in 'age'. Paired t-tests were performed individually to examine differences between conditions within each age group. Analysis of data was conducted using Minitab 16 Statistical Software. In each analysis differences were considered significant when $p < 0.05$. All descriptive statistics are presented as means with standard deviation (SD).

4.3 Results

Percentage Activation

An initial analysis of all the percentage activation data showed significant effects for age group mean (SD): young group = 78 (1.6) % compared with old group = 87 (1.7) % ($p < 0.002$), but not for condition ($p > 0.05$; See Figure 4.5). However, upon inspection of individual results it was found that the activation recorded was under 60% for two of the younger and one of the older participants. On inspection of the force record for the individual trials it was found that these subjects had not timed their MVC to match the delivery of the stimulus delivery, and therefore the stimulus was delivered after the point of at which peak force was achieved (See Figure 4.6). These trials were removed from the data set and the data was re-analysed. The re-analysed data showed no significant effects for age between the young group and the old group, who were able to voluntarily activate 86 (1.8)% and 91 (1.8)% of the gastrocnemius muscle, respectively. There was also no significant effect for condition ($p > 0.05$) and mean percentage activation is plotted in the graph shown in Figure 4.7). Paired t-tests also showed that within each age group there was no significant difference in percentage activation following each condition (younger: control = 82 (0.2)% and PNF = 75% (0.2); older: control = 87 (0.1)% and PNF = 87 (0.2)%; both $p > 0.05$).

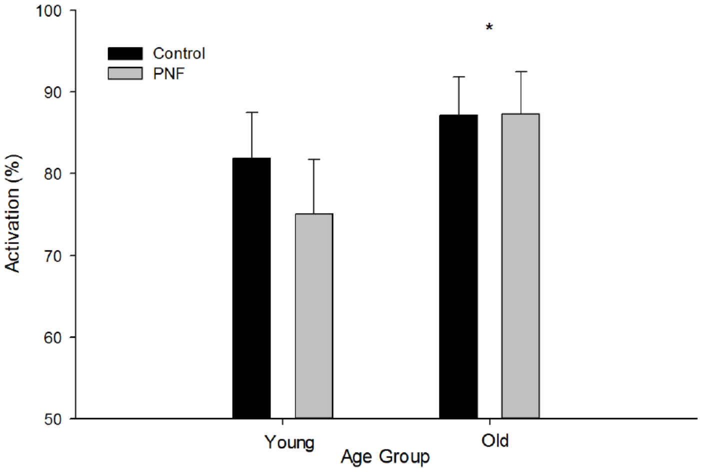


Figure 4.5: Mean activation for all participants in old and young groups for control and PNF conditions (n = 17; full data set presented). *denotes significant differences ($p < 0.05$) between old and young. Error bars show ± SE.

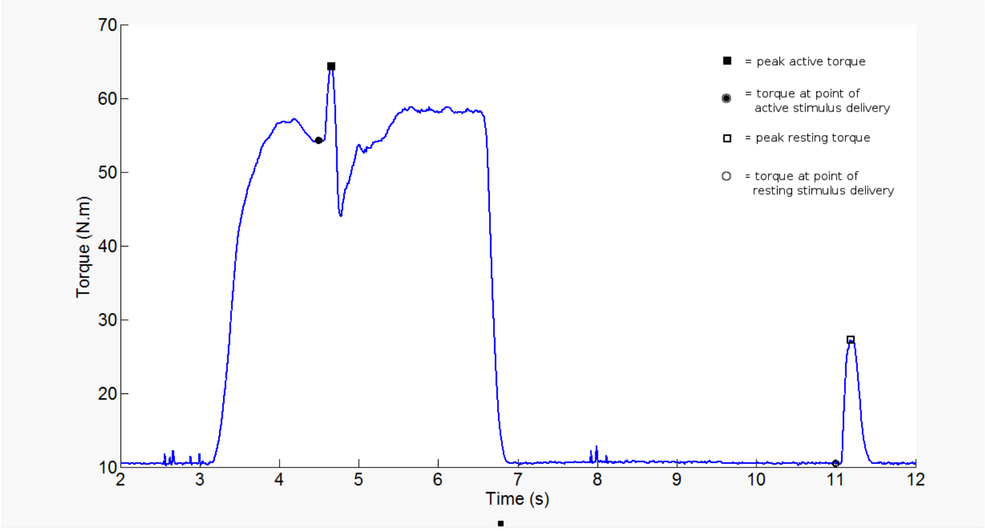


Figure 4.6: Example trial from data used in initial statistical analysis of torque data that was excluded from a second analysis due incorrect timing of MVC relative to the delivery of the first (active) stimulus; the participant has clearly begun to relax at the point of stimulation delivery.

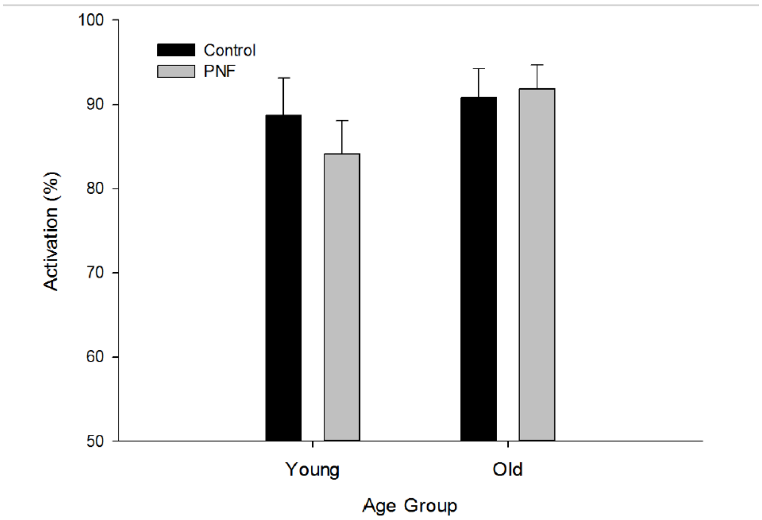


Figure 4.7: Mean activation for re-analysed data in old and young groups for control and PNF conditions. Error bars show ± SE.

Peak torque

Peak torque in plantarflexion during isometric MVC was not significantly different between age groups and conditions ($p > 0.05$). Mean values for peak torque in plantarflexion are presented in Table 4.1).

		Pt (N.m)	
Condition	Age	Mean	SD
Control	Young	126.7	42.2
	Old	116.4	45.6
PNF	Young	129.5	49.7
	Old	119.8	45.5

Table 4.1: Mean values with standard deviation (SD) for peak joint torque (Pt).

4.4 Discussion

The primary hypothesis for this study was that voluntary activation would be lower following completion of the PNF condition compared with the control condition. However, the findings showed that there was no significant acute difference in voluntary activation of the plantar-flexor muscles between the PNF or control conditions for either age group. The secondary hypothesis was that the older adults would demonstrate a greater decrement in activation of the calf muscles compared to the younger adults following completion of the PNF condition. However, the results reported no significant difference in voluntary activation of the plantar-flexor muscles between age groups for either condition once erroneous trials had been excluded. In fact the full data set suggested older adults to be better able to activate their plantar-flexors compared to younger adults, and that PNF stretching does not change this. However, the data revealed that younger adults produced greater peak torques in plantarflexion than the older adults under both conditions.

Voluntary activation refers to the ability to activate motor units in a muscle during a voluntary contraction, and has been shown to be positively associated with maximal strength in the joints of the lower limb, including the knee extensors (105, 106) and ankle dorsiflexors (107). Accordingly, sarcopenic changes in muscle function and architecture, i.e.: decreased muscle mass and muscle strength with age (74), have also been found to be associated with a reduced ability to voluntarily activate the ankle plantar-flexor muscles (210). However, no effect of age on voluntary activation and peak torque was found in this study, which supports evidence from a number of previous studies that have also demonstrated maximal voluntary muscle activation to be unaffected by age (104, 105, 106, 107). As such, the findings from this study indicate that voluntary activation cannot be fully accountable for age-related changes in muscle strength.

The results from this study showed no significant differences in percentage voluntary activation and peak torques between the PNF and control conditions, and suggest that voluntary activation of the plantar-flexor muscles is not acutely affected by PNF stretching when compared with a control condition. As such, the findings presented here regarding acute effects of PNF stretching on plantar-flexor torque are not in agreement with the findings of Babault et al. (163), who compared the immediate effects of PNF and static stretching on maximal isometric torque at the ankle during MVC in plantarflexion in a sample of ten young male participants (mean ± SD: age, 23 ± 1 years). Both stretching techniques resulting in a significant mean reduction in maximal isometric torque in plantarflexion (mean ± SD: 6.9 ± 11.6%)($p \leq 0.05$). Such a significant reduction in maximal voluntary torque in the plantar-flexors muscles is not a desirable outcome particularly considering the relationship between ankle strength and balance performance (85, 132). However, direct comparisons of the findings reported by Babault et al. (163) and those reported here cannot be made as there were notable differences between the studies. For example, Babault et al. (163) only examined the effects of PNF and static stretching in younger adults aged between 22 and 24 years, and the durations of the stretch and isometric contraction components of PNF methods used in Babault et al.'s study were 24 seconds and 6 seconds, respectively, compared to 5 and 10 seconds each for the stretch and contraction components used here in this study.

The absence of an acute strength or activation deficits immediately following administration in younger and older adults indicates that the PNF stretching method implemented in this study may be used in both younger and older adults safely without compromising ankle plantar-flexor torque. These findings are particularly important for older adults with pre-existing strength and balance deficits due to the role of the ankle plantar-flexors in the maintenance of balance during standing and walking (109, 110). However, the findings from this study should be interpreted with caution. PNF stretching is used to increase flexibility over long training durations and results presented here do not include measures of ankle ROM - without this information the effect of this PNF stretching method on plantar-flexor MTU length and stretch tolerance in older adults is unknown. Further evidence is needed to clarify the relationship between voluntary activation, strength and ROM in older adults, and the acute and chronic effects of PNF stretching on these measures.

Although not a significant finding the older adult participants here were stronger on average than the older adults studied by Morse et al. (210), producing mean (SD) peak torques during isometric MVC in plantarflexion of 116.4 (45.6) and 105.6 (4.3) N.m in each study, respectively. In contrast, the younger participants reported here (age range 22-28 years) were weaker than the participants of the younger age group used in Morse et al.'s (210) study (age range 19-35 years), who produced mean peak torques of 126.7 (42.2) and 173.4 (8.1) N.m, respectively. The weaker strength performance shown by the older adults used in Morse et al.'s (210) study may be attributed to an older age range of 70 and 82 years (210) compared to 61 and 66 years studied here, as lower limb strength measures associated with loss of muscle mass with age have been shown to decrease by around 15% per decade (75). However, although again non-significant, the lower percentage activation of the plantar-flexor muscles demonstrated here by the younger adults (78%) compared to the older adults (87%) is unexpected as it does not align with the predicted relationship of concurrent reductions in strength and percentage activation with age. These findings are also in direct conflict with those of Morse et al. (210) who reported greater activation in the younger adults (99%) than older adults (78%).

There is evidence to suggest that activity in the calf muscles increases with age as a means of compensation for faster declines in joint torque production and balance performance (132, 213). It is possible that the older adults have increased activation of the calf muscles to compensate for muscle strength and balance deficits with age known to accompany sarcopenic loss of muscle mass. However, the evidence used to demonstrate this compensatory effect is from electromyographical (EMG) data (132, 213), which represents the net muscle activity in a portion of motor units rather than activation capacity of a whole muscle. A further disadvantage of this method is that between laboratory visits it is difficult to locate the exact same motor units when placing electrodes, and therefore this method was not used to evaluate muscle activity here. It is possible that the unexpected age-related differences in activation reported here could be partly explained by greater physical activity levels of the older participants than the younger participants here. Voluntary activation, muscle strength and mass is greater in those with higher levels of physically activity (210, 214), and it is possible that the younger adults were comparatively less physically active than the older adults. However, the suggested influence of physical activity on any outcome measures here is merely speculation as physical activity levels were not specifically recorded as part of these studies.

A limitation of this study is that the peak torque values recorded at the ankle represent the resultant peak torque of all calf muscles, but the superimposed doublets administered during MVC were delivered only to a small area of the gastrocnemius - meaning that the gastrocnemius was the only muscle to make contributions by peripheral activation. Therefore the peak torque values obtained at the ankle following the superimposed doublets represented 100% activation of only a portion of the motor units in the gastronemius, while all other torque contributions are assumed to be made by central activation of the other plantar-flexor muscles of the calf. This means that the effect of the experimental conditions on voluntary activation has only been evaluated in a small portion of gastrocnemius muscle in this study, and that the effects of PNF on torque production by the other muscles of the calf, such as the soleus, are unknown. If possible, future studies should investigate the effect of PNF on voluntary activation of the calf muscles using stimulation of the tibial nerve, which has been used in previous research studies to evaluate activation of the plantar-flexors muscles of the calf (87, 88, 215, 216). This method was not used for this investigation simply due to a lack of equipment available to the investigators.

In addition the sample sizes used in this study were small compared to those used in previous studies investigating similar measures, for example in each age group of Morse et al.'s (210) study, there 21 older and 14 younger adults compared to 8 older and 9 younger adults here. It is possible that the smaller number of participants used here may have reduced the power of the data here, and may help to explain the absence of significant findings, despite differences in both peak torque and voluntary activation between the age-groups. It would also have been possible to examine the age-related responses in greater detail by comparing post-condition measures with baseline measures of activation. However, due to the increased likelihood of peripheral fatigue associated with repeated MVCs in plantarflexion (215), additional tests to obtain baseline measures of torque and activation were not conducted in this study. As such, it is unknown from the findings whether there was an acute effect of either experimental condition on baseline measures for either age group. Future investigations into age-related effects of PNF stretching at the ankle should use larger samples to ensure greater power and reliability, and include baseline measures to enable direct comparison of both acute and chronic pre- and post-PNF outcome measures.

PNF stretching is a flexibility training methods, and in order to confirm suitability of this stretching method for inclusion in long-term exercise interventions undertaken by frail older adults, such as the 36-week PSI (10), the chronic effects of long-term PNF stretching at the ankle still needs to be investigated in frail older adults. Reported baseline strength and balance deficits in frailer older adults and the suggested relationship with voluntary activation mean that a small acute reduction in strength or ability to activate the calf muscles may significantly undermine balance performance and increase falls risk. The findings reported here have confirmed that PNF stretching may be used safely in healthy older adults, which is a necessary and precautionary first step before investigating the effects of PNF in more frail older adult populations. It is now important to establish the chronic effects of PNF on ROM and strength in healthy older adults, so that the suitability of PNF as a flexibility training intervention for frail olders can be considered, particularly over durations that are reflective of the frequency and duration of exercise-based falls prevention interventions that they might be used in (i.e.: several weeks, months or years). It is also important that the effects of PNF on measures of strength that are known to influence the ability to perform ADLs is also evaluated.

4.5 Conclusion

The effects of PNF on muscle activation and strength at the ankle in older adults is relatively under-researched. Reduced percentage voluntary activation at the ankle results and a reduced ability to generate sufficient joint torque for activities such as walking, weight transfer (i.e.: transferring from a seated to standing position), maintaining balance during quiet standing and regaining balance following external perturbations. The results from this study indicate that PNF exercise at the ankle does not acutely reduce plantar-flexor strength or the ability to voluntarily activate the calf muscles in healthy younger and older adults. These findings present an early indication that PNF may be suitable for use as a flexibility training component of an exercise programme for healthy older adults, however, it is unclear from these findings how PNF stretching influences ROM at the ankle in older adults and if this is related in any way to the age-related changes in voluntary activation and strength that have been reported elsewhere in the literature. Future research is needed to establish the chronic effects of longer PNF stretching interventions on measures of ROM and strength at the ankle - in particular, to ensure that there are no detrimental effects to balance that might increase risk of falling in frailer portions of the older adult population.

Chapter 5

Study Three

Acute and chronic effects of a four week proprioceptive neuromuscular facilitation stretch training programme on ankle range of motion and isokinetic strength in older and younger adults.

5.1 Introduction

Lower limb ROM and strength are known to diminish with age (143), and targeted exercises to improve ROM and strength have been recommended in UK and worldwide guidelines for exercise in older adult populations (14, 37, 158). Although static stretching is the recommended method of stretching, acute improvements in ROM have been found following completion of only one bout of PNF stretching (151, 165, 166, 168, 175, 176, 205). Furthermore, PNF stretching interventions lasting 4 to 6 weeks in duration have been found to chronically increase lower limb joint ROM (149, 150, 151, 178, 217) and strength (167, 178) in younger adults. However, only a small amount of research conducted has investigated samples of older adults (147, 175, 205).

Age-related changes in mechanical properties of the MTU, including increased muscle stiffness associated with structural changes in the muscle tissues (169, 218, 219) and reduced rates of joint torque development (220), are likely to influence which are the most effective stretching methods to use in older adult populations.

Despite the effect of ageing on these factors and the significant role the ankle plays in restoring and maintaining balance during static and dynamic activities (i.e.: quiet standing and walking, respectively) (109) most studies have examined the effect of PNF stretching at the hip and knee (149, 150, 151, 168, 175, 176, 205, 217) in younger populations (149, 150, 151, 178, 217). In short, there is a paucity of research conducted into the chronic effects of PNF on ROM and strength at the ankle joint in older adults.

It is important to establish that PNF stretching does not result in acute or chronic strength losses that may be detrimental to performance of activities of daily living (ADL), such as walking, or increase risk of falling in older adults with existing strength deficits. The research that has been conducted on younger adults has found lower limb joint ROM after completion of only 4 to 6 weeks of participation in PNF stretching interventions (149, 167, 178, 217), and it has been suggested that chronic ROM gains found at the ankle following PNF stretching are likely to be explained by an increased stretch tolerance (167, 178, 206) rather than a reduction in muscle stiffness (178).

For example, a randomised controlled study by Rees et al. (178) examined the effects of a four-week PNF stretching programme at the ankle in a sample of twenty healthy young women (mean age: 20 ± 2 years) belonging to a control group (n = 10) or a training group (n = 10). The stretching programme involved three 132-second training sessions per week for four weeks, and the outcome measures were ankle ROM in dorsiflexion, peak force and rate of force development during isometric MVC in plantarflexion, muscle-tendon unit stiffness and stretch tolerance. Significant increments were found in all measures in the training group compared to the control group: ROM in dorsiflexion and muscle-tendon unit stiffness increased concurrently by 7.8 and 8.5%, respectively (both $p < 0.001$), peak force and rate of force development during isometric MVC in plantarflexion also increased concurrently by 26 and 25%, respectively ($p < 0.001$) and stretch tolerance increased by 231% after completion of the four-week PNF stretching programme ($p < 0.001$) (178). The concurrent increases in ROM and muscle stiffness reported by Rees et al. (178) indicate that muscle stiffness is not accountable for

ROM gains following PNF, and that the dramatically increased stretch tolerance is a more likely explanation. Similar findings and conclusions were also reported by Mahieu et al. (167) in another young sample following completion of a similar six-week PNF stretching programme.

However, there is no evidence indicating that similar changes in ROM and strength measures can be observed in older adults at the ankle. Additionally, not all evidence examining the effects of PNF on strength have found positive training responses - particularly in measures of dynamic strength (168). For example, Marek et al. (168) have reported significant acute reductions in isokinetic strength alongside ROM gains in the knee extensors immediately following a bout of PNF stretching in a sample of younger adults. These findings are important because lower limb isokinetic strength has been shown to be account for 17% of variance in gait speed in older adults aged over 60 years (221), and reduced gait speed is a known risk factor for falling in older adults (222).

The effects of long duration PNF stretching programmes on ROM and isokinetic strength at the ankle joint in older adults has not been investigated despite the important role the ankle plays in balance and forward progression during walking. Therefore, the primary purpose of this study is to investigate the effectiveness of a four-week PNF stretch training programme in improving range of motion (ROM) at the ankle, including a comparison of training responses in ROM between old and young. The four-week PNF stretching programme duration is selected based on existing evidence that changes in muscle mass may result from as few as 20 days of resistance training (98), and this intervention duration is comparable to a number of other research studies investigating the chronic effects of PNF stretching on ROM and isokinetic strength of the lower limb joints in younger participants (149, 167, 178, 217). In light of the conflicting evidence regarding the acute effects of PNF exercises on strength in younger adults and an absence of evidence regarding acute effects in older adults, the secondary purpose of this study is to investigate acute and chronic effects of the PNF stretch training programme on isokinetic force production at the ankle, to assess whether strength is adversely affected in younger or older adults.

5.1.1 Hypotheses

The primary hypothesis for this study is that chronic gains in ankle ROM will be demonstrated in both old and young age groups following completion of a four-week PNF stretching intervention. A secondary hypothesis is that there will be no chronic or acute changes in ankle strength measures in both age groups as a result of the PNF stretching intervention.

5.2 Method

5.2.1 Participants

Participants were volunteers from the local community and university who were recruited through placement of posters in public places and circulation of notifications via email lists. Sixteen volunteers belonging to one of two age categories (younger adults and older adults, aged 18-30 and 60-70 years, respectively) completed all five data collection points and the intervention: 4 females and 4 males belonging to the younger adult group (mean ± SD: age, 23.8 ± 3.7 years) and 3 females and five males belonging to the older adult group (mean ± SD: age, 62.5 ± 3.2 years). All participants completed a pre-activity health questionnaire (PARQ; See Appendix A.8) and pre-test questionnaire (PTQ; See Appendix A.9), and were physically active. All participants gave their written informed consent and ethical approval was gained from the Research Ethics Committee at Aberystwyth University.

5.2.2 Experimental Design

A longitudinal, repeated-measures design was used. The independent variables in this study were age (old versus young) and time (before versus after 4-week intervention, and pre-stretch versus post-stretch). The dependent variables recorded were peak torque produced in plantar- and dorsi-flexion during isokinetic MVCs at angular velocities of $60^\circ \cdot \mathrm{s}^{-1}$ and $120^\circ \cdot \mathrm{s}^{-1}$, and ankle ROM in plantar- and dorsi-flexion with the knee at 0° and 90° flexion.

The participants visited the laboratory on five separate occasions over a period of four to five weeks. The first visit also included a familiarisation of the study protocol. In each of the five visits the participants completed tests for ankle ROM immediately before and after performing the PNF ankle stretch. During the first and fifth visits two bouts of isokinetic strength testing were conducted; one bout immediately before and another bout immediately after performance of the PNF stretch. Therefore the order of procedures during the first and fifth visits was: strength testing, ROM measurement, PNF stretch, ROM measurement, strength testing.

At the end of the first visit following baseline testing, participants were provided with instructions to complete a four week PNF stretching programme (See Appendix 1.12, which included five weekly visits to the laboratory to test ankle ROM and check self-administered stretching technique (See Section 5.2.4). Participants were instructed to ensure a days rest between each set of stretches performed at home, and were provided with an exercise diary to record the date and time they performed the stretches and any other physical activity that they considered moderate or vigorous based on their existing levels of physical activity (See Appendix 1.13).

5.2.3 Experimental Procedures

5.2.3.1 Strength Testing

Participants were seated in the chair of the Biodex III isokinetic dynamometer (Biodex Medical Systems, Shirley, NY) with their right hip at 85 ° flexion and knee at 0 ° flexion. The ankle was always in the neutral position at the start of each testing procedure, i.e.: so that the angle between the plantar surface of the foot and the tibia and fibula was 90 °. The dynamometer axis was aligned with the ankle joint axis, and restraining straps were used around the mid-calf, thigh, waist, and chest to prevent any compensatory motion of the trunk that could influence force measures taken at the ankle. The strength testing protocol for this study involved isokinetic maximal voluntary contractions (MVCs) of the right ankle only. Each bout of strength testing comprised of three sets at

$60^\circ \cdot s^{-1}$) and three at $120^\circ \cdot s^{-1}$. Each set comprised of ten isokinetic MVCs taking less than thirty seconds to complete, and alternated between plantar- and dorsi-flexion and was immediately followed by one minute of rest; total duration for six sets was nine minutes. The order in which the speeds were delivered was randomly assigned to each participant. Both of these speeds have been used in previous studies to evaluate isokinetic strength at the right ankle (223, 224). In the first visit subjects were able to perform additional practice isokinetic submaximal voluntary contractions (MVCs) until they were comfortable with production of isokinetic force. During the trials the participants were strongly encouraged verbally by the investigator. The torque signal was sampled at a rate of 1 kHz.

5.2.3.2 Goniometry

Ankle joint range of motion in plantar- and dorsi-flexion was measured in the right ankle only, immediately prior to and following administration of the PNF stretch. Measurements of ROM at the ankle with the knee at both 0° and 90° flexion were made to enable a comparison of the effect of the intervention between triceps surae muscles responsible for single and dual joint actions. The participants lay prone on the assessment couch with both hips and knees fully extended to 0° flexion, with their feet and ankles were hanging over the end of the treatment couch so that motion was not restricted during the testing procedures. The arms of the goniometer were aligned with the long axes of the upper and lower leg segments; the goniometer centre of rotation was positioned over the lateral malleolus with one arm aligned with the head of the fibular and the other arm aligned with the head of the fifth metatarsal head. Measurements of the ankle angle were recorded once in both plantar- and dorsi-flexion, first with a knee angle of 0° flexion, and then 90° flexion.

5.2.4 Experimental Conditions

5.2.4.1 Laboratory-based PNF Stretch Procedures

The PNF stretch used in this experiment is an adapted version of the partner-assisted and self-administered gastrocnemius stretches described by McAtee and

Charland (211). The PNF stretching procedure was administered to both ankles with assistance from the investigator immediately following measurement of ankle ROM. Subjects sat upright on the treatment couch with both legs fully extended at the knee and hips flexed to approximately 85 ° flexion. The investigator supported the heel in one hand, while the palm of their other hand was placed vertically against the proximal half of the plantar surface of the foot (see Figure 5.1.A.). The participant was then instructed to take a breath in and then exhale as they dorsi-flexed their ankle to the end of their active ROM. As they did so the investigator kept their palm positioned against the proximal half of the plantar surface of the foot. When the participant had reached the end of their active ROM this position was held for five seconds (see Figure 5.1.B.). This was followed by a ten-second voluntary isometric contraction of the plantar-flexor muscles with 65% of the participant's self-perceived maximal force against the investigator's matching resistance (see Figure 5.1.C.). Finally, the participant plantar-flexed their ankle out of the stretch and relaxed their plantar-flexors for ten seconds before performing the next repetition of the stretch. These actions were repeated three times in the same order on each leg to complete one full set of the PNF stretch protocol.

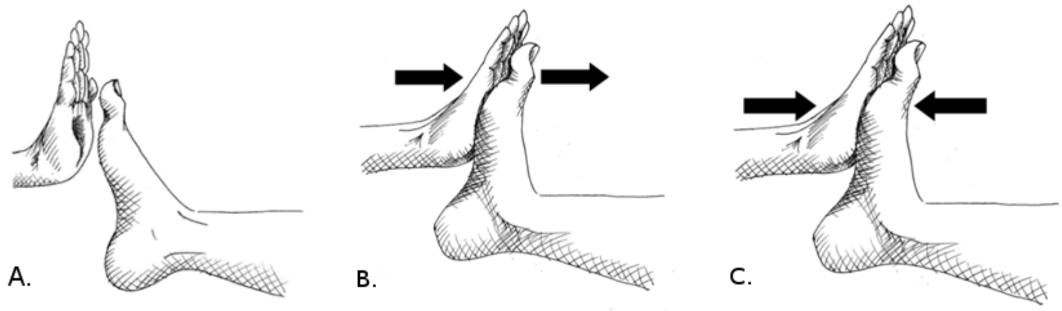


Figure 5.1: PNF Stretch - (A) The palm of the investigator's hand was placed vertically against the proximal half of the plantar surface of the subject's foot. (B) Subject actively moves their ankle in dorsiflexion to the end of its range of motion. (C) Subject isometrically contracts their plantar-flexors with 65% of their maximum effort.

5.2.4.2 Self-administered PNF Stretch Procedures

This stretch was also self-administered three times a week by the participants as part of a home-based PNF stretch training programme between weekly visits to the laboratory testing sessions using an adapted version of the lab-based PNF stretch procedures. Participants were instructed to position themselves in the same way at the laboratory-based PNF stretching procedures, and to use a non-elasticated belt or scarf to deliver the stretch in place of the investigator (see A. in Figure 5.2). The participant would hold this against the head of the first metatarsal and exhale as they exhaled they actively contracted their dorsi-flexors, moving their ankle to the end of their active range of motion in dorsi-flexion (see B. in Figure 5.2). They were to hold this position for five seconds, all the while keeping the scarf or belt taught. Then holding the scarf or belt securely to prevent any movement at the ankle, the participants plantar-flexed their ankle against the scarf or belt at 65% of their maximum effort for a further ten seconds (see C. in Figure 5.2). Participants were instructed to match their effort in plantar-flexion with provision of equal resistance by holding the scarf or belt to ensure only an isometric contraction of the plantar-flexor muscles was performed (i.e.: no movement at the ankle joint). One set comprised of three repetitions of this process with a ten second period of rest between each repetition, and one set was performed three days a week with at least one day of rest between each set.

5.2.5 Statistical Analyses

Dependent variables analysed in this study were ankle ROM end points for plantarflexion and dorsiflexion with the knee at an angle of 0° and 90° flexion, and peak torque values during isokinetic MVCs at angular velocities of $60^\circ \cdot \mathrm{s}^{-1}$ and $120^\circ \cdot \mathrm{s}^{-1}$. 3-way repeated-measures analysis of variance (ANOVA) was used to identify differences between and within weeks and between age groups for each of the dependent variables. Therefore the main factors were: age, weekl of visit and pre-/post-stretch within a visit. The variable of 'subject' was a random blocking factor nested in 'age'. Tukey's Simultaneous Test was used to make pairwise comparisons in each ROM variable between each week of the intervention. Paired t-tests were performed individually for each age group on the peak torque values

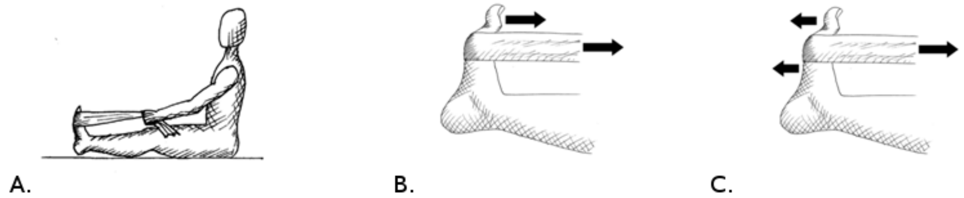


Figure 5.2: Self-administered PNF Stretch - (A) Subject in seated position with hip in 85 ° flexion and both knees fully extended, with a belt or scarf held around the mid-section of their foot. (B) Subject exhales as they actively move their ankle to end of range of motion in dorsiflexion. (C) Subject inhales as they isometrically contract in plantarflexion against the matched resistance provided by the belt or scarf held around their foot.

obtained during isokinetic strength trials. Analysis of data was conducted using Minitab 16 Statistical Software. In each analysis differences were considered significant when $p < 0.05$. All descriptive data are presented as means (SD).

5.3 Results

ROM

Mean ROM values and age group difference (*older adult ROM - younger adult ROM*) are shown in Table 5.1. A three-way repeated-measures ANOVA revealed significant overall differences between age groups in all four ROM variables (plantarflexion with the knee at 0 and 90 ° and dorsiflexion with the knee at 0 and 90 °) (all $p < 0.001$; See Figures 5.3, 5.4, 5.5 and 5.6). ROM end points were also found to be significantly different between visits for plantarflexion with the knee at 0 ° ($p = 0.001$; See Figure 5.3) and dorsiflexion with the knee at 90 ° ($p = 0.000$; See Figure 5.6). The interaction effect between age and week was not significant ($p > 0.05$).

		Younger		Older		Difference
		Mean	SD	Mean	SD	
Week 1	PF1	166.8	5.5	162.1	9.2	4.6
	PF2	164.1	7.6	159.0*	10.6	5.1
	DF1	111.0	6.7	108.4	6.9	2.6
	DF2	104.1	4.1	97.9*	7.3	6.3
Week 5	PF1	169.1	7.4	164.5*	14.7	4.6
	PF2	165.8	7.8	160.3*	13.8	5.5
	DF1	109.0	6.3	105.6	8.1	3.4
	DF2	98.4**	4.6	95.6	8.8	2.8

Table 5.1: Mean ROM in degrees with the knee at 0 and 90 degrees flexion for plantarflexion (PF1 and PF2) and dorsiflexion (DF1 and DF2), respectively, with age-related differences (Difference). * denotes significant difference to younger adults and ** significant increase from week 1 (both $p < 0.05$).

Differences in ankle ROM between the age groups were found: pairwise comparisons showed significantly greater ROM in younger adults at weeks 2, 4 and 5 in plantarflexion with the knee at 0 ° (See Figure 5.3), and at weeks 1 to 5 in plantarflexion with the knee flexed to 90 ° (See Figure 5.4), while older adults demonstrated significantly greater ROM than younger adults at weeks 1 and 2 in dorsiflexion with the knee at 90 ° (See Figure 5.6; all $p < 0.05$). Pre-training and post-training effects were also found: significantly increased ROM in dorsiflexion with the knee at 90 ° was demonstrated between week 1 and weeks 3 to 5 in the young group, and between week 1 and weeks 3 and 4 in the older adult group ($p < 0.05$; See Figure 5.6) - meaning that ROM in dorsiflexion was significantly improved by the second week in younger adults and by the third week in older adults, but only when the knee was in flexion. No significant differences between age groups or weeks were found in dorsiflexion with the knee at 0 ° ($p > 0.05$; See Figure 5.5). No significant differences were found between pre-stretch and post-stretch ROM measures ($p > 0.05$) for either age group (i.e.: no acute effects of PNF stretching were found).

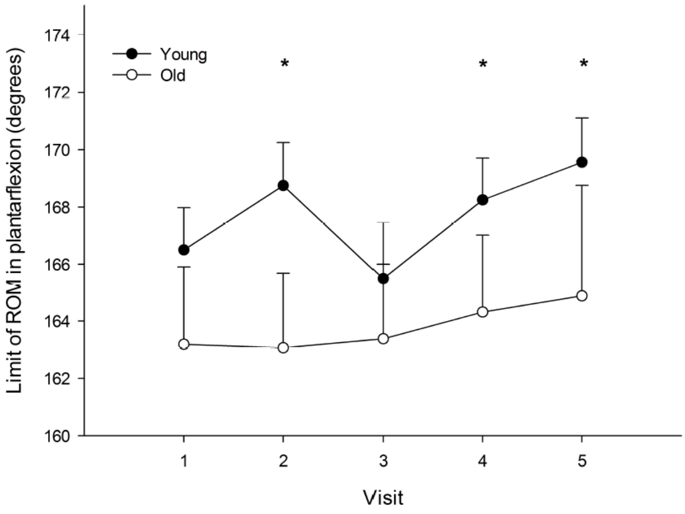


Figure 5.3: Mean limits of ROM in plantarflexion with 0 ° knee flexion for old and young age groups. *denotes significant differences ($p < 0.05$) between old and young in pre-stretch ROM. Error bars show ± SE.

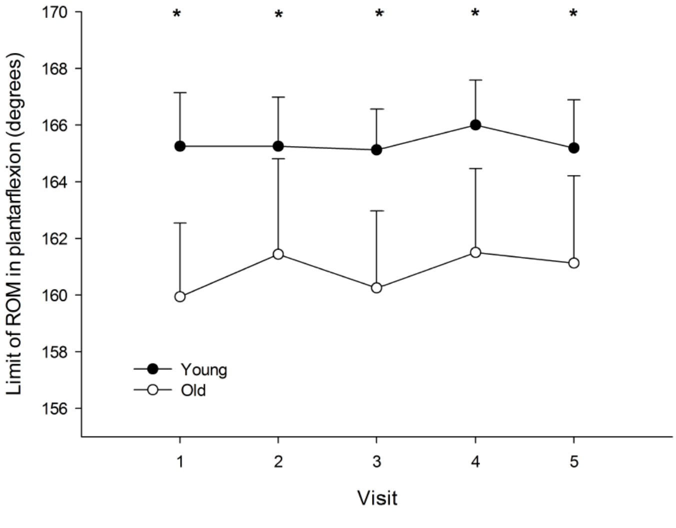


Figure 5.4: Mean limits of ROM in plantarflexion with 90 ° knee flexion for old and young age groups. *denotes significant differences ($p < 0.05$) between old and young. Error bars show ± SE.

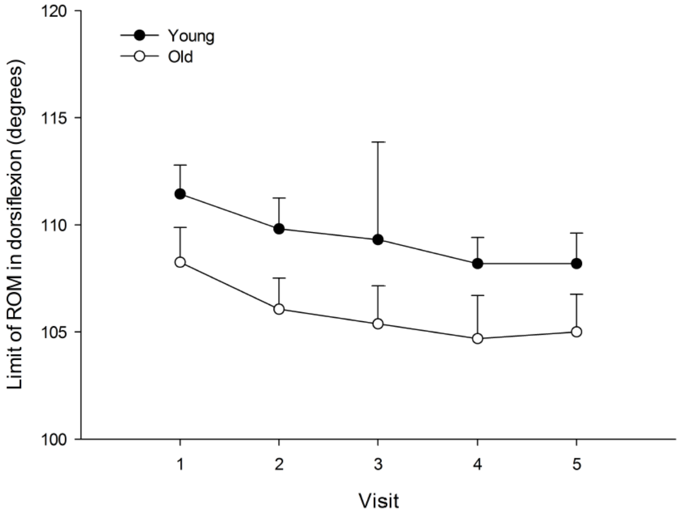


Figure 5.5: Mean limits of ROM in dorsiflexion with 0 ° knee flexion for old and young age groups. Error bars show ± SE.

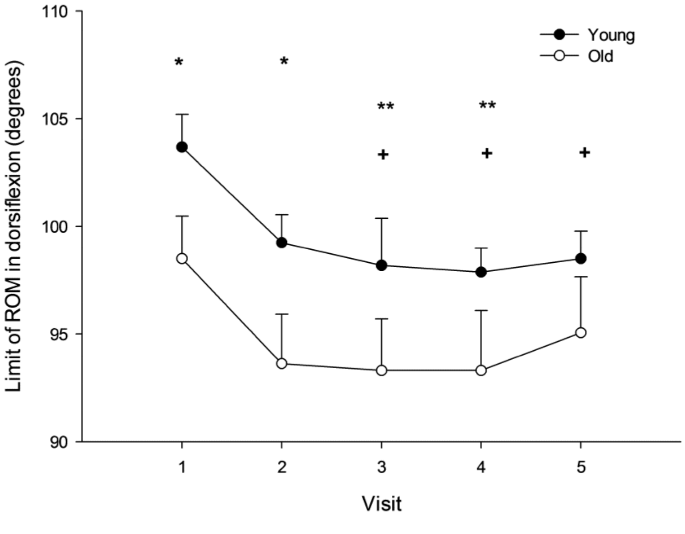


Figure 5.6: Mean limits of ROM in dorsiflexion with 90 ° knee flexion for old and young age groups. Significant differences in pre-stretch ROM at individual week number: *($p < 0.05$) between old and young; **($p < 0.05$) compared with old group at week 1; +($p < 0.05$) compared with young group at week 1. Error bars show ± SE.

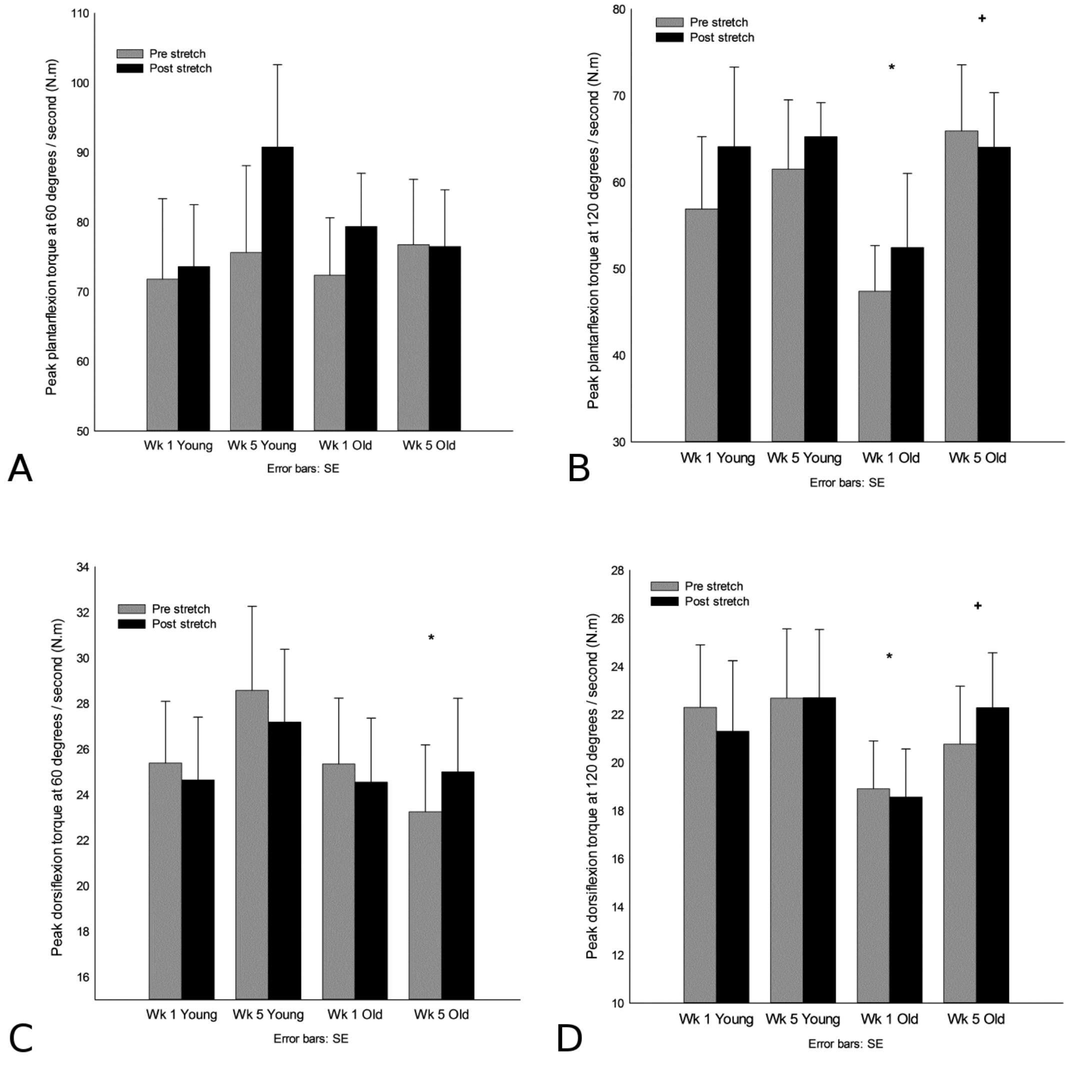


Figure 5.7: Mean pre- and post-stretch peak torques at each week in old and young during isokinetic MVCs in plantarflexion at (A) $60\,^\circ \cdot \mathrm{s}^{-1}$ and (B) $120\,^\circ \cdot \mathrm{s}^{-1}$ and dorsiflexion at (C) $60\,^\circ \cdot \mathrm{s}^{-1}$ and (D) $120\,^\circ \cdot \mathrm{s}^{-1}$. Significant differences in peak torque: $*(p < 0.05)$ between age groups at week number; $+(p < 0.05)$ between week 1 and week 5 within age group. Error bars show ± SE.

Strength

A three-way repeated-measures ANOVA showed significant overall differences between old and young in peak torque during isokinetic MVCs in dorsiflexion at angular velocities of $60\,^{\circ}\cdot \mathrm{s}^{-1}$ ($p = 0.018$) and $120\,^{\circ}\cdot \mathrm{s}^{-1}$ ($p = 0.003$). Significant overall increases in strength were also found between week 1 (pre-training) and week 5 (post-training) in plantarflexion at $120\,^{\circ}\cdot \mathrm{s}^{-1}$ ($p = 0.001$) and dorsiflexion at $120\,^{\circ}\cdot \mathrm{s}^{-1}$ ($p = 0.010$). Pairwise comparisons showed no significant effects of age or week on peak torque values during isokinetic MVCs in plantarflexion at an angular velocity of $60\,^{\circ}\cdot \mathrm{s}^{-1}$ ($p > 0.05$; See Figure 5.7.A). Significant differences were found between age groups in post-training peak torques during isokinetic MVCs in dorsiflexion at an angular velocity of $60\,^{\circ}\cdot \mathrm{s}^{-1}$ (See Figure 5.7.C), and in pre-training peak torques in plantarflexion and dorsiflexion at $120\,^{\circ}\cdot \mathrm{s}^{-1}$ ($p < 0.05$; See Figure 5.7.B and 5.7.D). Significant differences between pre- and post-training peak torque values were found in the old group in both plantarflexion and dorsiflexion at $120\,^{\circ}\cdot \mathrm{s}^{-1}$ ($p < 0.05$; See Figure 5.7.B and 5.7.D)). No significant differences were found between any pre-stretch and post-stretch measures of peak torque values ($p > 0.05$).

Physical Activity Records

All but one female younger adult confirmed that they had completed the required home-based stretch exercises, and provided records of moderate and high intensity physical activity over the four week PNF stretching programme. One younger female participant missed completion of one of the home-based stretch sessions. The mean number of days between completing stretches at home between lab visits was 1.67 (0.9) days in the younger group and 2.00 (1.5) days in the older group, and the mean number of days between each laboratory visit was 7.3 (1.5) days in the younger group and 7.1 (1.5) days in the older group. The total number of hours spent in moderate and high intensity physical activities by all participants, and per participant over the 4-week PNF stretching programme are presented in Table 5.3, as well as weekly mean per participant for older and younger adults. This data shows highly contrasting levels of physical activity between the older and younger adults: older adults reported much lower levels of high intensity physical activity and much lower levels of moderate physical activity compared to the younger adults over the course of the four week PNF stretching programme.

	Total hours		Mean hours/person		Mean hours/week/person	
	Mod.	High	Mod.	High	Mod.	High
Older adults	30.5	14.5	4.4	2.1	1.1	0.5
Younger adults	1	113.5	0.1	16.2	<0.1	4.1

Table 5.2: Table presents the total number of hours spent taking part in physical activity of moderate (Mod.) and high (High) intensity by all participants over 4 week PNF stretching programme duration (Total hours), along with mean hours per participant over the 4 weeks (Mean hours/person) and the mean weekly hours per participant (Mean hours/week/person) - each for older and younger adults.

5.4 Discussion

The primary hypothesis for this study was that chronic gains in ankle ROM would be demonstrated in both old and young age groups following completion of a four-week PNF stretching intervention. The results showed that chronic gains in ROM in dorsiflexion were demonstrated in older and younger adults after the three and four weeks of PNF stretching, respectively, but only when the knee was positioned to 90 ° flexion. The secondary hypothesis was that there would be no chronic or acute changes in ankle strength measures in both age groups as a result of the PNF stretching intervention. The findings demonstrated that the PNF intervention did not elicit any acute changes in peak torque during isokinetic MVCs at angular velocities of $60^\circ \cdot \mathrm{s}^{-1}$ or $120^\circ \cdot \mathrm{s}^{-1}$ in old or young age groups. However, chronic improvements in strength in both plantarflexion and dorsiflexion during isokinetic MVCs at an angular velocity of $120^\circ \cdot \mathrm{s}^{-1}$ were demonstrated in the older adults.

The findings from this study are important as they indicate that a PNF stretching intervention may be used to elicit chronic beneficial ROM gains in dorsiflexion at the ankle without causing acute detrimental reductions in ankle strength in old and young men and women. The increased ROM at the ankle reported here is in line with the findings of Rees et al. (178), as well as a number of studies that have investigated the effects of PNF stretching on ROM in the hip and knee joint in both younger and older adults (147, 149, 151, 151, 165, 166, 168, 175, 176, 205, 217). The mean values presented in Table 5.1 also demonstrate that the younger adults were found to generally have greater flexibility in plantarflexion (i.e.: greatest maximal joint angle) than the older adults, while the older adults generally had greater flexibility in dorsiflexion (i.e.: smallest maximal joint angle) than the younger adults.

The findings reported here also provide more detail regarding the individual responses of the triceps surae muscle to PNF, as ankle ROM of the participants of this study was measured with both the knee in full extension and at 90 ° of flexion to account for individual changes in the MTU length of the gastrocnmeius and soleus in response to the PNF training intervention. The gastrocnemius can only be fully elongated in dorsiflexion and contract maximally in plantarflexion if the knee joint is fully extended, due to its origins from the condyles of the femur and insertion at the calcaneus. In contrast, the soleus muscle originates from the posterior surfaces of the tibia and fibula and passes over only the ankle joint before inserting at the calcaneus, meaning that it is the only muscle in the triceps surae group that limits ankle range of motion in dorsiflexion when the knee is at 90 ° flexion. In other words the length of the gastrocnemius is affected by knee joint position, but the soleus muscle is not. Therefore, the increased ROM in dorsiflexion with the knee at 90 ° of flexion indicates a training response from the soleus in both age groups, while the absence of change in ROM with the knee in full extension would suggest no significant effect of PNF training on the gastrocnemius in either age group.

The chronic ROM gains observed in both age groups following completion of the PNF training intervention could be attributed to a change in viscoelastic properties, i.e.: a reduction in MTU stiffness in the soleus. However, Rees et al. (178) found that a four-week PNF stretching programme resulted in mean gains of 6.8 ° in chronic ankle ROM in dorsiflexion ($p < 0.001$) and strength gains of 559 Newtons (N) in maximal strength during isometric MVC at the ankle

($p < 0.001$), despite significantly increased passive stiffness in a sample of 20 healthy young women (mean ± SD: age, 19 ± 1.6 years). In light of the similar ROM and strength gains reported in Rees et al.'s (178) findings it seems that a reduction in passive stiffness is an unlikely explanation. A number of research studies that have examined the effects of PNF stretching on ROM at the ankle in younger adults, including Rees et al. (167, 178, 206) have suggested that increased ankle ROM in the plantar-flexors are caused by an increase in stretch tolerance, rather than a decrease in muscle tendon unit stiffness. However, it is more difficult to explain the isolated training response in the soleus but not the gastrocnemius, particularly given that the PNF stretch (both static stretch and isometric contraction components) were administered with the knee positioned at full extension, thus fully elongating and contracting both the gastrocnemius and soleus during the stretch.

The findings suggest that PNF stretching may also have chronic strength benefits when used in a healthy older adult population, which is in keeping with chronic strength gains at the ankle reported in younger adults by Rees et al. (178). However, not all studies have concurred with the increased strength measures reported here and by Rees et al. (178) following PNF stretching. A study by Babault et al. (163) comparing the acute effects of PNF stretching with static stretching methods in a sample of healthy young men (n = 10; mean ± SD: age, 23 ± 1 years) showed an immediate and significant reduction in maximal plantarflexor torque during isometric MVC at the ankle following both training interventions.

In addition to the discrepancies in findings caution must be used when comparing the findings from this study with those of Rees et al. (178) and Babault et al. (163) due to the different strength testing methods used; i.e.: both used isometric strength measures, while isokinetic strength tests were administered in this study. Isometric and isokinetic strength have been shown to be associated with performance in functional tests in older adults, such as stair ascent and descent (225). However, there is evidence indicating that the relationship between isometric strength and functional performance measures are not linear, i.e.: increments in one measure are not necessarily proportionate to increments in the other (84). Therefore performance in isometric strength tests should not be assumed to be equivocal to performance in functional tests. As such, the chronic gains and acute reductions in isometric strength found by Rees et al. (178) and Babault et al. (163), respectively, should not be assumed to be reflected in measures of isokinetic strength or functional performance of ADLs. Additionally, participants here were only strength tested with their knee at an angle of 0 ° of flexion. Given the large amounts of joint torque and variable knee and ankle joint angles required to perform activities of daily living (i.e.: transferring from a seated to a standing position, and ascending or descending stairs) it would seem appropriate for future studies to investigate the effects of PNF on isokinetic strength with the knee positioned at both angles of 0 and 90 ° of flexion, so that changes in torque contributions from both the soleus and gastrocnemius muscles may be examined individually.

A possible explanation for the lack of strength gains in the younger adults compared to the significant chronic strength gains demonstrated in younger adults by Rees et al. (178) could be the differences in intensity of the resistance components between the PNF stretching programmes used in the respective studies. For example, the participants of the study by Rees et al. (178) performed 100% MVCs during each PNF repetition, compared to only 65% MVCs used in this study. Strong dose response relationships between resistance training intensity and measures of muscle protein synthesis (226), strength and muscular endurance (227, 228) have been demonstrated in the lower limb in both old and young adults. Although the 65% MVC used in this study was selected to adhere to guidelines for exercise in frail older adult populations (40), it is possible that the lower % MVC used in this study may have limited the magnitude of the training response in the strength measures. However, a study by de Vos and colleagues (228) using a sample of 112 older adults (mean ± SD: age, 69 ± 6 years) found significant strength, power and muscular endurance gains following completion of 8-12 weeks of resistance training using a training intensity as low as 20% 1-RM compared to a control group.

However, younger adults may not respond in the same way to such low training intensities. Although the American College of Sport Medicine (ACSM) guidelines (229) recommend that younger adults of novice and intermediate experience in resistance training should perform exercise at intensities between 60 to 70% 1-RM (8-12 repetitions), the younger adults used in this study were healthy, active young adults who undertook regular physical activity - some of whom also regularly performed resistance training exercises. The younger adults reported eight times more hours spent participating in high intensity physical activity over the four-week study compared to the older adults. For such experienced individuals the ACSM recommend resistance intensities above 80% 1-RM - an intensity which is described at the upper limit of resistance recommended for older frail adults in exercise guidelines (12, 40). It may be that the resistance component of PNF exercises needs to be of a greater intensity (i.e.: 80% MVC - in line with ACSM guidelines (229)) for significant strength gains to be observed in younger active adults.

Furthermore, the healthy older adult participants of this study reported dramatically lower levels of physical activity than the younger adults - especially high intensity physical activity. The older adults used in this study are younger than those who have been used as participants in other research investigations into the effect of age on muscle strength (210). If the strength gains observed in the older adult group in this study can be attributed to age-related differences in levels of physical activity at baseline then it is possible that frailer older adults, who are even less likely to be physically active may experience greater relative gains in strength than the healthy older adult participants used in this study. It should be noted, however, that the low number of hours spent in moderate physical activity (1 hour) by the younger adults compared to the older adults (30.5 hours) is likely to be due to a difference in interpretation of the term moderate relative to their general day-to-day activity levels. For example, an older adult may be more likely to find walking to be a moderate intensity activity due to age-related declines in physical fitness associated with increasingly sedentary behaviours, while a younger person may only find walking to be a low intensity exercise.

The underlying mechanisms for increased ROM associated with PNF stretching are still not agreed upon. It is important that future investigations are conducted to establish the degree of neurological and physiological mechanisms responsible for acute and chronic changes in ROM and strength following PNF stretching. Future research must investigate the whether knee angle during strength testing influences the effects of PNF stretching on ankle plantarflexor strength in older adults, as the findings reported here indicate different training responses between the gastrocnemius and soleus - this is particularly important given the effects of age on muscle structure and function. It is important that future research focuses on identifying the most effective duration, intensity and frequency of PNF stretching required to elicit optimum ROM gains in frail older adults without impairing strength - particularly given that significant ROM gains were evident after only completing two weeks of PNF stretching in the older group and three weeks in the younger group. In light of the importance of strength in the ability to perform activities of daily living, investigation regarding the effects of PNF stretching on functional performance in frail older adults is needed, for example: future research studies should also examine changes in performance in clinical tests used to screen to falls risk, such as Romberg's Test (131) and the Timed Get-Up-and-Go-Test (138).

5.5 Conclusion

Flexibility and strength impairments associated with ageing are risk factors for falling, and targeted interventions to address these risk factors are needed. Age-related changes in the structure and mechanical properties of muscle tissues are likely to influence which are the most effective methods to use in exercise programmes for older adult populations. These findings demonstrate significant improvements in ankle ROM and strength in older adults following completion of a four-week PNF stretching intervention, therefore indicating that PNF stretching may be a suitable and effective form of flexibility training in healthy older adults. However, before PNF can be considered for inclusion in an exercise-based falls prevention intervention such as PSI (10), further research to establish whether these chronic changes are due to neurological adaptation or whether PNF is able to elicit structural changes in the MTU in older adults at the ankle, such as chronic increases in muscle mass. Investigation of the effects on older adults who are at greatest risk of falling is essential as this is the portion of the population who are most likely to undertake a falls prevention intervention. Therefore, it is important that the effects of PNF stretching on functional performance over durations that reflex falls prevention interventions, such as the 36-week PSI intervention (10), are examined in frail older adults.

Part IV

Chapter 6

General Discussion

Targeted exercise interventions have been shown to cause significant chronic reductions in falls incidence and risk factors for falling, such as strength, balance, and flexibility, in older adults (9). However, the acute effects of less than three months training are less well-known. The purpose of Study One (Part II) was to address this gap in the research literature by examining the effectiveness of an 18-week PSI intervention in reducing falls incidence and falls risk factors in a sample of patients referred from a rural falls clinic in Mid-Wales. The key findings from Study One were that there was a 33% reduction in falls prevalence during the 6-months following completion of the 18-week intervention. However, self-reported fear of falling and performance in functional tests of strength and balance improved significantly after 6 weeks. Additionally, psychological well-being along with some laboratory-based measures of postural stability also showed significant improvements after completion of the 18-week intervention. However, no significant changes in lean mass were found, which suggests that the reported changes in strength, and balance are likely to be caused by neurological adaptation following intervention, rather than increased muscle mass. However, the strength and balance improvements were not accompanied by a significant improvement in measures of gait performance, for example, there was no improvement in STS test scores and no redistribution in lower limb joint torques during walking over the course of the intervention.

PNF stretching is an alternative method of flexibility training to the traditional static stretching methods commonly employed in exercise-based falls prevention interventions. Studies Two and Three (Part III) were conducted to establish whether PNF training of the ankle plantar-flexors is a safe and effective flexibility training method suitable use by older adult fallers as part of a falls prevention intervention, such as PSI. However, some evidence indicates that acute reductions in strength occur at the ankle immediately following PNF stretching in younger adults (163). While the methodological quality of such studies is not high, any such effect would not be desirable in an already frail group of fallers. Study Two investigated the acute effects of PNF training at the ankle on the ability to voluntarily activate the ankle plantar-flexor muscles of the calf in both older and younger adults. The results showed no significant effect of PNF training or age on voluntary activation or peak isometric joint torque in younger or older adults, thus indicating that PNF training does not acutely influence central or peripheral activation of the plantarflexor muscles. Study Three compared the acute and chronic effects of a four-week PNF training on ankle range of motion and isokinetic torque production at the ankle in old and young adults. The results showed significant chronic gains in ankle ROM in both age groups and increased dorsiflexor strength at a contraction velocity of $120\,^{\circ} \cdot \mathrm{s}^{-1}$ in older adults. Therefore, the findings of Studies Two and Three indicate that four weeks of PNF training is long enough to elicit long-term ROM and strength gains at the ankle in older adults without acutely compromising maximal torque production. These findings are potentially useful in the early stages of PSI training to achieve strength and flexibility gains where frail older participants with low baseline physical activity levels may not be sufficiently strong to use resistance training equipment.

The findings of Study One demonstrate that an 18-week targeted group and home-based PSI intervention is not an adequate replacement for longer interventions that have been shown to significantly reduce falls risk and incidence, such as the 36-week FaME intervention (10) or 12-month OEP (187). It should also be noted that each participant of the study presented with considerable strength and balance deficits prior to commencing with the PSI intervention, which is likely to have influenced their achieved training loads. Participants also presented with a

FES-I score of over 32 (out of 64) indicating a fear of falling, as this was one of the criteria for referral onto the PSI intervention outlined by the falls clinic. It is likely that fear-related avoidance behaviours may have impacted on their adherence to prescribed training intensities of the programme. Fear-related avoidance behaviours have not only been shown to be associated with physical frailty, but also may be used to predict falls (230). As participants of this study were not only fearful, but also frail based on their poor performance scores for the STS (<3 repetitions in 30 s), TGUG (>20 s to complete), HGD (<80% of mean for age group) and Romberg's Balance Test scores (score >32), it is likely that fear-related avoidance may have been problematic, particularly during unsupervised home-based training sessions when support from an instructor was not immediately available. Therefore, baseline frailty and fear of falling may have restricted the potential for physiological gains such as increased muscle mass and quality. An additional consequence of the frailty of Study One participants was that they dropped out at a high rate due to injury and illness, making it difficult to measure the effectiveness of the intervention. It is suggested that future research investigating the effects of training interventions are conducted using healthier older adults with less advanced strength and balance deficits in the first instance, as was done in Studies Two and Three, before extending the findings to more frail populations.

There were also a number of uncontrolled factors may have influenced the outcomes of this study. For example, it was common for participants to present with a number of chronic and acute health conditions at the falls clinic. As a result most participants were taking a number of prescribed medications to manage multiple chronic health conditions, such as hypertension, osteoporosis, arthritis, chronic pain, sleep disorders and arrhythmias. Although a medications review was conducted at the falls clinic prior to commencement with the intervention, it is still possible that medications taken by participants may have influenced the findings, particularly those influencing systolic blood pressure (231). Vitamin D deficiency has also been linked to reduced muscle mass and strength impairment in older adults (232). As participants of this study are likely to have adopted fall-avoidance behaviours as a result of their frailty and fear of falling, it is also likely that participants may have also had a Vitamin D deficiency born from a poor diet and low exposure to sunlight due to being housebound. In short, it is likely that a large proportion of the participants of the study did not show significant reductions in falls risk factors and falls incidence due to their medical or nutritional status.

Although there is evidence reporting that programmes of between four and twelve weeks duration are effective in reducing falls risk (69, 184, 191), prior to this study the only interventions that have been shown to reduce falls incidence have been longer than nine months in duration (10, 45, 187, 193). The findings from Study One provide adequate evidence to support the use of a shortened 18-week PSI intervention in place of longer duration interventions. Steadman et al. (69) also reported significant improvements in a number of falls risk factors following completion of a 6-week enhanced balance training programme, although the effect of Steadmen et al.'s intervention on falls prevalence and muscle hypertrophy was not reported. The findings reported here demonstrate significant improvements in a number of falls risk factors and a reduction in falls prevalence in the absence of changes in muscle mass over PSI intervention durations of 18-weeks or less. This is in line with previous findings that older adults can achieve significant muscular strength, power and endurance gains following completion of only eight to twelve weeks of resistance training (228). However, strength gains in younger adults have been found to be attributable to hypertrophy after as few as three weeks of resistance training (233), but no changes in muscle mass were shown here in the older adult participants. It is possible that age-related differences in chronic training responses to the four-week PNF stretching intervention implemented in Study 3 may be due to an age-related delay in the onset of hypertrophy in older adults.

Due to the rural location of the community in Mid-Wales where the 18-week PSI intervention was delivered, ability to attend the classes was determined by access to transportation. A large number of participants had moved to live in the area after retirement, and did not have established networks of friends and family members to assist with transport to and from the sites where the PSI classes were delivered. This is a common issue for a large portion of the local older adult population in the region of Mid-Wales, which is compounded by the remote locations of the small communities in relation to Aberystwyth - where the majority of local health services are provided. The issues with transport in the area presented a major barrier to involvement in Study One, but more importantly to the completion of the PSI intervention; only 26 of the 54 patients who were identified as suitable actually took up the intervention in the first instance. However, although this location-specific transport issue is one of the reasons why many participants are unable or unwilling to attend group-based PSI interventions, it is also a critical cost- and time-saving element of the intervention design. Perhaps a middle-ground can be reached, whereby programmes can be delivered in the more rural locations of Mid-Wales so that a wider number of communities can access the PSI intervention. In addition, greater utilisation of the home-based training components would help to increase frequency and longevity of participation, while refinement of the training components would enhance the efficacy of PSI training interventions in reducing falls incidence and risk. For example: routine home-visits by the exercise instructor would have a positive impact on adherence to home-based training components as well as long-term attendance to community group-based classes, which offer opportunities for social support and interaction between patients.

In terms of refining individual components of home-based training it is important to identify effective training methods that can be performed autonomously in the home-environment by patients with minimum requirements for equipment and assistance. It is also critical that home-based components do not compromise the safety of the patients. The evidence from Study 2 indicates that PNF stretching is safe, while the findings of Study 3 demonstrate that it is also effective in improving ankle ROM in as little as four weeks. One of the strongest arguments supporting the inclusion of PNF training in PSI programmes is that the isometric nature of the contractions may elicit significant chronic strength gains, which has yet to be demonstrated following completion of a static stretching programmes of the same duration. Further still, these findings also provide new information regarding the effects of PNF training at the ankle. The chronic strength gains observed at the ankle in the older adults following the four-week PNF stretching intervention in Study 3 are in line with similar observations made in younger adults (178). The evidence obtained through Study 3 demonstrates that not only is PNF a safe method of flexibility training at the ankle, but that it may also be beneficial in parameters of strength in healthy older adults. Although it is more unlikely that the improvement in strength is due hypertrophy after such a short duration of training, these strength gains may be sufficient to allow progression to heavier loads in programmes of sufficient length. Inclusion of PNF training in PSI interventions may be useful in improving control, confidence, and ROM in the early stages of a sufficiently long programme.

Further knowledge regarding the chronic effects of PNF stretching on MTU length and viscoelasticity of the individual muscles of the triceps surae are needed (i.e.: soleus and gastrocnemius), particularly given the varying effects of PNF on ROM at the ankle with difference degrees of flexion at the knee observed in Study 3. In addition, the effects of PNF on muscle architecture within these muscles, such as changes in orientation and length of the sarcomeres, must also be investigated to help identify the factors that cause the chronic strength gains observed following the four-week PNF stretching programme used in Study 3. Future research extending the findings of Studies 2 and 3 in healthy older adults to more frail populations must be conducted before recommendations regarding suitability of PNF training for use in frail older adults can be made. This cautious approach of investigating training effects initially in healthy older adults before extending research to frailer older adult populations is needed to evaluate the effectiveness of individual PSI training components. This will enable the refinement of each training component used in PSI interventions to improve the overall time and cost effectiveness of the programme.

Chapter 7

Conclusion

The evidence obtained from all three studies conducted as part of this thesis indicate that PSI interventions of 18-weeks duration are adequate in reducing falls prevalence and inducing sufficient physiological adaptation to robustly reduce the falls risk factors of strength and balance. In light of this evidence, it is concluded that a shortened 18-week adaptation of the original 36-week PSI intervention can be used to elicit significant reductions in falls prevalence and risk factors (fear of falling, mental HRQoL, strength and balance). In order to enhance the cost and time efficiency of falls prevention interventions further, future research must establish the effectiveness of individual training components used in PSI interventions. The findings from this thesis also indicate that PNF training may be used in older adult populations without acutely compromising volitional torque production at the ankle. Further still, the findings indicate that PNF stretching cause significant chronic strength and ROM gains at the ankle that may be beneficial to balance in older adults with lower limb strength and flexibility deficits. Therefore, it is suggested that further research into the effects of PNF training in frail older adult populations is conducted to establish suitability for inclusion as a flexibility and/or strength training component in PSI interventions, as well the mechanisms responsible for such improvements.

Appendix A

.1 Study One: Bronglais Falls Clinic: Multifactorial Falls Risk Assessment

GIG CYMRU NHS WALES | Bwrdd Iechyd Hywel Dda Health Board

Bronglais Hospital Falls Clinic Multifactorial Falls Risk Assessment (MFFRA) and Multifactorial Falls Risk Reduction Plan (MFRRP)

Stick patient's addressograph label here

Name and address of person making the referral

Date of referral

Date of patient's first attendance at Falls Clinic

Date when details assessment sent to referrer

Name and relationship of person(s) attending Falls Clinic with the patient

Version of 26 January 2010

HISTORY

PC

HPC

HISTORY OF THREE MOST RECENT FALLS

State exact date, place, time, details of activity, whether there was a warning, whether the patient lost consciousness, any injuries sustained and whether seen by a health care professional

Fall #3 (most recent)

Fall #2

Fall #1

PAST MEDICAL HISTORY (with dates)

DRUG HISTORY

OTC medicines? **Herbal preparations?**

Culprit drugs?

Does the patient understand the purpose and side effects of the drugs listed? **Yes/No**

SOCIAL HISTORY

Has the home been assessed for hazards? **Yes/No**

By whom?

Details of adaptations made to home

SYSTEMS REVIEW

CARDIOVASCULAR SYSTEM

SOB, palpitations, chest pain, PND, pedal oedema?

RESPIRATORY SYSTEM

Cough or wheeze? Sputum?

GASTRO-INTESTINAL SYSTEM

Appetite, weight, 5 a day, indigestion, bowels?

GENITO-URINARY SYSTEM

Urgency, UTI, nocturia?

Continence, especially recent changes

MUSCULO-SKELETAL SYSTEM

Upper or lower back pain, hip or knee pain? Small joint problems?

NERVOUS SYSTEM

Headaches, dizziness, double vision?
Dropping things? Legs giving way?

Syncope or pre-syncope?

Spectacles; bi-focals, vari-focals?

Date of last eye test?

CLINICAL EXAMINATION

CARDIO-VASCULAR SYSTEM

BP sitting **BP standing**

Pulse **JVP**

Carotid bruit?

Pedal, ankle, leg oedema?

Leg pulses	**RIGHT**	**LEFT**
	Pop	**Pop**
	DP	**DP**
	PT	**PT**

Previous ECG?

Previous Echocardiogram?

RESPIRATORY SYSTEM

Symmetry **Expansion**

Percussion **Auscultation**

Wheeze? **Creps?**

GASTRO-INTESTINAL SYSTEM

Height **Weight** **BMI**

Abdomen

GENITO-URINARY SYSTEM

Catheter **Pad**

MUSCULO-SKELETAL SYSTEM

Strength and balance in Nervous System

Muscle bulk?

Height **Weight** **BMI**

Spinal palpation

Cervical
Dorsal
Lumbar
Sacral
Coccyx

Previous X-ray spine?

Previous MRI?

FRAX

http://www.shef.ac.uk/FRAX/tool.jsp?locationValue=1

10 year hip fracture risk **%**

10 year other fracture risk **%**

NERVOUS SYSTEM

Cognition **Affect**

Previous MMSE? **/30**

Previous GDS?

Visual acuity

External auditory canal

STRENGTH TESTING

(1) Hand grip dynamometry R1 L1
R2 L2
Percentile for age?

(2) 30 second sit to stand (no arms) /30

BALANCE TESTING

(1) Romberg WBEO WBEC

NBEO NBEC

(2) Three metre TGUG

Rise
GI
Outbound
Turn
Return
Sit
Aid
Time seconds
Rated /5

COORDINATION

Finger to nose test

Heel to shin test

REFLEXES

RIGHT	RIGHT
Biceps	Biceps
Triceps	Triceps
Supinator	Supinator
Knee	Knee
Ankle	Ankle
Plantar	Plantar

SENSATION

10g mono	Dorsal	Dorsal
	Plantar	Plantar

Previous CT of brain?

FALLS RISK FORMULATION

Risk #1

Risk #2

Risk #3

Risk #4

Risk #5

INVESTIGATIONS AND INTERVENTIONS

#1

#2

#3

#4

#5

Referrals

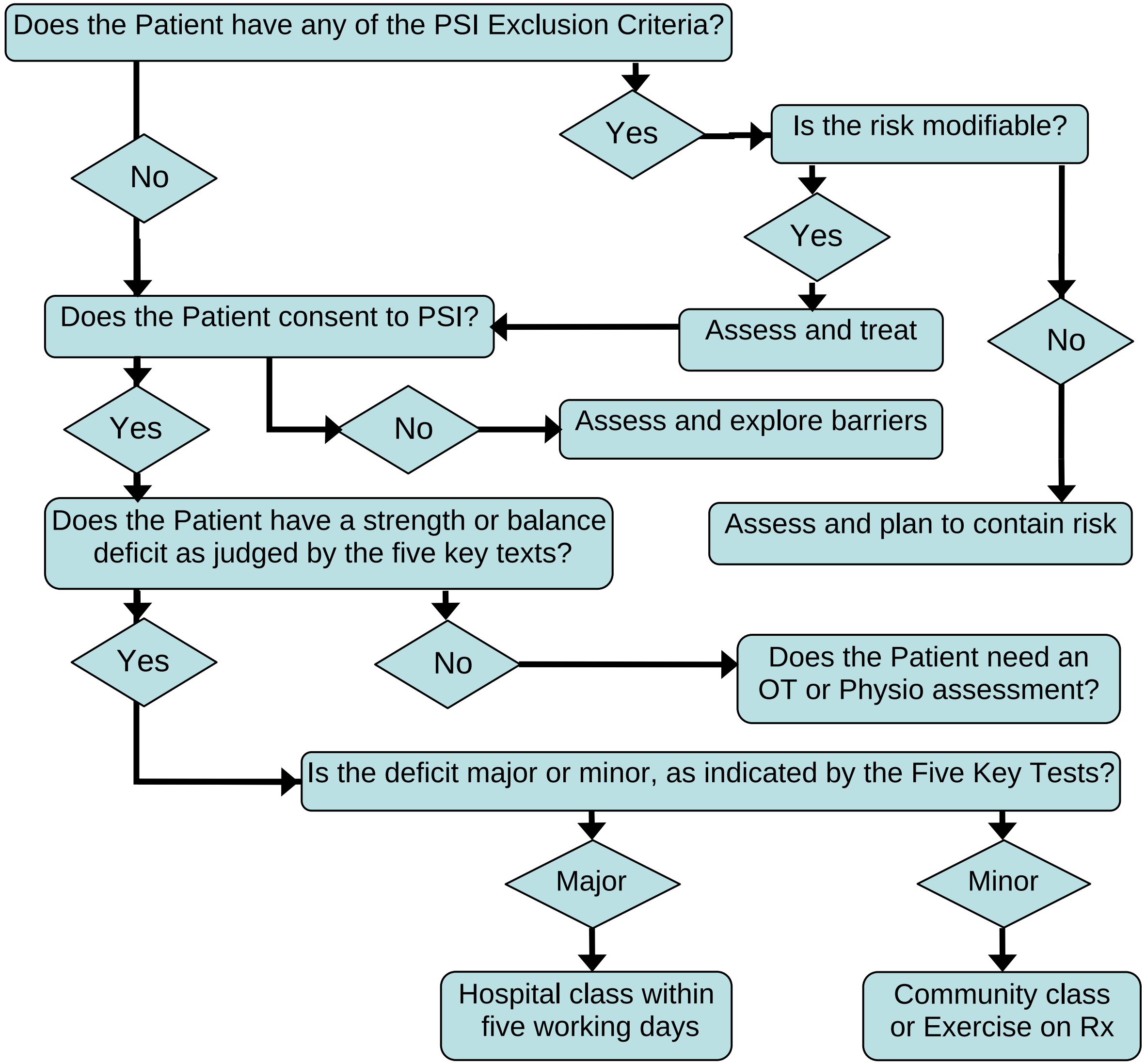
Care and Repair Homes Safety Assessment	Yes/No
Re-ablement Team	Yes/No
Osteoporosis Service	Yes/No
Physiotherapy assessment	Yes/No
Community MUR	Yes/No

Age Concern Community PSI	Yes/No
Rapid Response PSI	Yes/No

Follow-up in Falls Clinic?	Yes/No

Name and designation of person conducting this assessment

APPENDIX 1. COMMUNITY PSI OR RAPID RESPONSE PSI?



PSI Exclusion Criteria:

- **Acute illness**
- **Deteriorating neurological condition**
- **MMSE <24**
- **Behavioural risk**
- **Unassessed syncope**
- **Uncontrolled tachycardia, hypertension or heart failure**
- **Uncontrolled diabetes**
- **Uncontrolled pain**
- **Untreated osteoporosis**

Five Key Tests:

- **Balance – 3m TGUG**
- **Balance – Romberg**
- **Strength – HGD**
- **Strength – 30 sec StS test**
- **Fear of falling - FES**

.2 Study One: FRAX Questionnaire and Osteoporosis Clinic Review

Title of Project: Evaluation of a rapid response strength and balance exercise class for falls prevention.

SUBJECT NUMBER:

FRAX QUESTIONNAIRE

1. Age:
or Date of Birth:

2. Sex: Male Female

3. Mass: kg

4. Height: cm

5. Previous fracture: YES NO

6. Parent fractured hip: YES NO

7. Current smoking: YES NO

8. Glucocorticoids: YES NO

9. Rheumatoid arthritis: YES NO

10. Secondary osteoporosis: YES NO

11. Alcohol (>3 units per day): YES NO

<u>FRAX Result</u> 10 yr major osteoporotic fracture probability:

10 yr hip fracture probability:

Suitability for Biodex Testing

.3 Study One: Participant Information Sheet Informed and Consent

Participant Information and Informed Consent Document

Title of Project: Evaluation of a rapid response strength and balance exercise class for falls prevention.

Overview

You will be asked to attend the labs at the Department of Sport and Exercise Science four times over six months.

At your first visit you will undertake the following procedures:

1) Whole body, lumbar spine and femoral neck DXA scan
2) Psychological surveys to assess your attitude to exercise and your ability to carry out your usual activities.

At your second visit you will undertake the following procedures:

3) Strength testing
4) A lab-based gait and balance assessment.

You will be asked to complete these two visits before starting the programme of strength and balance training. You will be asked to repeat Procedures 2, 3 and 4 after six weeks of training. You will then repeat all four procedures after 18 weeks of training. After the strength and balance training programme you will be contacted once a month by phone to check whether you have suffered any falls or injuries.

Further information: DXA scan:

DXA stands for dual energy X-ray absorptiometry. This is a common procedure for testing bone mineral density and body composition and involves lying on a bed (left) while a low radiation X-ray scanner passes over you. If the scan shows you have normal bone density then you will undertake the strength testing. If the scan does not indicate normal bone density you should not undertake the strength testing but may participate in the gait and balance assessments, the body composition assessments and the psychological questionnaires. If the scan does not indicate normal bone density you may also be referred by the Falls Clinic to the Osteoporosis Service at the Bronglais Hospital.

Further information: Strength testing:

You will be given the chance to warm up by stretching for several minutes. You will then sit in a strength testing machine (left). You will be able to set a limit on the range of motion that the machine will allow in order to prevent injury by overstretching. The exercise involves both static and moving contractions. Three exercises will be performed: straightening the knee, bending the knee, and flexing the ankle. You will be given a chance to perform practice exercises and will then be asked to perform the exercises with as much effort as possible. In order to undertake this part of the test you must have adequate bone mineral density in your hip and spine.

Further Information: Gait and balance analysis:

This will involve walking ten metres along the laboratory with plastic reflective markers attached to your skin and clothing using hypo-allergenic sticky tape. Infra-red video cameras will record the position of these markers as you walk and the force that you apply to the ground will be measured via a force platform. You will be asked to perform four trials at your preferred walking speed. You will then be asked to stand on the force platform for one minute while data is recorded. If you complete this test successfully you will be asked to stand on the force platform on top of a foam pad with and without your eyes closed. Finally you will be asked to stand from a chair and walk forward and then turn and walk back while the same data is recorded.

Further information: Follow up phone calls

After your final lab visit you will be contacted by one of the investigators by phone to check on the number of falls or near misses, or injuries you have suffered in the past month. This phone call should take no more than ten minutes and can be conducted at a time convenient to you.

Further information: Use of anonymous medical history

The evaluation of the strength and balance exercise must include a consideration of your medical history since this will affect how well you respond to the programme. The parts of your medical history included in the analysis will only include those factors known to affect the response to strength training. The information will be passed to the investigators at Aberystwyth University in coded form. For example, a “1” next to Subject 2345 will indicate the presence of medication affecting muscle strength whereas a “0” would indicate absence of this medication. The clinic based measures of your strength and balance ability will also be compared to the laboratory based measures.

CONSENT

If you understand the study procedures and the information given in this form, then please read and sign the following consent. You will be given a copy of this signed and dated information and consent form for your records. If you need more time to consider whether to participate then please say now.

I agree to take part in the Hywel Dda Health Board and Aberystwyth University research study entitled ‘Evaluation of a rapid response strength and balance exercise class for falls prevention’. I understand that my participation is voluntary, that I can choose not to participate in part or all of the project, and that I can withdraw at any stage of the project without being penalised in any way.

Procedure / data	Initial showing consent
Use of anonymous Falls Clinic medical history	☐
DXA scans	☐
Completion of psychological questionnaires	☐
Gait and balance analysis	☐
Strength testing	☐
Six month follow up of fall incidence	☐

Participant Signature Date

Person Obtaining Consent Date

ADDITIONAL NOTES

1. Research Personnel:

Principal Investigators:

Dr Hugh Chadderton	Leri Day Unit, Bronglais Hospital Phone: 01970 623131
Dr Samantha L. Winter	Department of Sport and Exercise Science Aberystwyth University e-mail: sbw@aber.ac.uk Phone: 01970 621545

Other research personnel:

Dr Joanne Thatcher (Aberystwyth University)
Dr Joanne Wallace (Aberystwyth University)
Fiona Higgs (Aberystwyth University)
David Langford (Leri Day Unit, Bronglais Hospital)
Claire Rose (Leri Day Unit, Bronglais Hospital)

2. Purpose of the research study:

The purpose of this study is to find out how effective the strength and balance exercise programme that you are following is at improving your strength and balance. A second purpose is to find out how well the clinic based measures of your strength and balance capacity agree with scientific laboratory based measures. This information will be of use in planning falls services and exercise programmes.

3. Discomforts and Risks:

DXA scans involve low energy X-rays and this form of radiation is known to cause damage to the body. However, the scan gives low dosages of radiation, and in the 20 minute time period taken to carry out the test you will be exposed to the same amount of radiation that you would ordinarily be exposed to during a transatlantic flight. The scan will require you to lie still in a certain position on the table and some people find this position is uncomfortable. The technician may be able to adjust the position to make it more comfortable for you.

If the results of the DXA scan show that you can safely perform the strength testing then the risk of injury during this procedure is low. However, there is a risk of muscle strain, sprains, or muscle soreness that wears off over 48 hours following exercise. This soreness may temporarily restrict movement slightly. This risk is no more than would be associated with the strength and balance training in the Leri Day Unit and the likelihood of these discomfort occurring can be reduced by resting between tests, by warming up before tests, by performing practice contractions, and by building up the force gradually when we are testing your maximum effort

We want you to know that you can ask to stop at any time during the test procedures. If you do experience any discomfort, please tell one of the testers immediately. If you think you have a condition that means you cannot, or should not perform any of the procedures, then you must tell the person testing you. If you seem to be in pain during any of the procedures then the person testing you will ask you to stop.

4. Duration/Time:

You will be asked to visit the laboratory on four occasions. The first three visits will last one hour and the last visit will last one and a half hours. You will then be contacted by phone once a month following the initial eighteen weeks of training to report any falls and these six phone calls will last approximately ten minutes. Your maximum time commitment will be five and a half hours over a nine month period.

5. Pre-test Instructions

Please avoid vigorous exercise prior to testing. Do not consume alcohol during the day before the test. You should eat and drink normally during the day leading up to the test and please bring with you any hearing aids or glasses that you normally use. Please tell the investigator if you have been ill in the two weeks prior to the test, or if you are suffering from any injury. During the DXA scan you will be asked to remove all jewellery and metal items. The results of the DXA scan will be affected by barium meals or enemas (used to investigate throat, stomach and bowel function) so you should schedule your scan for at least 48 hours after a barium procedure. Please tell the investigator if you have any metal implants or joint replacements.

6. Safety

All procedures in the Department of Sport and Exercise Science are subject to audit by the University Ethics Committee for Research Procedures and the NHS Research Ethics Committee and are carried out in accordance with the University’s Health and Safety procedures and good practice guidelines issued by the British Association of Sport and Exercise Sciences.

7. Statement of Confidentiality:

Your participation in this research is confidential. Your medical history data and any computer data collected during the procedures will be stored using codes and the list of participant names and the corresponding codes will be stored in a locked office. Your psychological questionnaires and informed consent document are kept for a period of five years in a locked filing cabinet and will be shredded at the end of this time.

8. Right to Ask Questions:

You can ask any of the investigators for additional information before giving your consent if you do not understand this form. You can also ask questions about this research at any time once the study has commenced by contacting the Principal Investigators (Dr Hugh Chadderton at 01970 623131 or Dr Samantha Winter at 01970 621545). You can also call this number if you have complaints or concerns about this research. You can also contact the Ethics Committee for Research Procedures at Aberystwyth University if you have any complaints about the way that this research has been conducted.

9. Voluntary Participation:

You must be 18 years of age or older to consent to take part in this research study. Your decision participate in this research is voluntary. You can stop at any time and you can withdraw your consent for any reason. Declining to participate or withdrawing once the testing has started will not affect your entitlement to any NHS treatment.

To ensure that we are acting fairly, the ways in which we get your consent and the ways in which we run the research may be audited to check that you have been given all the information you need and that you gave your consent voluntarily.

Please note that if you lose the capacity to consent during the study you will not be required to complete the study. However, data already collected with your consent may be used in the manner described in this information form.

.4 Study One: Motion Capture Markerset

Study 1: Motion Capture Markerset

Segment	**Marker name**	**Marker position**	**Markerset**	
			Static	**Dyn.***
Head	Head_Top	Where the Saggital suture meets the Frontal cranial bone	☑	☑
	L.Head_Frontal	Frontal cranial bone above left eye	☑	☑
	R.Head_Frontal	Frontal cranial bone above right eye	☑	☑
Trunk	C7	Spinous process of C-7 vertebrae	☑	☑
	T10	Spinous process of T10 vertebrae	☑	☑
	L.ASIS	Left Anterior Superior Iliac Spine (ASIS)	☑	☑
	L.PSIS	Left Posterior Superior Iliac Spine (PSIS)	☑	☑
	R.ASIS	Right ASIS	☑	☑
	R.PSIS	Right PSIS	☑	☑
	Sternum	Sternum	☑	☑
	R.Offset	Right trunk offset	☑	☑
Left Arm	L.Should_Ant	Left coracoid process	☑	☑
	L.Should_Post	Spine of the left scapula	☑	☑
	L.Elbow_Med	Left medial process of the elbow	☑	
	L.Elbow_Lat	Left lateral process of the elbow	☑	☑
	L.Wrist_Med	Left medial process of the wrist	☑	
	L.Wrist_Lat	Left lateral process of the wrist	☑	☑
	L.Fing	Left third metacarpal	☑	☑
	L.Upperarm_Offset	Left upper arm offset	☑	☑
	L.Forearm_Offset	Left lower arm offset	☑	☑
Right Arm	R.Should_Ant	Right coracoid process	☑	☑
	R.Should_Post	Spine of the right scapula	☑	☑
	R.Elbow_Med	Right medial process of the elbow	☑	
	R.Elbow_Lat	Right lateral process of the elbow	☑	☑
	R.Wrist_Med	Right medial process of the wrist	☑	
	R.Wrist_Lat	Right lateral process of the wrist	☑	☑
	R.Fing	Right third metacarpal	☑	☑
	R.Upperarm_Offset	Right upper arm offset	☑	☑
	R.Forearm_Offset	Right lower arm offset	☑	☑
Left Leg	L.Ankle_Med	Left medial process of the ankle	☑	
	L.Ankle_Lat	Left lateral process of the ankle	☑	☑
	L.Knee_Med	Left medial process of the knee	☑	
	L.Knee_Lat	Left lateral process of the knee	☑	☑
	L.Thighclust_Prox, L.Thighclust_Dist.Left, L.Thighclust_Dist.Right	Left upper leg cluster positioned over anterior mid-femur - comprised of three passive markers	☑	☑
	L.Shankclust_Prox, L.Shankclust_Dist.Left, L.Shankclust_Dist.Right	Left lower leg cluster positioned over anterior mid-calf - comprised of three passive markers	☑	☑

.5 Study One: 12-item Short-form Health Survey

For office use only				
Subject ID				
Date completed				
Week completed				
Time taken to complete				

SF-12® Participant Questionnaire

SF-12®:

Answer every question by placing a check mark on the line in front of the appropriate answer. If you are unsure about how to answer a question, please give the best answer you can and make a written comment beside your answer.

1. In general, would you say your health is:
_____ Excellent (1)
_____ Very Good (2)
_____ Good (3)
_____ Fair (4)
_____ Poor (5)

The following two questions are about activities you might do during a typical day. Does YOUR HEALTH NOW LIMIT YOU in these activities? If so, how much?

2. MODERATE ACTIVITIES, such as moving a table, pushing a vacuum cleaner, bowling, or playing golf:
_____ Yes, Limited A Lot (1)
_____ Yes, Limited A Little (2)
_____ No, Not Limited At All (3)

3. Climbing SEVERAL flights of stairs:
_____ Yes, Limited A Lot (1)
_____ Yes, Limited A Little (2)
_____ No, Not Limited At All (3)

During the PAST 4 WEEKS have you had any of the following problems with your work or other regular activities AS A RESULT OF YOUR PHYSICAL HEALTH?

4. ACCOMPLISHED LESS than you would like:
_____ Yes (1)
_____ No (2)

SF-12® Cont'd:

5. Were limited in the KIND of work or other activities:
_____ Yes (1)
_____ No (2)

During the PAST 4 WEEKS, were you limited in the kind of work you do or other regular activities AS A RESULT OF ANY EMOTIONAL PROBLEMS (such as feeling depressed or anxious)?

6. ACCOMPLISHED LESS than you would like:
_____ Yes (1)
_____ No (2)

7. Didn't do work or other activities as CAREFULLY as usual:
_____ Yes (1)
_____ No (2)

8. During the PAST 4 WEEKS, how much did PAIN interfere with your normal work (including both work outside the home and housework)?
_____ Not At All (1)
_____ A Little Bit (2)
_____ Moderately (3)
_____ Quite A Bit (4)
_____ Extremely (5)

The next three questions are about how you feel and how things have been DURING THE PAST 4 WEEKS. For each question, please give the one answer that comes closest to the way you have been feeling. How much of the time during the PAST 4 WEEKS –

9. Have you felt calm and peaceful?
_____ All of the Time (1)
_____ Most of the Time (2)
_____ A Good Bit of the Time (3)
_____ Some of the Time (4)
_____ A Little of the Time (5)
_____ None of the Time (6)

SF-12® Cont'd:
10. Did you have a lot of energy?
_____ All of the Time (1)
_____ Most of the Time (2)
_____ A Good Bit of the Time (3)
_____ Some of the Time (4)
_____ A Little of the Time (5)
_____ None of the Time (6)

11. Have you felt downhearted and blue?
_____ All of the Time (1)
_____ Most of the Time (2)
_____ A Good Bit of the Time (3)
_____ Some of the Time (4)
_____ A Little of the Time (5)
_____ None of the Time (6)

12. During the PAST 4 WEEKS, how much of the time has your PHYSICAL HEALTH OR EMOTIONAL PROBLEMS interfered with your social activities (like visiting with friends, relatives, etc.)?
_____ All of the Time (1)
_____ Most of the Time (2)
_____ A Good Bit of the Time (3)
_____ Some of the Time (4)
_____ A Little of the Time (5)
_____ None of the Time (6)

.6 Study Two: Participant Information Sheet

INFORMATION SHEET FOR PARTICIPANTS

Project title: Effects of proprioceptive neuromuscular facilitation (PNF) stretching on activation of the gastrocnemius during isometric maximal voluntary contractions (MVC).

We would like to invite you to take part in our research study. Before you decide, we would like you to understand why the research is being done, and what it would involve for you. One of our team will also go through the information sheet with you and answer any questions you have.

What is the purpose of the research?

The purpose of this study is to investigate how well old and young subjects can activate the plantarflexor muscles (calf muscles that point the toe) during maximum effort contractions. This information is important in understanding the influence of stretching techniques on balance and strength and the development of strategies for falls prevention in older adults. This study will form part of the Principal Investigator’s PhD thesis: Fiona Higgs a PhD student whose thesis and research experience includes collaborative work with the NHS, involving collecting biomechanical, physiological and psychological data from older adult populations.

Do I have to take part?

No, taking part is voluntary. It is up to you whether you want to join the study. We will describe the study and go through this information sheet with you. If you agree to take part we will ask you to sign a consent form and will give you a copy of this form. However, you are free to withdraw from the study at any time without giving a reason. There is no penalty if you withdraw. If you are a student of the university, your academic marks or your entitlement to academic support will be unaffected whether or not you choose to participate in the study.

What will I be asked to do if I take part?

In this study you will be asked to perform maximum effort ankle contractions using your right leg. You will visit the laboratory on three separate occasions over a period of 10-14 days. The first visit will be used to familiarise you with the equipment and testing procedures, and you will practice two different stretching techniques. You will perform one of these stretching techniques prior to testing procedures at each of two separate testing sessions conducted during the two remaining visits.

During each visit you will perform a short cycling warm up for 5 minutes on a stationary cycle ergometer. You will then be seated in the chair of the strength testing machine (below; Biodex III isokinetic dynamometer, Biodex Medical Systems), which is a piece of equipment that will be used to measure and collect the force produced by your plantarflexor muscles (the muscles that point the toe). Measurements of muscle activation in two of your calf muscles (gastrocnemius and tibialis anterior) will also be collected which will involve small adhesive recording electrodes to be applied to the skin over these muscles. Electrodes will also be placed over the gastrocnemius muscle to enable electrical stimulation to be delivered to the muscle.

At this point you will perform several practice submaximal contractions following which a comfortable stimulation current level will be set by increasing the current slowly from a low level. During the contractions with stimulation, two pulses of electrical stimulation will be delivered to the gastrocnemius muscle during the maximal effort testing procedures in order to assess whether the maximum possible level of muscle activation has been attained during your maximum effort contractions.

At the testing sessions, you will perform one of the two different stretch conditions (both of which will be demonstrated at the end of the familiarisation) after which you will perform six maximum effort contractions of the ankle muscles, during which, the two pulses of electrical stimulation will be delivered to the gastrocnemius. Force and muscle activity measures will be recorded.

If you experience any pain or discomfort you should stop contracting the muscle and report the pain to the investigator. If the investigator senses that you are experiencing a high level of pain or discomfort at any point they will use their initiative to stop the procedures. You will be given a one minute rest period between contractions. You will be asked during each rest period whether you wish to continue.

What are the possible side effects of taking part?

During testing of maximum voluntary strength there is a slight risk of muscle strain, sprains, or muscle soreness that wears off over 48 hours following exercise. This soreness may temporarily restrict movement slightly. This risk is no more than would be associated with a strength training session and the likelihood of these discomforts occurring can be reduced by resting between efforts, by warming up, by performing practice contractions, and by building up the force gradually during the maximum effort contractions.

Some skin redness and irritation may occasionally develop under the electrodes used for the neuromuscular stimulator if you have particularly sensitive skin. You should tell the Principal Investigator if you have had a strong skin reaction in the past. There is a small risk to the subjects of skin burns or discomfort arising from the neuromuscular stimulation. This risk is low for the stimulation pattern used and will be limited by putting all of the stimulator unit’s settings to their minimum settings before placing electrodes on your skin. Neuromuscular stimulation is used to cause an involuntary contraction of muscle tissue. When delivered correctly this stimulation causes a twitch lasting only a fraction of a second. The sensation accompanying this twitch feels similar to a ‘tick’ or ‘hiccup’ in the stimulated muscle.

Remember that you may ask to stop at any time during the test procedure or during the training. If you do experience any pain or discomfort please report this to the Principal Investigator immediately. Please remember that if you change your mind about participating in the study for any reason at any time that you are able to withdraw your participation and you must inform the investigator immediately.

How much time will the study involve?

You will be asked to visit the lab three times over a period of 10-14 days. The first visit is a 45-minute familiarisation session and the two following visits are testing sessions lasting approximately 60-minutes.

Will my taking part in this study be kept confidential?

All of the information we collect from you will be kept strictly confidential. Your data will be stored electronically with a numeric code so that you cannot be identified from this information. The key relating your name to the numeric code is kept in a locked cabinet at the university and is accessible only to the research team.

What will happen to the results of the research?

We will publish the information in scientific journals. Only your de-identified (no personal information attached) data will be reported: your name and personal information will be kept confidential and only known to the research team. We may share your de-identified strength and muscle activity data with other investigators if this is necessary for a better analysis of the data.

Who is organising the research?

This research is organised and funded by the Department of Sport and Exercise Science, Aberystwyth University, Carwyn James Building, Penglais Campus, Aberystwyth University, Ceredigion, SY23 3FD.

Who has reviewed the study?

The Aberystwyth Ethics Committee for Research Procedures has reviewed and approved the study.

Who can I contact if I need to ask questions?

You can ask any of the research team for more information before agreeing to take part. You can also ask questions about this research at any time once the study has commenced by contacting the Principal Investigator (Fiona Higgs at 01970 622306, or by e-mail: fhh09@aber.ac.uk) or you can contact Fiona’s academic supervisor (Dr Joanne Thatcher: jet@aber.ac.uk; 01970 628629).

Who should I contact if I need to complain about the study?

If you have complaints or concerns about this research you can contact Dr Mark Burnley, the Director of Research for the Department of Sport and Exercise Science, on 01970 628560.

What do I do now?

If you understand the information given in this form, then please fill in the attached consent form. Please avoid high intensity or exhausting exercise in the 24 hours prior to testing. Do not consume alcohol during the day before the test. Please tell the Investigator if you have been ill in the two weeks prior to the test, or if you are suffering from any injury.

.7 Study Three: Participant Information Sheet

INFORMATION SHEET FOR PARTICIPANTS

Project title: Effects of a four week proprioceptive neuromuscular facilitation (PNF) stretch training programme on isokinetic strength and range of motion (ROM) at the ankle in old and young adults.

We would like to invite you to take part in our research study. Before you decide, we would like you to understand why the research is being done, and what it would involve for you. One of our team will also go through the information sheet with you and answer any questions you have.

What is the purpose of the research?

The purpose of this study is to investigate force production and ROM at the ankle in old and young subjects and whether these measures are influenced by a four week stretch training programme. This information is important in understanding the influence of stretching techniques on balance and strength and the development of strategies for falls prevention in older adults. This information is important in understanding balance and developing methods that reduce risk of falling and is also important information for future studies in this line of work. Subjects will not themselves benefit from the protocol.

Do I have to take part?

No, taking part is voluntary. It is up to you whether you want to join the study. We will describe the study and go through this information sheet with you. If you agree to take part we will ask you to sign a consent form and will give you a copy of this form. However, you are free to withdraw from the study at any time without giving a reason. There is no penalty if you withdraw. If you are a student of the university, your academic marks or your entitlement to academic support will be unaffected whether or not you choose to participate in the study.

What will I be asked to do if I take part?

In this study you will be asked to perform maximum effort ankle contractions using your right leg. You will visit the laboratory on five separate occasions over a period of 4-5 weeks. The first visit will be used to familiarise you with the equipment and testing procedures, and to participate in two bouts of testing before and after performing an ankle stretch. You will provided with instructions to perform this stretch regularly over the four weeks following the first visit; during this time you will return to the laboratory once a week to meet with the research team, who will check that you are performing the stretch in the safest and most effective way, and measure the change in range of motion with the stretch. During your fifth visit to the laboratory you will participate in one bout of testing. Each bout of testing involves collection of force data and measurement of ROM of the right ankle.

During the first and fifth visit you will perform a short cycling warm up for 5 minutes on a stationary cycle ergometer, after which ROM in your right ankle will be measured. You will then be seated in the chair of the strength testing machine (below; Biodex III isokinetic dynamometer, Biodex Medical Systems), which is a piece of equipment that will be used to measure and collect the force produced by your plantarflexor muscles (the muscles that point the toe downwards, away from the body) and dorsiflexors (the muscles that point the toe upwards, towards the body).

At this point you will perform several practice contractions, followed by the collection of force data during which you will perform six maximum effort contractions of the ankle muscles.

After the first bout of testing at the first testing session, you will perform a stretch condition (which will be demonstrated during the familiarisation) after which you will perform a second bout of testing, beginning with measurement of ROM followed by collection of force data.

The fifth testing session will take place after you have completed four weeks of stretch training and will only involve one bout of testing for ROM and force data. This training programme will be explained to you at the end of the first testing session, and will involve repeating the ankle stretch administered in the first testing session three times weekly over a four week period. The overall time required to perform these stretches over the four weeks will be no more than 30 minutes in total.

If you experience any pain or discomfort you should stop contracting the muscle and report the pain to the investigator. You will be given a one minute rest period between contractions.

What are the possible side effects of taking part?

During testing of maximum voluntary strength there is a slight risk of muscle strain, sprains, or muscle soreness that wears off over 48 hours following exercise. This soreness may temporarily restrict movement slightly. This risk is no more than would be associated with a strength training session and the likelihood of these discomforts occurring can be reduced by resting between efforts, by warming up, by performing practice contractions, and by building up the force gradually during the maximum effort contractions.

Remember that you may ask to stop at any time during the test procedure or during the training. If you do experience any discomfort please report this to the Principal Investigator immediately.

How much time will the study involve?

You will be asked to visit the lab five times over a period of 4-5 weeks. The first visit is a 45-minute familiarisation and testing session and the fifth visit is a testing session lasting approximately 30-minutes. Visits 2-4 will last for no longer than 15 minutes. The time required to perform all stretches included in the four week stretch training programme is no more than 30 minutes.

Will my taking part in this study be kept confidential?

All of the information we collect from you will be kept strictly confidential. Your data will be stored electronically with a numeric code so that you cannot be identified from this information. The key relating your name to the numeric code is kept in a locked cabinet at the university and is accessible only to the research team.

What will happen to the results of the research?

We will publish the information in scientific journals. Only your de-identified (no personal information attached) data will be reported: your name and personal information will be kept confidential and only known to the research team. We may share your de-identified strength and ROM with other researchers if this is necessary for a better analysis of the data.

Who is organising the research?

This research is organised and funded by the Department of Sport and Exercise Science, Aberystwyth University, Carwyn James Building, Penglais Campus, Aberystwyth University, Ceredigion, SY23 3FD.

Who has reviewed the study?

The Aberystwyth Ethics Committee for Research Procedures has reviewed and approved the study.

Who can I contact if I need to ask questions?

You can ask any of the research team for more information before agreeing to take part. You can also ask questions about this research at any time once the study has commenced by contacting the Principal Investigator (Fiona Higgs at 01970 622306, or by e-mail: fhh09@aber.ac.uk) or you can contact Fiona's academic supervisor (Dr Joanne Thatcher: jet@aber.ac.uk; 01970 628629).

Who should I contact if I need to complain about the study?

If you have complaints or concerns about this research you can contact Dr Mark Burnley, the Director of Research for the Department of Sport and Exercise Science, on 01970 628560.

What do I do now?

If you understand the information given in this form, then please fill in the attached consent form. Please avoid high intensity or exhausting exercise in the 24 hours prior to testing. Do not consume alcohol during the day before the test. Please tell the Investigator if you have been ill in the two weeks prior to the test, or if you are suffering from any injury.

.8 Pre-activity Health Questionnaire

Department of Sport and Exercise Science
Aberystwyth University
Pre-exercise health questionnaire (Updated 01/09/06)

STRICTLY CONFIDENTIAL

Please answer these questions truthfully and completely. The purpose of this questionnaire is to ensure that you are in a fit and healthy state to complete exercise associated with projects in the Department of Sport and Exercise Science.

1. How frequent would you describe your present level of vigorous activity?

   ____

2. Are you over 45 years (if male) or 55 years (if female)?
   Yes No

3. Do you suffer, or have you ever suffered from any form of heart complaint?
   Yes No

4. Do you have a family history of heart attack or sudden death below 65 years?
   Yes No

5. Do you suffer, or have you ever suffered from:
   - High Cholesterol Yes No
   - Asthma Yes No
   - Diabetes Yes No
   - Bronchitis Yes No
   - Epilepsy Yes No
   - High blood pressure Yes No

6. Do you smoke? Yes No

7. Have you had to consult your doctor in the last three months about any matter which may affect your ability to exercise? If yes, please give brief details

   ____

8. Are you currently taking any form of medication which may affect your ability to exercise? If yes, please give brief details

   ____

9. Do you currently have any form of muscle or joint injury?
   Yes No

10. Have you suffered from a bacterial or viral infection in the last two weeks?
    Yes No

11. Have you had cause to suspend your training in the last two weeks for a physical reason?
    Yes No

12. Is there any reason why you should not be able to successfully complete a test which requires a maximum effort?
    Yes No

13. If blood samples are being taken as part of the test, do you suffer from shock symptoms, nausea or dizziness at the sight of needles or human blood?
    Yes No

Informed consent

The above information is correct to the best of my belief and I understand it will be treated in the strictest confidence. The experimenter has fully explained the purpose of the experiment and the possible risks involved. I understand that I may withdraw from the experiment at any time and that I am under no obligation to give reasons for withdrawal. I will adhere the instructions of the experimenter regarding safety before, during, and after during experimentation. I hereby volunteer to participate in experimental work as a participant.

Name of participant ……………………………………...

Signature of participant ……………………………………...

Date ……….........

Name of experimenter …………………………………………………..

Signature of experimenter *……………………………………………….

Date ………………

***Please Note; if the experimenter is a student and there are answers where ill health is or <u>may</u> be indicated, this form must be passed to your supervisor for clearance <u>before</u> any tests are undertaken.**

.9 Pretest Questionnaire

ABERYSTWYTH UNIVERSITY
Pre-test questionnaire

NAME:

DATE:

EXPERIMENTER:

YES/NO

1. HAVE YOU HAD ANY KIND OF ILLNESS
OR INFECTION IN THE LAST 2 WEEKS?
…………………………

2. ARE YOU TAKING ANY FORM OF MEDICATION?
…………………………

3 DO YOU HAVE ANY FORM OF INJURY?
…………………………

4. HAVE YOU EATEN IN THE LAST HOUR?
…………………………

5. HAVE YOU CONSUMED ANY ALCOHOL IN
THE LAST 24 HOURS?
…………………………

6. HAVE YOU PERFORMED EXHAUSTIVE
EXERCISE WITHIN THE LAST 48 HOURS?
…………………………

IF THE ANSWER TO ANY OF THE ABOVE QUESTIONS IS YES, THEN YOU MUST CONSULT A MEMBER OF ACADEMIC STAFF BEFORE UNDERGOING ANY EXERCISE TEST.

SIGNATURE OF SUBJECT …………………………………………………

.10 Study Two: Informed Consent Document

Project title: Effects of proprioceptive neuromuscular facilitation (PNF) stretching on activation of the gastrocnemius during isometric maximal voluntary contractions (MVC).

Chief Investigator: Fiona Higgs
Department of Sport and Exercise Science,
Aberystwyth University
Carwyn James Building, Penglais Campus,
Ceredigion, SY23 3FD.
Tel: 01970 622306

Other research personnel: Dr Samantha Winter, Dr Joanne Thatcher, Dr Mark Burnley.

Participant Identification Number for this study:

CONSENT FORM

Please initial boxes

1. I have read and understood the information sheet for participants dated 24/01/2012, Version 1. I have had the opportunity to think about whether to take part and ask questions, and I have had satisfactory answers to my questions. ☐

2. I understand that my participation is voluntary and that I am free to withdraw at any time without giving any reason, without being penalised in any way. If I am an student I understand that declining to participate or withdrawing once the test has started will not affect my position as a student. ☐

3. I am over the age of 18. ☐

4. I understand that agreeing to take part means that I am willing to perform the procedures explained in the information sheet. ☐

5. I agree to take part in the Aberystwyth University study entitled “Effects of proprioceptive neuromuscular facilitation (PNF) stretching on activation of the gastrocnemius during isometric maximal voluntary contractions (MVC)”. ☐

Signature (participant)…………………………………………………………………

Name in block letters…………………………………………………………………..

Date ……………

Signature (person taking consent)……………………………………………………

Name in block letters…………………………………………………………………..

Date ……………

.11 Study Three: Informed Consent Document

Project title: Effects of a four week proprioceptive neuromuscular facilitation (PNF) stretch training programme on isokinetic strength and range of motion (ROM) at the ankle in old and young adults.

Chief Investigator: Fiona Higgs
Department of Sport and Exercise Science,
Aberystwyth University
Carwyn James Building, Penglais Campus,
Ceredigion, SY23 3FD.
Tel: 01970 622306

Other research personnel: Dr Samantha Winter, Dr Joanne Thatcher, Dr Mark Burnley.

Participant Identification Number for this study:

CONSENT FORM

Please initial boxes

1. I have read and understood the information sheet for participants dated 24/01/2012, Version 1. I have had the opportunity to think about whether to take part and ask questions, and I have had satisfactory answers to my questions. ☐

2. I understand that my participation is voluntary and that I am free to withdraw at any time without giving any reason, without being penalised in any way. If I am an student I understand that declining to participate or withdrawing once the test has started will not affect my position as a student. ☐

3. I am over the age of 18. ☐

4. I understand that agreeing to take part means that I am willing to perform the procedures explained in the information sheet. ☐

5. I agree to take part in the Aberystwyth University study entitled “Effects of proprioceptive neuromuscular facilitation (PNF) stretching on activation of the gastrocnemius during isometric maximal voluntary contractions (MVC)”. ☐

Signature (participant)…………………………………………………………………

Name in block letters…………………………………………………………………..

Date ……………

Signature (person taking consent)……………………………………………………

Name in block letters…………………………………………………………………..

Date ……………

.12 Participant Instructions: Home-based PNF training

Instructions for Home Stretches

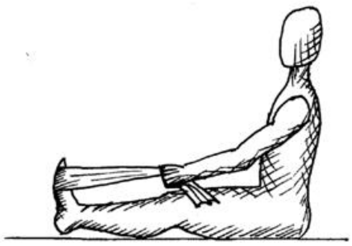
You may choose to perform either:

- the self-administered
- the assisted stretch (as performed during the lab visits)

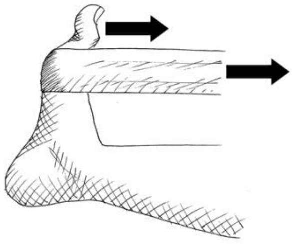
The self-administered stretch

For the adapted PNF stretch at the ankle:

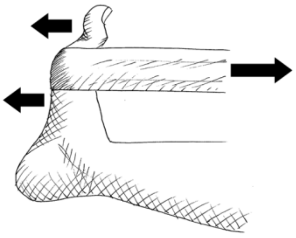
1. Sit on the floor or level surface with both legs extended in front of you – your knees should be straight (the backs of your knees should be as close to the floor a possible).



2. Hold the two loose ends of the a non-elasticated belt or scarf securely in one or both of your hands and loop the belt or scarf around the mid-section of your right foot so that it is held against the ball of the foot, keeping the scarf or belt taught.



3. Take a breath in and then exhale as you point your toes upwards and towards you as far as possible. Hold this position for 5 seconds.

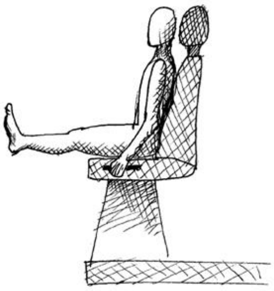


4. Now, push your foot against the scarf or belt at 65% of your maximum effort for 5-10 seconds , as though trying to point your toes, all the while your hands providing an equal resistance with the scarf/belt to stop any actual movement occurring at your ankle or in the foot in any direction. Keep breathing normally throughout this step.

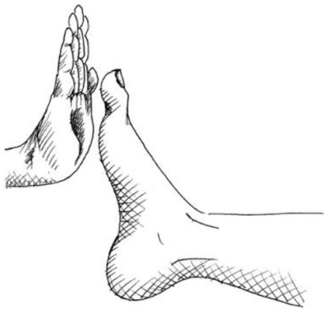
5. Relax your ankle out of the stretch for 5–10 seconds before going back into the next stretch.
6. Steps 1-5 must be repeated 3 times each in the same order.

The assisted stretch (to be performed with assistance from a partner as performed during the lab visits)

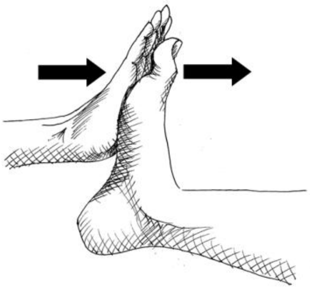
1. Sit on the floor, chair bed or other level surface with both legs extended in front of you – your knees should be straight (the backs of your knees should be as close to the floor a possible)



2. Your partner should support your right heel in the palm of their left hand, while the palm of their other hand is to be placed against the ball of your foot on the underside of your foot.

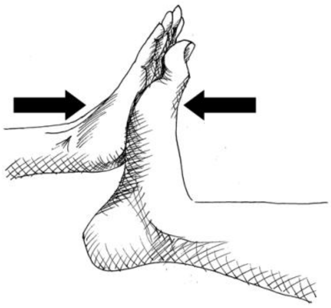


3. Take a breath in and then exhale as you point your toes upwards and towards you as far as possible. As you do so your partner will keep their palm positioned against the proximal half of the plantar surface of the foot, but will not apply any force at this point.



4. When your ankle has reached the end of their range of motion this position will be held for 5 seconds, during which time your will continue to breath normally.

5. Now, push your toes downwards and away from yourself (pointing your toes) against your partner's hand for 5- to 10-seconds at 65% of your maximum effort while your partner provides a matching level of resistance to ensure that there is no movement in the ankle or foot in any direction.



6. Relax your ankle out of the stretch for 5–10 seconds before going back into the next stretch.
7. Steps 1-6 must be repeated 3 times each in the same order.

Please complete the stretch programme as described below for three repetitions on three days once a week for four weeks, with at least one day of rest between performing the stretch.

.13 Physical Activity and Exercise Diary

RECORD DIARY

Please record each time that you complete the stretch training activity, including the date and time of your stretching activity as soon as you have completed a stretching session. It is important to know the exact number of times you perform the stretch, as this information helps us to understand how much effect the training programme has. **Please continue your normal exercise and stretching activities,** but make sure that you record any vigorous activity that elevates your heart rate in the Exercise/Sport activity diary, e.g.: running, cycling, swimming, etc.

Stretching activity diary:

Week number	Date	Time	Date	Time	Date	Time
1						
2						
3						
4						

Exercise/Sport activity diary:

Week number	Date	Time	Activity + Duration (hours)	Date	Time	Activity+ Duration (hours)	Date	Time	Activity+ Duration (hours)	Date	Time	Activity+ Duration (hours)
1												
2												
3												
4												

References

[1] WHO. Global Recommendations on Physical Activity for Health, 2010. URL `http://www.who.int/dietphysicalactivity/factsheet_olderadults/en/`. 2

[2] P. Scuffham, S. Chaplin, and R. Legood. Incidence and costs of unintentional falls in older people in the United Kingdom. *Journal of Epidemiology and Community Health*, 57(9):740–744, 2003. 2, 6, 7, 8, 53, 86

[3] T. P. Van Staa, E. M. Dennison, H. G. Leufkens, and C. Cooper. Epidemiology of fractures in England and Wales. *Bone*, 29(6):517–522, 2001. 2, 7

[4] Office for National Statistics. Injury and Poisoning Mortality in England and Wales, 2011, 2011. URL `http://www.ons.gov.uk/ons/rel/vsob1/injury-and-poisoning-mortality-in-england-and-wales/2011/stb-injury-and-poisoning-2011.html`. 2, 7

[5] J. A. Kanis. The incidence of hip fracture in Europe. *Osteoporosis International*, 3 Suppl 1:10–15, 1993. 2

[6] R. Marks. Hip fracture epidemiological trends, outcomes, and risk factors, 1970-2009. *International Journal of General Medicine*, 3:1–17, 2010. 2, 7, 8

[7] B. D. Lloyd, D. A. Williamson, N. A. Singh, R. D. Hansen, T. H. Diamond, T. P. Finnegan, B. J. Allen, J. N. Grady, T. M. Stavrinos, E. U. R. Smith, A. D. Diwan, and M. A. Fiatarone Singh. Recurrent and injurious falls

in the year following hip fracture: a prospective study of incidence and risk factors from the Sarcopenia and Hip Fracture study. *The Journals of Gerontology Series A: Biological Sciences and Medical Sciences*, 64(5): 599–609, 2009. 2, 19, 20, 21, 24

[8] J. Malley, R. Hancock, M. Murphy, J. Adams, R. Wittenberg, A. Comas-Herrera, C. Curry, D. King, S. James, M. Morciano, and L. Pickard. The effect of lengthening life expectancy on future pension and long-term care expenditure in England, 2007 to 2032. *Health Statistics Quarterly Office for National Statistics*, (52):33–61, 2011. 2

[9] L. D. Gillespie, M. C. Robertson, W. J. Gillespie, S. E. Lamb, S. Gates, R. G. Cumming, and B. H. Rowe. Interventions for preventing falls in older people living in the community (Review). *Cochrane Database of Systematic Reviews (Online)*, 2(2):CD007146, 2009. 2, 6, 42, 43, 59, 135

[10] D. A. Skelton, S. M. Dinan, M. Campbell, and O. Rutherford. Tailored group exercise (Falls Management Exercise – FaME) reduces falls in community-dwelling older frequent fallers (an RCT). *Age and Ageing*, 34 (6):636–9, 2005. 2, 42, 43, 53, 59, 60, 61, 64, 85, 90, 91, 93, 111, 132, 133, 136, 138

[11] D. A. Skelton, K. Stranzinger, S. M. Dinan, and O. M. Rutherford. BMD Improvements Following FaME (Falls Management Exercise) in Frequently Falling Women Age 65 and Over: An RCT. In *7th World Congress on Aging and Physical Activity, Japan*, pages S89–S90, Champaign, IL, 2008. Human Kinetics. 2, 43, 53

[12] M. E. Nelson, W. J. Rejeski, S. N. Blair, P. W. Duncan, J. O. Judge, A. C. King, C. A. Macera, and C. Castaneda-Sceppa. Physical activity and public health in older adults: recommendation from the American College of Sports Medicine and the American Heart Association. *Circulation*, 116 (9):1094–1105, 2007. 2, 45, 93, 94, 131

[13] W. J. Chodzko-Zajko, D. N. Proctor, M. A. Fiatarone Singh, C. T. Minson, C. R. Nigg, G. J. Salem, and J. S. Skinner. American College of Sports

Medicine Position Stand. Exercise and physical activity for older adults. *Medicine and Science in Sports and Exercise*, 30(7):992–1008, 2009. 2, 45, 48, 53, 55, 93, 94

[14] NICE. CG21 Falls: NICE guideline. Technical report, 2004. URL `http://guidance.nice.org.uk/CG21/NICEGuidance/pdf/English`. 2, 13, 14, 15, 17, 18, 44, 45, 51, 52, 53, 54, 55, 61, 93, 113

[15] Office for National Statistics. 2011 Census, Key Statistics for Unitary Authorities in Wales, 2011. URL `http://www.ons.gov.uk/ons/rel/census/2011-census/key-statistics-for-unitary-authorities-in-wales/index.html`. 3, 10, 11

[16] Office for National Statistics. Neighbourhood Statistics (Area: Ceredigion - Key Figures for Health and Care), 2011. URL `http://neighbourhood.statistics.gov.uk/dissemination/LeadKeyFigures.do;jsessionid=wHrnRTpc3sMLcVsvrGX5R91gm8JrxmxdQ1hdnNScts9C2R8NDvVF!416580655!1364401916460?a=7&b=276865&c=ceredigion&d=13&e=6&g=415741&i=1001x1003x1004&o=1&m=0&r=1&s=1364401916460&enc=1&nsjs=true&nsck=true&nssvg=false&nswid=1280`. 3, 10, 11

[17] M. J. Spink, M. R. Fotoohabadi, E. Wee, K. D. Hill, S. R. Lord, and H. B. Menz. Foot and ankle strength, range of motion, posture, and deformity are associated with balance and functional ability in older adults. *Archives of Physical Medicine and Rehabilitation*, 92(1):68–75, 2011. 3, 41, 42

[18] T. Masud and R. O. Morris. Epidemiology of falls. *Age and Ageing*, 30 (suppl 4):3–7, 2001. 5, 6, 19, 20, 61

[19] D. M. Buchner, M. C. Hornbrook, N. G. Kutner, M. E. Tinetti, M. G. Ory, C. D. Mulrow, K. B. Schechtman, M. B. Gerety, M. A. Fiatarone, and S. L. Wolf. Development of the common data base for the FICSIT trials. *Journal of the American Geriatrics Society*, 41(3):297–308, 1993. 6

[20] M. J. Gibson, R. O. Andres, B. Isaacs, T. Radebaugh, and J. Worm-Petersen. The prevention of falls in later life. A report of the Kellogg

International Work Group on the Prevention of Falls by the Elderly. *Danish Medical Bulletin*, 34 Suppl 4:1–24, 1987. 6

[21] N. D. Carter, K. M. Khan, H. A. McKay, M. A. Petit, C. Waterman, A. Heinonen, P. A. Janssen, M. G. Donaldson, A. Mallinson, L. Riddell, K. Kruse, J. C. Prior, and L. Flicker. Community-based exercise program reduces risk factors for falls in 65- to 75-year-old women with osteoporosis: randomized controlled trial. *Canadian Medical Association Journal*, 167 (9):997–1004, 2002. 6

[22] H. W. Lach, A. T. Reed, C. L. Arfken, J. P. Miller, G. D. Paige, S. J. Birge, and W. A. Peck. Falls in the elderly: reliability of a classification system. *Journal of the American Geriatrics Society*, 39(2):197–202, 1991. 6

[23] K. Koski, H. Luukinen, P. Laippala, and S. L. Kivela. Physiological factors and medications as predictors of injurious falls by elderly people: a prospective population-based study. *Age and Ageing*, 25(1):29–38, 1996. 6, 53

[24] A. A. Zecevic, A. W. Salmoni, M. Speechley, and A. A. Vandervoort. 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, 2006. 6

[25] S. E. Lamb, E. C. Jø rstad Stein, K. Hauer, and C. Becker. Development of a common outcome data set for fall injury prevention trials: The prevention of falls network Europe consensus. *Journal of the American Geriatrics Society*, 53(9):1618–1622, 2005. 6, 24, 25, 26, 56

[26] J. Gribbin, R. Hubbard, C. Smith, J. Gladman, and S. Lewis. Incidence and mortality of falls amongst older people in primary care in the United Kingdom. *Quarterly Journal of Medicine*, 102(7):477–483, 2009. 7, 86

[27] The NHS Information Centre for health and social care. Mortality from accidental falls, Compendium of Population Health Indicators. URL `https://indicators.ic.nhs.uk/webview/`. 7

[28] D. Prudham and J. G. Evans. Factors associated with falls in the elderly: a community study. *Age and Ageing*, 10(3):141–146, 1981. 7

[29] Ceredigion County Council. Health, Social Care and Well-being Needs Assessment of the population of Ceredigion 2010, 2010. 8, 11

[30] United Nations. World Population Prospects: The 2010 Revision, CD-ROM Edition. Technical Report June, United Nations, Department of Economic and Social Affairs, Population Division (2011)., 2011. 8, 9, 10

[31] Office for National Statistics. Births and Deaths in England and Wales, 2011, 2011. URL `http://www.ons.gov.uk/ons/rel/vsob1/death-reg-sum-tables/2011--final-/sb-births-and-deaths-in-england-and-wales--2011--final-.html#tab-Key-findings`. 9

[32] Office for National Statistics. Death Registrations by Single Year of Age - United Kingdom, 2011, 2011. URL `http://www.ons.gov.uk/ons/rel/vsob1/death-registrations-by-single-year-of-age/united-kingdom-2011/index.html`. 10

[33] C. Breakwell and M. Bajekal. Health expectancies in the UK and its constituent countries, 2001. *Health Statistics Quarterly Office for National Statistics*, 29(29):18–25, 2006. 10

[34] Office for National Statistics. Disability in England and Wales, 2011 and Comparison with 2001, 2013. URL `http://www.ons.gov.uk/ons/rel/census/2011-census/key-statistics-and-quick-statistics-for-wards-and-output-areas-in-england-a`
`rpt-disability-short-story.html`. 11

[35] WAG. National Service Framework for Older People in Wales. Technical report, 2006. URL `http://wales.gov.uk/topics/olderpeople/publications/nationalserviceframeworkolderppl/;jsessionid=5176446FAB0976C594F2F9782F18439F?status=closed&lang=en`. 12, 13, 14, 15, 16

[36] WAG. The Strategy for Older People in Wales 2008-2013. Technical report, 2008. URL `http://wales.gov.uk/topics/olderpeople/publications/strategy2008-2013/;jsessionid=5176446FAB0976C594F2F9782F18439F?status=closed&lang=en`. 13, 53

[37] WHO. WHO Global Report on Falls Prevention in Older Age. Technical report, World Health Organization, 2007. URL `http://www.who.int/ageing/publications/Falls_prevention7March.pdf`. 14, 45, 53, 59, 93, 113

[38] Royal College of Physicians. Older peoples experiences of therapeutic exercise as part of a falls prevention service patient and public involvement. Technical report, London, UK, 2012. URL `http://www.rcplondon.ac.uk/sites/default/files/documents/patient_and_public_involvement_report__2011_final.pdf`. 16, 54, 55

[39] D. A. Skelton and S. M. Dinan. Exercise for falls management: Rationale for an exercise programme aimed at reducing postural instability. *Physiotherapy Theory and Practice*, 15(2):105–120, 1999. 17, 20, 42, 53, 59

[40] Better Ageing Project. Guidelines for exercise programming for the frail elderly, 2005. 17, 42, 45, 53, 130, 131

[41] S. R. Lord, J. A. Ward, P. Williams, and K. J. Anstey. Physiological factors associated with falls in older community-dwelling women. *Journal of the American Geriatrics Society*, 42(10):1110–1117, 1994. 19

[42] A. B. Dufour, M. T. Hannan, J. M. Murabito, D. P. Kiel, and R. R. McLean. Sarcopenia Definitions Considering Body Size and Fat Mass Are Associated With Mobility Limitations: The Framingham Study. *The Journals of Gerontology Series A: Biological Sciences and Medical Sciences*, 68(2):1–7, 2012. 19, 27

[43] S. Tennstedt, J. Howland, M. Lachman, E. Peterson, L. Kasten, and A. Jette. A randomized, controlled trial of a group intervention to reduce

fear of falling and associated activity restriction in older adults. *The Journals of Gerontology Series B: Psychological Sciences and Social Sciences*, 53(6):P384–P392, 1998. 19, 20, 22, 23, 86

[44] R G. Cumming, G. Salkeld, M. Thomas, and G. Szonyi. Prospective study of the impact of fear of falling on activities of daily living, SF-36 scores, and nursing home admission. *The Journals of Gerontology Series A: Biological Sciences and Medical Sciences*, 55(5):M299–M305, 2000. 19, 20, 21, 25

[45] A. Campbell. Falls prevention over 2 years: a randomized controlled trial in women 80 years and older. *Age and Ageing*, 28(6):513–518, October 1999. 20, 59, 60, 138

[46] M. M. Gardner, M. C. Robertson, and A. J. Campbell. Exercise in preventing falls and fall related injuries in older people: a review of randomised controlled trials. *British Journal of Sports Medicine*, 34(1):7–17, 2000. 20, 43, 53

[47] M. E. Tinetti, D. Richman, and L. Powell. Falls efficacy as a measure of fear of falling. *Journal of Gerontology*, 45(6):P239–P243, 1990. 20, 22, 23

[48] J. Howland, M. E. Lachman, E. W. Peterson, J. Cote, L. Kasten, and A. Jette. Covariates of fear of falling and associated activity curtailment. *The Gerontologist*, 38(5):549–555, 1998. 20, 21, 25

[49] C. L. Arfken, H. W. Lach, S. J. Birge, and J. P. Miller. The prevalence and correlates of fear of falling in elderly persons living in the community. *American Journal of Public Health*, 84(4):565–570, 1994. 20, 21

[50] S. L. Murphy, C. S. Williams, and T. M. Gill. Characteristics associated with fear of falling and activity restriction in community-living older persons. *Journal of the American Geriatrics Society*, (3):516–520. 20, 21, 22

[51] D. De Kam, E. Smulders, V. Weerdesteyn, and B. C. M. Smits-Engelsman. Exercise interventions to reduce fall-related fractures and their risk factors

in individuals with low bone density: a systematic review of randomized controlled trials. *Osteoporosis International*, 20(12):2111–2125, 2009. 20

[52] F. Li, K. J. Fisher, P. Harmer, E. McAuley, and N. L. Wilson. Fear of falling in elderly persons: association with falls, functional ability, and quality of life. *The journals of Gerontology Series B: Psychological Sciences and Social Sciences*, 58(5):P283–P290, 2003. 21, 24, 25

[53] A. Bueno-Cavanillas, F. Padilla-Ruiz, J. J. Jiménez-Moleón, C. A. Peinado-Alonso, and R. Gálvez-Vargas. Risk factors in falls among the elderly according to extrinsic and intrinsic precipitating causes. *European Journal of Epidemiology*, 16(9):849–59, 2000. 21

[54] M. E. Lachman, J. Howland, S. Tennstedt, A. Jette, S. Assmann, and E. W. Peterson. Fear of falling and activity restriction: the survey of activities and fear of falling in the elderly (SAFE). *The Journals of Gerontology Series A: Biological Sciences and Medical Sciences*, 53(1):P43–P50, 1998. 21, 22

[55] G. A. Zijlstra, J. C. Van Haastregt, J. T. Van Eijk, E. Van Rossum, P. A. Stalenhoef, and G. I. Kempen. Prevalence and correlates of fear of falling, and associated avoidance of activity in the general population of community-living older people. *Age and Ageing*, 36(3):304–309, 2007. 21, 22, 23, 86

[56] M. E. Tinetti and L. Powell. Fear of falling and low self-efficacy: a case of dependence in elderly persons. *Journal of Gerontology*, 48(Special Issue): 35–38, 1993. 21

[57] L. E. Powell and A. M. Myers. The Activities-specific Balance Confidence (ABC) Scale. *The Journals of Gerontology Series A: Biological Sciences and Medical Sciences*, 50A(1):M28–34, 1995. 22

[58] L. Yardley, N. Beyer, K. Hauer, G. Kempen, C. Piot-Ziegler, and C. Todd. Development and initial validation of the Falls Efficacy Scale-International (FES-I). *Age and Ageing*, 34(6):614–619, 2005. 22, 23, 24, 66

[59] K. Delbaere, J. C. T. Close, H. Brodaty, P. Sachdev, and S. R. Lord. Determinants of disparities between perceived and physiological risk of falling among elderly people: cohort study. *BMJ*, 341(aug18 4):c4165–c4165, 2010. 22, 23, 24, 66, 87

[60] G. I. J. M. Kempen, L. Yardley, J. C. M. Van Haastregt, G. A. R. Zijlstra, N. Beyer, K. Hauer, and C. Todd. The Short FES-I: a shortened version of the falls efficacy scale-international to assess fear of falling. *Age and Ageing*, 37(1):45–50, 2007. 22, 23, 66

[61] F. Li, K. J. Fisher, P. Harmer, and E. McAuley. Falls self-efficacy as a mediator of fear of falling in an exercise intervention for older adults. *The journals of Gerontology Series B: Psychological Sciences and Social Sciences*, 60(1):P34–P40, 2005. 22

[62] NICE. Hip Facture: The management of hip fracture in adults. Technical report, National Institute of Clinical Excellence, London, UK, 2011. URL `http://publications.nice.org.uk/hip-fracture-cg124`. 22

[63] B. E. Maki, P. J. Holliday, and A. K. Topper. Fear of Falling and Postural Performance in the Elderly. *Journal of Gerontology*, 46(4):M123–131, 1991. 23

[64] T. Balboa-Castillo, L. M. León-Muñoz, A. Graciani, F. Rodríguez-Artalejo, and P. Guallar-Castillón. Longitudinal association of physical activity and sedentary behavior during leisure time with health-related quality of life in community-dwelling older adults. *Health and Quality of Life Outcomes*, (1):47. 24

[65] W. Pavot and E. Diener. Review of the Satisfaction With Life Scale. *Psychological Assessment*, 5(2):164–172, 1993. 24

[66] D. W. Brown, L. S. Balluz, G. W. Heath, D. G. Moriarty, E.S. Ford, W. H. Giles, and A. H. Mokdad. Associations between recommended levels of physical activity and health-related quality of life. Findings from the 2001 Behavioral Risk Factor Surveillance System (BRFSS) survey. *Preventive Medicine*, 37(5):520–528, 2003. 24

[67] F. A. C. Wanderley, G. Silva, El. Marques, J. Oliveira, J. Mota, and J. Carvalho. Associations between objectively assessed physical activity levels and fitness and self-reported health-related quality of life in community-dwelling older adults. *Quality of Life Research*, 20(9):1371–8, 2011. 24

[68] S. R. Lord, A. Tiedemann, K. Chapman, B. Munro, S. M. Murray, and C. Sherrington. The effect of an individualized fall prevention program on fall risk and falls in older people: a randomized, controlled trial. *Journal of the American Geriatrics Society*, 53(8):1296–1304, 2005. 24

[69] J. Steadman, N. Donaldson, and L. Kalra. A randomized controlled trial of an enhanced balance training program to improve mobility and reduce falls in elderly patients. *Journal of the American Geriatrics Society*, 51(6): 847–852, 2003. 24, 25, 59, 60, 138

[70] J. Ware, M. Kosinski, and S. D. Keller. A 12-Item Short-Form Health Survey: construction of scales and preliminary tests of reliability and validity. *Medical Care*, 34(3):220–233, 1996. 24, 25, 26

[71] EuroQol Group. EuroQol–a new facility for the measurement of health-related quality of life. The EuroQol Group. *Health Policy*, 16(3):199–208, 1990. 24

[72] M. E. Tinetti, D. I. Baker, G. McAvay, E. B. Claus, P. Garrett, M. Gottschalk, M .L. Koch, K. Trainor, and R. I. Horwitz. A multifactorial intervention to reduce the risk of falling among elderly people living in the community. *The New England Journal of Medicine*, 331(13):821–827, 1994. 25

[73] J. E. Ware. SF-36 health survey update. *Spine*, 25(24):3130–3139, 2000. 25, 68

[74] A. J. Cruz-Jentoft, J. P. Baeyens, J. M. Bauer, Y. Boirie, T. Cederholm, F. Landi, F. C. Martin, J. Michel, Y. Rolland, S. M. Schneider, E. Topinková, M. Vandewoude, and M. Zamboni. Sarcopenia: European consensus on definition and diagnosis. *Age and Ageing*, 39(4):412–423, 2010. 26, 28, 29, 36, 67, 108

[75] V. A. Hughes, W. R. Frontera, M. Wood, W. J. Evans, G. E. Dallal, R. Roubenoff, and M. A. F. Singh. 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, 2001. 27, 28, 29, 52, 109

[76] S A Jubrias, I R Odderson, P C Esselman, and K E Conley. Decline in isokinetic force with age: muscle cross-sectional area and specific force. *Pflugers Archiv European Journal of Physiology*, 434(3):246–253, 1997. 27

[77] I. Janssen, S. B. Heymsfield, and R. Ross. 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, 2002. 27

[78] J. Lexell. Human aging, muscle mass, and fiber type composition. *The Journals of Gerontology Series A: Biological Sciences and Medical Sciences*, 50 Spec No(3):11–16, 1995. 27

[79] F. M. Ivey, B. L. Tracy, J. T. Lemmer, M. NessAiver, E. J. Metter, J. L. Fozard, and B. F. Hurley. Effects of strength training and detraining on muscle quality: age and gender comparisons. *The Journals of Gerontology Series A: Biological Sciences and Medical Sciences*, 55(3):B152–B157; discussion B158–B159, 2000. x, 27, 30, 31

[80] K. Häkkinen, M. Kallinen, M. Izquierdo, K. Jokelainen, H. Lassila, E. Mälkiä, W. J. Kraemer, R. U. Newton, and M. Alen. Changes in agonist-antagonist EMG, muscle CSA, and force during strength training in middle-aged and older people. *Journal of Applied Physiology*, 84(4): 1341–1349, 1998. 27, 28

[81] J. Kim, Z. Wang, S. B. Heymsfield, R. N. Baumgartner, and D. Gallagher. Total-body skeletal muscle mass: estimation by a new dual-energy X-ray absorptiometry method. *The American Journal of Clinical Nutrition*, 76 (2):378–383, 2002. 28

[82] Z. Chen, Z. Wang, T. Lohman, S. B. Heymsfield, E. Outwater, J. S. Nicholas, T. Bassford, A. LaCroix, D. Sherrill, M. Punyanitya, G. Wu, and S. Going. Dual-Energy X-Ray Absorptiometry Is a Valid Tool for Assessing Skeletal Muscle Mass in Older Women. *Journal of Nutrition*, 137 (12):2775–2780, December 2007. 28

[83] J. M. Gaines and L. A. Talbot. Isokinetic strength testing in research and practice. *Biological Research For Nursing*, 1(1):57–64, 1999. 29, 31

[84] L. Ferrucci, J. M. Guralnik, D. Buchner, J. Kasper, S. E. Lamb, E. M. Simonsick, M. C. Corti, K. Bandeen-Roche, and L. P. Fried. Departures from linearity in the relationship between measures of muscular strength and physical performance of the lower extremities: the Women's Health and Aging Study. *The Journals of Gerontology Series A: Biological Sciences and Medical Sciences*, 52(5):M275–M285, 1997. 29, 130

[85] G. Onambélé-Pearson, M. V. Narici, and C. N. Maganaris. Calf muscle-tendon properties and postural balance in old age. *Journal of Applied Physiology*, 100(6):2048–2056, 2006. 29, 44, 95, 103, 108

[86] L. Z. Rubenstein. Falls in older people: epidemiology, risk factors and strategies for prevention. *Age and Ageing*, 35 Suppl 2(S2):ii37–ii41, 2006. 29

[87] E. Simoneau, A. Martin, M. M. Porter, and J. Van Hoecke. Strength training in old age: adaptation of antagonist muscles at the ankle joint. *Muscle nerve*, 33(4):546–555, 2006. 29, 34, 35, 88, 103, 111

[88] E. Simoneau, A. Martin, and J. Van Hoecke. Adaptations to long-term strength training of ankle joint muscles in old age. *European Journal of Applied Physiology*, 100(5):507–514, 2007. 29, 111

[89] J. Ochala, D. Lambertz, M. Pousson, F. Goubel, and J. Van Hoecke. Changes in mechanical properties of human plantar flexor muscles in ageing. *Experimental Gerontology*, 39(3):349–358, 2004. 29

[90] G. B. Salsich and M .J. Mueller. Effect of plantar flexor muscle stiffness on selected gait characteristics. *Gait and Posture*, 11(3):207–216, 2000. 29

[91] O. S. Mian, J. M. Thom, L. P. Ardigò, A. E. Minetti, and M. V. Narici. Gastrocnemius muscle-tendon behaviour during walking in young and older adults. *Acta Physiologica Scandinavica*, 189(1):57–65, 2007. 29, 31, 32, 33

[92] J. O. Judge, R. B. Davis, and S. Ounpuu. Step length reductions in advanced age: the role of ankle and hip kinetics. *The journals of gerontology. Series A, Biological sciences and medical sciences*, 51(6):M303–12, 1996. 29, 30

[93] D. A. Winter, A. E. Patla, J. S. Frank, and S. E. Walt. Biomechanical walking pattern changes in the fit and healthy elderly. *Physical therapy*, 70 (6):340–7, 1990. 29

[94] P. O. Riley, U. DellaCroce, and D. C. Kerrigan. Effect of age on lower extremity joint moment contributions to gait speed. *Gait & posture*, 14(3): 264–70, 2001. 29, 30

[95] P. DeVita and T. Hortobagyi. Age causes a redistribution of joint torques and powers during gait. *Journal of Applied Physiology*, 88(5):1804–1811, 2000. 29, 30

[96] Chris A. McGibbon. Toward a better understanding of gait changes with age and disablement: neuromuscular adaptation. *Exercise and sport sciences reviews*, 31(2):102–8, 2003. 29, 30

[97] D. C. Kerrigan, M. K. Todd, U. Della Croce, L. A. Lipsitz, and J. J. Collins. Biomechanical gait alterations independent of speed in the healthy elderly: evidence for specific limiting impairments. *Archives of physical medicine and rehabilitation*, 79(3):317–22, 1998. 30

[98] O. R. Seynnes, M. de Boer, and M. V. Narici. Early skeletal muscle hypertrophy and architectural changes in response to high-intensity resistance training. *Journal of Applied Physiology*, 102(1):368–373, 2007. 30, 115

[99] M. V. Narici, C. N. Maganaris, N. D. Reeves, and P. Capodaglio. Effect of aging on human muscle architecture. *Journal of applied physiology (Bethesda, Md. : 1985)*, 95(6):2229–34, 2003. 32

[100] M. V. Narici, C. Maganaris, and N. Reeves. Myotendinous alterations and effects of resistive loading in old age. *Scandinavian journal of medicine & science in sports*, 15(6):392–401, 2005. 32

[101] S. P. Magnusson, N. Beyer, H. Abrahamsen, P. Aagaard, K. Neergaard, and M. Kjaer. Increased Cross-sectional Area and Reduced Tensile Stress of the Achilles Tendon in Elderly Compared With Young Women. *The Journals of Gerontology Series A: Biological Sciences and Medical Sciences*, 58(2): B123–B127, 2003. 32

[102] N. D. Reeves, M. V. Narici, and C. N. Maganaris. In vivo human muscle structure and function: adaptations to resistance training in old age. *Experimental physiology*, 89(6):675–89, 2004. 33, 34

[103] J. Duclay, A. Martin, A. Duclay, G. Cometti, and M. Pousson. Behavior of fascicles and the myotendinous junction of human medial gastrocnemius following eccentric strength training. *Muscle & nerve*, 39(6):819–27, 2009. 33, 34

[104] S. K. Phillips, S. A. Bruce, D. Newton, and R. C. Woledge. The weakness of old age is not due to failure of muscle activation. *The Journals of Gerontology Series A: Biological Sciences and Medical Sciences*, 47(2):M45–M49, 1992. 34, 35, 95, 108

[105] C. A. Knight and G. Kamen. Adaptations in muscular activation of the knee extensor muscles with strength training in young and older adults. *Journal of Electromyography and Kinesiology*, 11(6):405–412, 2001. 34, 35, 49, 88, 95, 107, 108

[106] C. A. Knight and G. Kamen. Relationships between voluntary activation and motor unit firing rate during maximal voluntary contractions in young and older adults. *European Journal of Applied Physiology*, 103(6):625–630, 2008. 34, 35, 36, 49, 88, 95, 103, 107, 108

[107] J. A. Kent-Braun and A. V. Ng. Specific strength and voluntary muscle activation in young and elderly women and men. *Applied Physiology*, 87 (1):22–29, 1999. 34, 35, 95, 107, 108

[108] A. Shield and S. Zhou. Assessing voluntary muscle activation with the twitch interpolation technique. *Sports Medicine*, 34(4):253–267, 2004. 34, 37

[109] M. Q. Liu, F. C. Anderson, M. H. Schwartz, and S. L. Delp. Muscle contributions to support and progression over a range of walking speeds. *Journal of Biomechanics*, 41(15):3243–3252, 2008. 34, 93, 109, 114

[110] M. Q. Liu, F. C. Anderson, M. G. Pandy, and S.L. Delp. Muscles that support the body also modulate forward progression during walking. *Journal of Biomechanics*, 39(14):2623–30, 2006. 34, 109

[111] D. R. Bouchard, M. Héroux, and I. Janssen. Association between muscle mass, leg strength, and fat mass with physical function in older adults: influence of age and sex. *Journal Of Aging And Health*, 23(2):313–328, 2011. 36

[112] C. M. Arnold, K. D. Warkentin, P. D. Chilibeck, and C. R. A. Magnus. The reliability and validity of handheld dynamometry for the measurement of lower-extremity muscle strength in older adults. *The Journal of Strength & Conditioning Research*, 24(3):815–824, 2010. 36

[113] A. P. Marsh, W. J. Rejeski, M. A. Espeland, M. E. Miller, T. S. Church, R. A. Fielding, T. M. Gill, J. M. Guralnik, A. B. Newman, and M. Pahor. Muscle strength and BMI as predictors of major mobility disability in the Lifestyle Interventions and Independence for Elders pilot (LIFE-P). *The Journals of Gerontology Series A: Biological Sciences and Medical Sciences*, 66(12):1376–83, 2011. 36

[114] F. Lauretani, C. R. Russo, S. Bandinelli, B. Bartali, C. Cavazzini, A. Di Iorio, A. M. Corsi, T. Rantanen, J. M. Guralnik, and L. Ferrucci. Age-associated changes in skeletal muscles and their effect on mobility: an op-

erational diagnosis of sarcopenia. *Journal of Applied Physiology*, 95(5): 1851–1860, 2003. 37, 67, 87

[115] P. Painter, A. L. Stewart, and S. Carey. Physical functioning: definitions, measurement, and expectations. *Advances in Renal Replacement Therapy*, 6(2):110–23, 1999. 37

[116] P. Quadri, M. Tettamanti, S. Bernasconi, F. Trento, and F. Loew. Lower limb function as predictor of falls and loss of mobility with social repercussions one year after discharge among elderly inpatients. *Aging Clinical and Experimental Research*, 17(2):82–89, 2005. 37, 38

[117] L. Ferrucci, B. W. Penninx, S. G. Leveille, M. C. Corti, M. Pahor, R. Wallace, T. B. Harris, R. J. Havlik, and J. M. Guralnik. Characteristics of nondisabled older persons who perform poorly in objective tests of lower extremity function. *Journal of the American Geriatrics Society*, 48(9):1102–1110, 2000. 38

[118] S. P. Sayers, A. M. Jette, S. M. Haley, T. C. Heeren, J. M. Guralnik, and R. A. Fielding. Validation of the Late-Life Function and Disability Instrument. *Journal of the American Geriatrics Society*, 52(9):1554–1559, 2004. 38

[119] M. E. Tinetti. Performance-oriented assessment of mobility problems in elderly patients. *Journal of the American Geriatrics Society*, 34(2):119–126, 1986. 38

[120] S. R. Lord, H. B. Menz, and A. Tiedemann. A physiological profile approach to falls risk assessment and prevention. *Physical Therapy*, 83(3):237–252, 2003. 38

[121] R.W. Bohannon. Sit-to-stand test for measuring performance of lower extremity muscles. *Perceptual and Motor Skills*, 80(1), 1995. 38

[122] R.W. Bohannon. Test rig and software for recording force and muscle activity. *Clinical Rehabilitation*, 12(5):434–440, 1998. 38

[123] O. Eriksrud and R. W. Bohannon. Relationship of knee extension force to independence in sit-to-stand performance in patients receiving acute rehabilitation. *Physical Therapy*, 83(6):544–51, 2003. 38

[124] C. J. Jones, R. E. Rikli, and W. C. Beam. 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, 1999. 38, 39, 67

[125] S. L. Whitney, D. M. Wrisley, G. F. Marchetti, M. M. Gee, M. S. Redfern, and J. M. Furman. Clinical measurement of sit-to-stand performance in people with balance disorders: validity of data for the Five-Times-Sit-to-Stand Test. *Physical Therapy*, 85(10):1034–45, 2005. 38

[126] S. R. Lord, S. M. Murray, K. Chapman, B. Munro, and A. Tiedemann. Sit-to-Stand Performance Depends on Sensation , Speed , Balance , and Psychological Status in Addition to Strength in Older People. *The Journals of Gerontology Series A: Biological Sciences and Medical Sciences*, 57(8): 539–543, 2002. 39

[127] A. Khasnis and R. M. Gokula. Romberg's test. *Journal of Postgraduate Medicine*, 49(2):169–72, 2003. 39

[128] R. W. Bohannon, P. A. Larkin, A. C. Cook, J. Gear, and J. Singer. Decrease in timed balance test scores with aging. *Physical Therapy*, 64(7):1067–70, July 1984. 39, 67

[129] Y. Agrawal, J. P. Carey, H. J. Hoffman, D. A. Sklare, and M.C. Schubert. The modified Romberg Balance Test: normative data in U.S. adults. *Otology & Neurotology*, 32(8):1309–11, 2011. 39

[130] National Health and Nutrition Examination Survey. Balance Procedures Manual, 2001. URL `http://www.cdc.gov/nchs/data/nhanes/ba.pdf`. 39

[131] C. Y. Cho and G. Kamen. Detecting balance deficits in frequent fallers using clinical and quantitative evaluation tools. *Journal of the American Geriatrics Society*, 46(4):426–30, 1998. 39, 40, 67, 132

[132] M. Billot, E. M. Simoneau, J. Van Hoecke, and A. Martin. Age-related relative increases in electromyography activity and torque according to the maximal capacity during upright standing. *European Journal of Applied Physiology*, 109(4):669–680, 2010. 39, 40, 108, 110

[133] R A Dobie. Does computerized dynamic posturography help us care for our patients? *The American Journal of Otology*, 18(1):108–12, 1997. 40

[134] D. K. Heitmann, M. R. Gossman, S. A. Shaddeau, and J. R. Jackson. Balance performance and step width in noninstitutionalized, elderly, female fallers and nonfallers. *Physical Therapy*, 69(11):923–31, 1989. 40

[135] Y. Agrawal, J. P. Carey, C. C. Della Santina, M. C. Schubert, and L. B. Minor. Disorders of balance and vestibular function in US adults: data from the National Health and Nutrition Examination Survey, 2001-2004. *Archives of Internal Medicine*, 169(10):938–44, 2009. 40

[136] G. P. Jacobson, D. L. Mccaslin, E. G. Piker, J. Gruenwald, S. Grantham, and L. Tegel. Insensitivity of the "Romberg test of standing balance on firm and compliant support surfaces" to the results of caloric and VEMP tests. *Ear and Hearing*, 32(6):e1–5, 2011. 40

[137] E. Simoneau, A. Martin, and J. Van Hoecke. Muscular performances at the ankle joint in young and elderly men. *The Journals of Gerontology Series A: Biological Sciences and Medical Sciences*, 60(4):439–447, 2005. 40

[138] A. Shumway-Cook, S. Brauer, and M. Woollacott. Predicting the probability for falls in community-dwelling older adults using the Timed Up & Go Test. *Physical Therapy*, 80(9):896–903, 2000. 40, 132

[139] D. Podsiadlo and S. Richardson. The timed "Up & Go": a test of basic functional mobility for frail elderly persons. *Journal of the American Geriatrics Society*, 39(2):142–8, 1991. 40, 41, 66, 79

[140] H. A. Bischoff. Identifying a cut-off point for normal mobility: a comparison of the timed 'up and go' test in community-dwelling and institutionalised elderly women. *Age and Ageing*, 32(3):315–320, May 2003. 40, 66

[141] J. C. Wall, C. Bell, S. Campbell, and J. Davis. The Timed Get-up-and-Go test revisited: measurement of the component tasks. *Journal Of Rehabilitation Research And Development*, 37(1):109–113, 2000. 41, 66, 79

[142] R. W. Bohannon. Reference values for the timed up and go test: a descriptive meta-analysis. *Journal of Geriatric Physical Therapy*, 29(2):64–68, 2006. 41

[143] G. Scott, H. B. Menz, and L. Newcombe. Age-related differences in foot structure and function. *Gait and Posture*, 26(1):68–75, 2007. 41, 113

[144] C. Mecagni, J. P. Smith, K. E. Roberts, and S. B. O'Sullivan. Balance and ankle range of motion in community-dwelling women aged 64 to 87 years: a correlational study. *Physical Therapy*, 80(10):1004–1011, 2000. 41

[145] H. B. Menz, M. E. Morris, and S. R. Lord. Foot and ankle risk factors for falls in older people: a prospective study. *The Journals of Gerontology Series A: Biological Sciences and Medical Sciences*, 61(8):866–870, 2006. 41, 42, 93

[146] M. E. Daubney and E. G. Culham. Lower-extremity muscle force and balance performance in adults aged 65 years and older. *Physical Therapy*, 79(12):1177–1185, 1999. 41

[147] J. B. Feland, J. W. Myrer, S. S. Schulthies, G. W. Fellingham, and G. W. Measom. The effect of duration of stretching of the hamstring muscle group for increasing range of motion in people aged 65 years or older. *Physical Therapy*, 81(5):1110–1117, 2001. 41, 44, 48, 113, 128

[148] D. A. Klein, W. J. Stone, W. T. Phillips, J. Gangi, and S. Hartman. PNF training and physical function in assisted-living older adults. *Journal of Aging and Physical Activity*, 10(4):476–488, 2002. 42, 44

[149] F. Higgs and S. L. Winter. The effect of a four-week proprioceptive neuromuscular facilitation stretching program on isokinetic torque production. *The Journal of Strength and Conditioning Research*, 23(5):1442–1447, 2009. 42, 44, 48, 113, 114, 115, 128

[150] D. S. Davis, P. E. Ashby, K. L. McCale, J. A. McQuain, and J. M. Wine. The effectiveness of 3 stretching techniques on hamstring flexibility using consistent stretching parameters. *Journal of Strength & Conditioning Research*, 19(1):27–32, 2005. 42, 44, 48, 113, 114

[151] M. E. Maddigan, A. A. Peach, and D. G. Behm. A comparison of assisted and unassisted proprioceptive neuromuscular facilitation techniques and static stretching. *The Journal of Strength and Conditioning Research*, 26 (5):1238–44, 2012. 42, 44, 48, 90, 93, 94, 95, 113, 114, 128

[152] N. Kofotolis, I. S. Vrabas, E. Vamvakoudis, A. Papanikolaou, and K. Mandroukas. Proprioceptive neuromuscular facilitation training induced alterations in muscle fibre type and cross sectional area. *British Journal of Sports Medicine*, 39(3):e11, 2005. 42, 44, 48

[153] M. M. Gardner. Practical implementation of an exercise-based falls prevention programme. *Age and Ageing*, 30(1):77–83, 2001. 42

[154] J. Hudson, E. J. Oliver, L. Thomas, and F. Higgs. Functional and Psychological Changes During a Community Based 32 Week Postural Stability Training Programme: Recommendations for Future Practice. Technical report, Physical Activity in Ageing, Rehabilitation and Health Research Group Aberystwyth University, Department of Sport and Exercise Science and Betsi Cadwaladr University Health Board, Aberystwyth, Wales, 2012. 43, 44, 53, 59, 86, 87, 90

[155] C. Sherrington, J. C. Whitney, S. R. Lord, R. D. Herbert, R. G. Cumming, and J. C. T. Close. Effective exercise for the prevention of falls: a systematic review and meta-analysis. *Journal of the American Geriatrics Society*, 56 (12):2234–43, 2008. 43, 53

[156] C. Sherrington, A. Tiedemann, N. Fairhall, J. C. T. Close, and S. R. Lord. Exercise to prevent falls in older adults: an updated meta-analysis and best practice recommendations. *New South Wales Public Health Bulletin*, 22(3-4):78–83, 2011. 43, 53, 85

[157] L. D. Gillespie, M. C. Robertson, W. J. Gillespie, C. Sherrington, S. Gates, L. M. Clemson, and S. E. Lamb. Interventions for preventing falls in older people living in the community. *Cochrane Database of Systematic Reviews (Online)*, 9:CD007146, 2012. 43, 53, 54

[158] J. M. Simpson, R. Harrington, and N. Marsh. Guidelines for Managing Falls Among Elderly People. *Physiotherapy*, 84(4):173–177, 1998. 44, 93, 113

[159] P. Page. Current concepts in muscle stretching for exercise and rehabilitation. *International journal of sports physical therapy*, 7(1):109–19, 2012. 44, 45, 47, 48

[160] A. D. Kay and A. J. Blazevich. Effect of acute static stretch on maximal muscle performance: a systematic review. *Medicine and Science in Sports and Exercise*, 44(1):154–64, 2012. 44, 46, 47, 89, 94

[161] D. G. Behm and A. Chaouachi. A review of the acute effects of static and dynamic stretching on performance. *European Journal of Applied Physiology*, 111(11):2633–51, 2011. 44

[162] W. B. Young. The use of static stretching in warm-up for training and competition. *International Journal of Sports Physiology and Performance*, 2(2):212–6, 2007. 44, 46, 47

[163] Ni. Babault, B.Y. L. Kouassi, and K. Desbrosses. Acute effects of 15min static or contract-relax stretching modalities on plantar flexors neuromuscular properties. *Journal of Science and Medicine in Sport*, 13(2):247–252, 2010. 44, 48, 49, 50, 89, 94, 95, 108, 129, 130, 136

[164] M. J. Sharman, A. G. Cresswell, and S. Riek. Proprioceptive neuromuscular facilitation stretching : mechanisms and clinical implications. *Sports Medicine*, 36(11):929–939, 2006. 44

[165] L. R. Osternig, R. N. Robertson, R. K. Troxel, and P. Hansen. Differential responses to proprioceptive neuromuscular facilitation (PNF) stretch tech-

niques. *Medicine and Science in Sports and Exercise*, 22(1):106–111, 1990. 44, 47, 48, 95, 113, 128

[166] L. R. Osternig, R. Robertson, R. Troxel, and P. Hansen. Muscle activation during proprioceptive neuromuscular facilitation (PNF) stretching techniques. *American Journal of Physical Medicine*, 66(5):298–307, 1987. 44, 48, 113, 128

[167] N. N. Mahieu, A. Cools, B. De Wilde, M. Boon, and E. Witvrouw. Effect of proprioceptive neuromuscular facilitation stretching on the plantar flexor muscle-tendon tissue properties. *Scandinavian Journal of Medicine and Science in Sports*, 19(4):553–560, 2009. 44, 48, 50, 90, 94, 95, 113, 114, 115, 129

[168] S. M. Marek, J. T. Cramer, A. L. Fincher, L. L. Massey, S. M. Dangelmaier, S. Purkayastha, K. A. Fitz, and J. Y. Culbertson. Acute Effects of Static and Proprioceptive Neuromuscular Facilitation Stretching on Muscle Strength and Power Output. *Journal of Athletic Training*, 40(2):94–103, 2005. 44, 48, 90, 93, 94, 95, 113, 114, 115, 128

[169] R. L. Gajdosik, D. W. Vander Linden, P. J. McNair, T. J. Riggin, J. S. Albertson, D. J. Mattick, and J. C. Wegley. Viscoelastic properties of short calf muscle-tendon units of older women: effects of slow and fast passive dorsiflexion stretches in vivo. *European Journal of Applied Physiology*, 95 (2-3):131–139, 2005. 44, 93, 113

[170] A. G. Nelson, R. S. Chambers, C. M. McGown, and K .W. Penrose. Proprioceptive neuromuscular facilitation versus weight training for enhancement of muscular strength and athletic performance. *The Journal of Orthopaedic and Sports Physical Therapy*, 7(5):250–253, 1986. 45, 48

[171] P. Magnusson and P. Renström. The European College of Sports Sciences Position statement: The role of stretching exercises in sports. *European Journal of Sport Science*, 6(2):87–91, 2006. 46, 47

[172] M. P. McHugh and C. H. Cosgrave. To stretch or not to stretch: the role of stretching in injury prevention and performance. *Scandinavian Journal of Medicine and Science in Sports*, 20(2):169–181, 2010. 46, 47

[173] I. M. D. Shrier. Does Stretching Improve Performance?: A Systematic and Critical Review of the Literature. [Review]. *Clinical Journal of Sport Medicine*, 14(5):267–273, 2004. 46, 47

[174] E. C. Rubini, A. L. L. Costa, and P. S. C. Gomes. The effects of stretching on strength performance. *Sports Medicine*, 37(3):213–224, 2007. 46, 47

[175] J. B. Feland, J. W. Myrer, and R. M. Merrill. Acute changes in hamstring flexibility: PNF versus static stretch in senior athletes. *Physical Therapy in Sport*, 2(4):186–193, 2001. 47, 48, 49, 90, 93, 94, 113, 114, 128

[176] R. Ferber, L. Osternig, and D. Gravelle. Effect of PNF stretch techniques on knee flexor muscle EMG activity in older adults. *Journal of Electromyography and Kinesiology*, 12(5):391–397, 2002. 47, 48, 49, 90, 93, 94, 113, 114, 128

[177] N. Place, Y. Blum, S. Armand, N. A. Maffiuletti, and D. G. Behm. Effects of a Short Proprioceptive Neuromuscular Facilitation Stretching Bout on Quadriceps Neuromuscular Function, Flexibility, and Vertical Jump Performance. *The Journal of Strength and Conditioning Research*, 27(2), 2013. 48, 49, 50, 95

[178] S. S Rees, A. J Murphy, M. L Watsford, K. A McLachlan, and A. J Coutts. Effects of proprioceptive neuromuscular facilitation stretching on stiffness and force-producing characteristics of the ankle in active women. *Journal of Strength and Conditioning Research*, 21(2):572–7, 2007. 50, 90, 94, 95, 113, 114, 115, 128, 129, 130, 140

[179] D. Oliver, F. Daly, F. C. Martin, and M. E. T. McMurdo. Risk factors and risk assessment tools for falls in hospital in-patients: a systematic review. *Age and Ageing*, 33(2):122–130, 2004. 53

[180] L. Letts, J. Moreland, J. Richardson, L. Coman, M. Edwards, K. M. Ginis, S. Wilkins, and L. Wishart. The physical environment as a fall risk factor in older adults: Systematic review and meta-analysis of cross-sectional and cohort studies. *Australian Occupational Therapy Journal*, 57(1):51–64, 2010. 53

[181] P. M. Wayne, D. P. Kiel, D. E. Krebs, R. B. Davis, J. Savetsky-German, M. Connelly, and J. E. Buring. The effects of Tai Chi on bone mineral density in postmenopausal women: a systematic review. *Archives of Physical Medicine and Rehabilitation*, 88(5):673–80, 2007. 54

[182] H. Huang, C. Liu, Y. Huang, and W. G. Kernohan. Community-based interventions to reduce falls among older adults in Taiwan - long time follow-up randomised controlled study. *Journal of Clinical Nursing*, 19(7-8):959–68, 2010. 54

[183] M. C. Hornbrook, V. J. Stevens, D. J. Wingfield, J. F. Hollis, M. R. Greenlick, and M. G. Ory. Preventing Falls Among Community-Dwelling Older Persons: Results From a Randomized Trial. *The Gerontologist*, 34(1):16–23, 1994. 54

[184] A. Shumway-Cook, W. Gruber, M. Baldwin, and S. Liao. The effect of multidimensional exercises on balance, mobility, and fall risk in community-dwelling older adults. *Physical Therapy*, 77(1):46–57, 1997. 54, 60, 138

[185] B. E. Maki, K. C-C. Cheng, A. Mansfield, C. Y. Scovil, S. D. Perry, A. L. Peters, S. McKay, T. Lee, A. Marquis, P. Corbeil, G.R. Fernie, B. Liu, and W. E. McIlroy. Preventing falls in older adults: new interventions to promote more effective change-in-support balance reactions. *Journal of Electromyography and Kinesiology*, 18(2):243–54, 2008. 54

[186] J. Davison, J. Bond, P. Dawson, I. N. Steen, and R. A. Kenny. Patients with recurrent falls attending Accident & Emergency benefit from multifactorial intervention–a randomised controlled trial. *Age and Ageing*, 34(2):162–8, 2005. 59

[187] A. J. Campbell, M. C. Robertson, M. M. Gardner, R. N. Norton, M. W. Tilyard, and D. M. Buchner. Randomised controlled trial of a general practice programme of home based exercise to prevent falls in elderly women. *British Medical Journal (Clinical research ed.)*, 315(7115):1065–9, 1997. 59, 60, 136, 138

[188] M. C. Robertson, N. Devlin, M. M. Gardner, and A. J. Campbell. Effectiveness and economic evaluation of a nurse delivered home exercise programme to prevent falls. 1: Randomised controlled trial. *British Medical Journal (Clinical research ed.)*, 322(7288):697–701, 2001. 59

[189] S. L. Wolf, H. X. Barnhart, N. G. Kutner, E. McNeely, C. Coogler, and T. Xu. Reducing frailty and falls in older persons: an investigation of Tai Chi and computerized balance training. Atlanta FICSIT Group. Frailty and Injuries: Cooperative Studies of Intervention Techniques. *Journal of the American Geriatrics Society*, 44(5):489–97, 1996. 59

[190] T. Liu-Ambrose, M. G. Donaldson, Y. Ahamed, P. Graf, W. L. Cook, J. Close, S. R. Lord, and K. M. Khan. Otago home-based strength and balance retraining improves executive functioning in older fallers: a randomized controlled trial. *Journal of the American Geriatrics Society*, 56 (10):1821–1830, 2008. 59, 89

[191] C. Sherrington and S. R. Lord. Home exercise to improve strength and walking velocity after hip fracture: a randomized controlled trial. Technical Report 2, Bankstown-Lidcombe Hospital, Randwick, New South Wales, Australia., 1997. 60, 138

[192] M. C. Robertson, N. Devlin, P. Scuffham, M. M. Gardner, D. M. Buchner, and A. J. Campbell. Economic evaluation of a community based exercise programme to prevent falls. *Journal of Epidemiology and Community Health*, 55(8):600–606, 2001. 60

[193] S. Thomas, S. Mackintosh, and J. Halbert. Does the 'Otago exercise programme' reduce mortality and falls in older adults?: a systematic review and meta-analysis. *Age and Ageing*, 39(6):681–7, 2010. 60, 138

[194] M. M. Gardner, M. Phty, M. C. Robertson, R. McGee, and A. J. Campbell. Application of a falls prevention program for older people to primary health care practice. *Preventive Medicine*, 34(5):546–53, 2002. 60

[195] WMA General Assembly. World Medical Association Declaration of Helsinki. Technical Report June 1964, 1964. 63

[196] T. D. Collins, S. N. Ghoussayni, D. J. Ewins, and J. A. Kent. A six degrees-of-freedom marker set for gait analysis: Repeatability and comparison with a modified Helen Hayes set. *Gait and Posture*, 30(2):173–180, 2009. 71

[197] A. L. Bell, R. A. Brand, and D. R. Pedersen. Prediction of hip joint centre location from external landmarks. *Human Movement Science*, 8(1):3–16, 1989. 71

[198] J. Hertel, L.C. Olmsted-Kramer, and J. H. Challis. Time-to-boundary measures of postural control during single leg quiet standing. *Journal of Applied Biomechanics*, 22(1):67–73, 2006. 72, 73, 89

[199] J. Hertel and L.C. Olmsted-Kramer. Deficits in time-to-boundary measures of postural control with chronic ankle instability. *Gait and Posture*, 25(1): 33–39, 2007. 72, 73, 89

[200] J. D. Moreland, J. A. Richardson, C. H. Goldsmith, and C. M. Clase. Muscle weakness and falls in older adults: a systematic review and meta-analysis. *Journal of the American Geriatrics Society*, 52(7):1121–9, 2004. 87

[201] D. R. Taaffe, C. Duret, S. Wheeler, and R. Marcus. Once-weekly resistance exercise improves muscle strength and neuromuscular performance in older adults. *Journal of the American Geriatrics Society*, 47(10):1208–14, 1999. 88

[202] R. Orr, J. Raymond, and M. A. Fiatarone Singh. Efficacy of Progressive Resistance Training on Balance Performance in Older Adults. *Sports Medicine*, 38(4):317–343, 2008. 89

[203] J. R. Fowles, D. G. Sale, and J. D. MacDougall. Reduced strength after passive stretch of the human plantarflexors. *Journal of Applied Physiology*, 89(3):1179–1188, 2000. 89, 94, 96, 103

[204] G. S. Trajano, L. Seitz, K. Nosaka, and A. J. Blazevich. Contribution of central vs. peripheral factors to the force loss induced by passive stretch of the human plantar flexors. *Journal of Applied Physiology*, 115(2):212–8, 2013. 89, 94, 96

[205] R. Ferber, D. C. Gravelle, and L. R. Osternig. Effect of proprioceptive neuromuscular facilitation stretch techniques on trained and untrained older adults. *Journal of Aging and Physical Activity*, (10):132–142, 2002. 90, 93, 94, 113, 114, 128

[206] G. Chalmers. Re-examination of the possible role of Golgi tendon organ and muscle spindle reflexes in proprioceptive neuromuscular facilitation muscle stretching. *Sports Biomechanics*, 3(1):159–183, 2004. 90, 94, 95, 114, 129

[207] Y. Kawakami, H. Kanehisa, and T. Fukunaga. The relationship between passive ankle plantar flexion joint torque and gastrocnemius muscle and achilles tendon stiffness: implications for flexibility. *The Journal of Orthopaedic and Sports Physical Therapy*, 38(5):269–76, 2008. 94

[208] C. I. Morse, H. Degens, O. R. Seynnes, C. N. Maganaris, and D. A. Jones. The acute effect of stretching on the passive stiffness of the human gastrocnemius muscle tendon unit. *The Journal of Physiology*, 586(1):97–106, 2008. 94

[209] Hylton B Menz, Meg E Morris, and Stephen R Lord. Foot and ankle characteristics associated with impaired balance and functional ability in older people. *The journals of gerontology Series A Biological sciences and medical sciences*, 60(12):1546–1552, 2005. 95

[210] C. I. Morse, J. M. Thom, M. G. Davis, K. R. Fox, K. M. Birch, and M. V. Narici. Reduced plantarflexor specific torque in the elderly is associated with a lower activation capacity. *European Journal Of Applied Physiology*, 92(1-2):219–26, 2004. 95, 96, 108, 109, 110, 111, 131

[211] R. E. McAtee and J. Charland. *Facilitated stretching.* Human Kinetics, Champaign, IL, 3 edition, 2007. 101, 119

[212] D. G. Behm, D. M. St-Pierre, and D. Perez. Muscle inactivation: assessment of interpolated twitch technique. *Journal of Applied Physiology*, 81(5):2267–2273, 1996. 103

[213] Carrie A Laughton, Mary Slavin, Kunal Katdare, Lee Nolan, Jonathan F Bean, D Casey Kerrigan, Edward Phillips, Lewis A Lipsitz, and James J Collins. Aging, muscle activity, and balance control: physiologic changes associated with balance impairment. *Gait and Posture*, 18(2):101–108, 2003. 110

[214] G. Grimby. Muscle performance and structure in the elderly as studied cross-sectionally and longitudinally. *The Journals of Gerontology Series A: Biological Sciences and Medical Sciences*, 50 Spec No:17–22, 1995. 110

[215] M. M. Nordlund, A. Thorstensson, and A. G. Cresswell. Central and peripheral contributions to fatigue in relation to level of activation during repeated maximal voluntary isometric plantar flexions. *Journal of Applied Physiology*, 96(1):218–225, 2004. 111

[216] Emilie Simoneau, Alain Martin, and Jacques Van Hoecke. Effects of joint angle and age on ankle dorsi- and plantar-flexor strength. *Journal of Electromyography and Kinesiology*, 17(3):307–316, 2007. 111

[217] J. Wicke, K. Gainey, and M. Figueroa. A comparison of self-administered proprioceptive neuromuscular facilitation to static stretching on range of motion and flexibility (In Press). *The Journal of Strength & Conditioning Research*, 2013. 113, 114, 115, 128

[218] M. A. Alnaqeeb and G. Goldspink. Changes in fibre type, number and diameter in developing and ageing skeletal muscle. *Journal of Anatomy*, 153(1962):31–45, 1987. 113

[219] V. Kovanen, H. Suominen, and E. Heikkinen. Mechanical properties of fast and slow skeletal muscle with special reference to collagen and endurance training. *Journal of Biomechanics*, 17(10):725–735, 1984. 113

[220] D. G. Thelen, A. B. Schultz, N. B. Alexander, and J. A. Ashton-Miller. Effects of Age on Rapid Ankle Torque Development. *The Journals of Gerontology Series A: Biological Sciences and Medical Sciences*, 51A(5): M226–M232, 1996. 113

[221] D. M. Buchner, E. B. Larson, E. H. Wagner, T. D. Koepsell, and B. J. De Lateur. Evidence for a Non-linear Relationship between Leg Strength and Gait Speed. *Age and Ageing*, 25(5):386–391, 1996. 115

[222] S. R. Lord, D. G. Lloyd, and S. Keung Li. Sensori-motor Function, Gait Patterns and Falls in Community-dwelling Women. *Age and Ageing*, 25(4): 292–299, July 1996. ISSN 0002-0729. doi: 10.1093/ageing/25.4.292. 115

[223] A. M. Holmbäck, M. M. Porter, D. Downham, and J. Lexell. Reliability of isokinetic ankle dorsiflexor strength measurements in healthy young men and women. *Scandinavian Journal of Rehabilitation Medicine*, 31(4):229–239, 1999. 118

[224] I . S. Hwang and L. D. Abraham. Quantitative EMG analysis to investigate synergistic coactivation of ankle and knee muscles during isokinetic ankle movement. Part 1: time amplitude analysis. *Journal of Electromyography and Kinesiology*, 11(5):319–325, 2001. 118

[225] T. B. Symons, A. A. Vandervoort, C. L. Rice, T. J. Overend, and G. D. Marsh. Effects of Maximal Isometric and Isokinetic Resistance Training on Strength and Functional Mobility in Older Adults. *The Journals of Gerontology Series A: Biological Sciences and Medical Sciences*, 60(6):777–781, 2005. 129

[226] V. Kumar, A. Selby, D. Rankin, R. Patel, P. Atherton, W. Hildebrandt, J. Williams, K. Smith, O. Seynnes, N. Hiscock, and M. J. Rennie. Age-related differences in the doseresponse relationship of muscle protein synthe-

sis to resistance exercise in young and old men. *The Journal of Physiology*, 587(1):211–217, 2009. 130

[227] O. Seynnes, M. A. Fiatarone Singh, O. Hue, P. Pras, P. Legros, and P. L. Bernard. Physiological and Functional Responses to Low-Moderate Versus High-Intensity Progressive Resistance Training in Frail Elders. *The Journals of Gerontology Series A: Biological Sciences and Medical Sciences*, 59 (5):M503–M509, 2004. 130

[228] N. J. de Vos, N. A. Singh, D. A. Ross, T. M. Stavrinos, R. Orr, and M. A. Fiatarone Singh. Optimal Load for Increasing Muscle Power During Explosive Resistance Training in Older Adults. *The Journals of Gerontology Series A: Biological Sciences and Medical Sciences*, 60(5):638–647, 2005. 130, 138

[229] C. E. Garber, B. Blissmer, M. R. Deschenes, B. A. Franklin, M. J. Lamonte, I. Lee, D. C. Nieman, and D. P. Swain. Quantity and Quality of Exercise for Developing and Maintaining Cardiorespiratory, Musculoskeletal, and Neuromotor Fitness in Apparently Healthy Adults: Guidance for Prescribing Exercise. *Medicine and Science in Sports and Exercise*, 43(7): 1334–1359, 2011. 131

[230] K. Delbaere, G. Crombez, G. Vanderstraeten, T. Willems, and D Cambier. Fear-related avoidance of activities, falls and physical frailty. A prospective community-based cohort study. *Age and ageing*, 33(4):368–73, 2004. 137

[231] A. J. Davies and R. A. Kenny. Falls Presenting to the Accident and Emergency Department: Types of Presentation and Risk Factor Profile. *Age and Ageing*, 25(5):362–366, 1996. 137

[232] M. Visser. Low Vitamin D and High Parathyroid Hormone Levels as Determinants of Loss of Muscle Strength and Muscle Mass (Sarcopenia): The Longitudinal Aging Study Amsterdam. *Journal of Clinical Endocrinology & Metabolism*, 88(12):5766–5772, 2003. 137

[233] Neural factors versus hypertrophy in the time course of muscle strength gain. *American journal of physical medicine*, 58(3):115–30, 1979. 138