Implications for Falls Prevention of Lifetime Physical Activity and Control of Gait, Posture and Balance in Older Adults

Rachel Wright

A thesis submitted in partial fulfilment of the requirements for the Degree of Doctor of Philosophy

February 2009

Coventry University in collaboration with the University of Worcester

Abstract

Falls and fall-related injuries are among the most common, serious, and medically-expensive problems facing the growing older population. Regular physical activity has been proposed to reduce falls, but no research has examined the efficacy of compliance with official recommended amounts of physical activity over the adult life-course and falls in community dwelling older adults. From the development and implementation of a new questionnaire to assess guideline related lifetime physical activity levels and falls history with a sample of 314 community-dwelling older adults, it was identified that lifetime adherence to the 2004 Department of Health physical activity guidelines offered no protective benefit for reduction in falls, fear of falling or fall outcome.

A sub-sample of the 314 participants was then invited to participate in three laboratory investigations. Biomechanical measures of stability were utilised in studies investigating quiet standing, straight line walking and performing a 360º standing turn with groups of young adults (n = 15), older non-fallers (n = 15), older single fallers (max n = 13) and older multiple fallers (n = 14). During standing, young adults placed their centre of mass (COM) anterior to their centre of pressure (COP), whilst older adults primarily placed their COM posterior to their COP. There were no differences between faller groups and it was therefore concluded that quiet standing was not a challenging enough task to differentiate faller status. During walking, multiple fallers displayed greater COM-COP separation than the non-fallers and single fallers, and greater COM acceleration than the non-fallers at heel strike in the antero-posterior direction thus identifying both measures as capable of

differentiating between faller status groups in similar populations. At the initiation of the 360º standing turn, multiple fallers demonstrated a significantly shorter latency between reorientation onset of the thorax and the pelvis compared to all the other groups and thus exhibited a more en-bloc strategy of turning. Therefore, the onset of body segment reorientation was identified as capable of differentiating between fallers and non-fallers in otherwise healthy, community dwelling older adults.

Discussion of and conclusions drawn from the findings of the four empirical studies identify the need for future research to identify more appropriate falls-related physical activity recommendations for public health messages for adults, and recommend the use of biomechanical variables such as COM-COP separation, COM acceleration and the assessment of segment reorientation in future falls-related research and as outcome measures for the efficacy of physical activity intervention programmes for fall prevention.

Acknowledgments

I would like to thank my Director of Studies Derek Peters, my supervisors Paul Robinson and Mark Hollands, and my advisor Tom Watt for all their support for this study. I would also like to thank the Motion Analysis Research & Rehabilitation Centre for match-funding this Ph.D. project, and for the members of staff within the centre who gave me assistance. I would like to thank the staff and students of the Graduate Research School for support and friendship. In particularly, I would like to thank my office colleague, Berni, for the support, laughs, friendship and great taste in music. Most of all, I would like to thank Joe and my family.

Declaration

I declare that this thesis is a presentation of my original research work and all the written work and investigations are entirely my own. Wherever contributions of others are involved, this is clearly acknowledged and referenced.

I declare that no portion of the work referred to in this thesis has been submitted for another degree or qualification of any comparable award at this or any other university or other institution of learning.

Rachel Wright

February 2009

Table of Contents

List of Tables

List of Figures

List of Definitions

Physical activity – any bodily movement produced by skeletal muscles that results in energy expenditure (Caspersen *et al.* 1985).

Exercise – physical activity that is planned, structured and repetitive with the aim to improve or maintain one or more components of physical fitness (Caspersen *et al.* 1985). Exercise is, therefore, a subset of physical activity and is incorporated under physical activity in this thesis.

Moderate intensity – any physical activity with an energy cost of 3-6 metabolic equivalents (Pate *et al.* 1995).

Fall – a loss of balance resulting in the body, or part of the body, coming to rest on the ground (Nowalk *et al.* 2001; Jensen *et al.* 2002).

Non-faller – a participant who did not report any falls on their questionnaire response. Participants who later took part in the laboratory testing were asked whether they had any falls between completing the questionnaire and testing to check whether they were still eligible for this group.

Single faller – a participant who reported one fall on their questionnaire response. Participants who later took part in the laboratory testing were asked whether they had any falls between completing the questionnaire and testing to check whether they were still eligible for this group.

Multiple faller – a participant who reported more than one fall on their questionnaire response.

Centre of mass (COM) – the point equivalent of the total body mass in the global reference system (Winter, 1995b)

Centre of pressure (COP) – the point location of the ground reaction force vector and representative of a weighted average of all the pressures over the surface of area in contact with the ground (Winter, 1995a).

Chapter 1: Introduction

1.1 Rationale

The older adult population is rapidly increasing all over the World, particularly in developed nations. There was an increase in those of pensionable age from 18.3 to 18.7% of the population in England and Wales between 1985 and 2005, and this is predicted to rise to 23.9% by 2025 (Office for National Statistics, 2006). Statistics from Australia show the annual growth rate of those aged 60-99 years old over the last 45 years has been 2.1% (Richmond, 2008), and the number of people aged 65 years and over in the USA is estimated to reach 70 million by the year 2030 (Mazzeo *et al.* 1998). As a result of these increases in the ageing population and with increased life expectancy of retirees (WHO Regional Office for Europe, 2008), the importance of maintaining mobility has become ever more critical (Winter, 1995a).

Falls and fall-related injuries are among the most serious and common medical problems experienced by the older population. In a 12-month period during 1999, there were over 640 000 attendances at hospital accident and emergency departments by people aged 60 and over in the UK, with over 200 000 of these leading to hospital admission and over 4800 fatalities (Scuffham *et al.* 2003). These figures are only representative of those seeking hospital treatment, and approximately one-third of community-dwelling people aged 65 and over have been reported to fall at least once a year (Tinetti *et al.* 1988), with women appearing more likely than men to have a fall (de Rekeneire *et al.* 2003). In non-fatal falls, almost half of all fallers are unable to get up without help (Tinetti *et al.* 1993), and nearly one-third of falls in community dwelling older adults have been reported to produce pain lasting for 2 or more days

(Berg *et al.* 1997). With an increasing ageing population, these statistics signify a major concern for health professionals.

The total cost of falls in the UK population aged 60 and over in 1999 was £981 million; 59% of this was incurred by the National Health Service and the remainder by the Personal Social Services for long term care (Scuffham *et al.* 2003). This represents a considerable economic impact of falls in older persons. Based on year 2000 prices, the cost per 10 000 population in the 60-64 age group was £300 000, increasing to £1 500 000 in the 75 and over age group (Scuffham *et al.* 2003). This is the most recent data published on the costs of falls in the UK, but with inflation it can be assumed that this financial cost has increased each year.

A 5% fracture rate has been observed as an outcome of falling (Berg *et al.* 1997) and one of the most serious outcomes of a fall is a hip fracture (Hayes *et al.* 1996). Although hip fracture only occurs in about 1% of falls (Tinetti *et al.* 1988), over 90% of hip fractures are associated with falls (Grisso *et al.* 1991). Approximately 40% of hip fractures occur from a fall during walking with a further 18% occurring from a fall during turning (Nevitt and Cummings, 1993). A six- to sevenfold increase in the risk of death has also been observed in male hip fracture cases compared with population controls, with the majority of deaths occurring in the first year after fracture (Pande *et al.* 2006). This mortality rate increased with increasing age with 100% survival reported if the hip fracture occurred in the 5th decade, but dropping to 50% survival if the fracture occurred in the 7th decade. There were also significant reductions in function, with only 36% of patients being able to walk independently 12 months after fracture (Pande *et al.* 2006).

Falls that do not result in physical injury can still have serious consequences. The loss of confidence in mobility tasks and fear of falling are commonly reported in older people (Hill *et al.* 1996), with 43% of community-dwelling older adults reporting a fear of falling (Tinetti *et al.* 1994). In a study conducted in Australia, older women were prepared to trade off considerable length of life to avoid the reduction in the quality of life that is associated with a bad hip fracture (Salkeld *et al.* 2000). Most noticeably, 80% of the respondents stated they would rather be dead than experience the loss of independence and quality of life that could result from a bad hip fracture and subsequent admission to a nursing home (Salkeld *et al.* 2000). However, the conclusions from this study should not be interpreted as older women would prefer death to treatment in the event of a hip fracture; rather that older women place a very high marginal value on their health. These findings imply that it is important for intervention and rehabilitation programmes to focus not only on enhancing mobility but also to optimise the ability to live independently and partake in social activities.

Many studies, therefore, indicate that falls are a frequent event in the older population. This provides a significant cost implication for the health services. In addition, falls represent a major concern for the older population as shown through fear of falling and also fear of the loss of independence associated with a bad hip fracture.

1.2. Physical activity recommendations

The recommendations for physical activity for health in the United Kingdom state that a minimum of 30 minutes of at least moderate intensity exercise on at least 5 days of the week are recommended for health benefits (Department of Health, 2004b). This is consistent with recommendations from other health organisations (Department of Health and Ageing, 1999; Swiss Federal Office of Sports *et al.* 2000; World Health Organization *et al.* 2003). These recommendations are predominantly believed to provide protection against conditions such as cardiovascular disease, type II diabetes, cancer and obesity. Regular physical activity has been proposed as one method of preventing falls and therefore fall-related injuries in older adults (Kannus, 1999). Physical activity interventions have also been investigated with the aim of reducing the risk factors associated with falling (Lord *et al.* 1995; Lan *et al.* 1998; Li *et al.* 2004). It has also been estimated that if the whole population adopted the physical activity recommendations, health care costs for hip fractures alone could be reduced by 50% (Nicholl *et al.* 1994). However, most studies have investigated the effects of physical activity on risk factors for falls rather than falls themselves, and no studies have evaluated the impact of lifetime adherence to physical activity recommendations on fall occurrence.

The assessment of lifetime physical activity is key to the identification of aetiologically relevant prior age periods for disease risk as well as the optimum duration, intensity, and frequency of regular lifetime activity (Chasan-Taber *et al.* 2002). Any study investigating lifetime physical activity in current older adults, out of necessity, invariably involves information gathered retrospectively in the form of self-reports (Dawson *et al.* 2003). Retrospective methods of this nature present limitations in terms of accuracy and reliability as they rely on the ability to recall, so they may not be suitable for all groups of older adults. However, unless a study group is assessed on a regular basis, which may have feasibility issues and also will not present older adult data for many years, recall is the only option available to many researchers.

Of the recall options available to the researcher, the physical activity questionnaire remains one of the most feasible and cost-effective methods for assessing physical activity in the epidemiological context (Livingstone *et al.* 2001). Whilst self-administered questionnaires are believed to be less precise than those that are administered by an interviewer (Montoye and Taylor, 1984), interviews can take 1-1.5 hours to administer, which makes them less practical when using large sample numbers. Therefore, the questionnaire becomes an important and most appropriate tool when using large study populations.

Few physical activity questionnaires have been investigated and validated in exclusively elderly populations. Many questionnaires used in epidemiological studies have been developed predominantly using younger, male populations, making it unclear if the same questionnaires can distinguish levels of activity in older and/or female populations (Slattery, 1996). In addition, few questionnaires are designed to assess physical activity for a time period of longer than 1 year. Therefore, these questionnaires are unable to provide information of historical physical activity and are of greater use in current habitual physical activity studies.

The first questionnaire designed to assess lifetime activity was the Historical Leisure Activity Questionnaire (Kriska *et al.* 1988), which was an interviewer administered design and aimed initially at women. This questionnaire focussed on leisure time physical activity, but did not include either occupational or household activity.

Although this questionnaire was subsequently modified to include occupational activity (Kriska *et al.* 1990), this questionnaire may still underestimate physical activity levels due to the exclusion of household activity, particularly in females (Livingstone *et al.* 2001). This questionnaire was subsequently modified to be self-administered (Chasan-Taber *et al.* 2002; Daly and Bass, 2006) and has been shown to be highly reproducible in this form for both total activity and activities of different intensities and types (Chasan-Taber *et al.* 2002). The modifications included adding questions about household activity. However, this reliability study by Chasan-Taber *et al* was only conducted in women aged 39-65 years, so may not be as reproducible in men or older adults. The resultant questionnaire from these modifications was a physical activity grid, which looks complex and may be daunting to complete. The detail required about individual activities may be difficult to recall, and may be in excess of what is required to gain an insight into health enhancing physical activity levels. As health benefits generally depend on the amount of activity performed as opposed to the individual types of activity, a questionnaire that includes a global assessment of activity is useful in epidemiological studies (Shephard, 2003).

The Lifetime Total Physical Activity Questionnaire (LTPAQ) was designed to cover lifetime occupational, household and sporting activities and was aimed at women (Friedenreich *et al.* 1998). The questionnaire was designed to be interview-administered rather than self-administered, and requires interviewers trained in cognitive interviewing methods. This increases the collection time required and adds training costs to any study using this questionnaire, so it is less practical for epidemiological studies using large participant numbers. The questionnaire focuses on intensity and duration of activities, which may have assisted recall as the specifics of every activity were not required in detail. However, the detail required for duration may have been too specific to recall accurately as hours and minutes were requested. This questionnaire was designed and tested on women, but possibly could be adapted for use with men as well with further research to assess validity and repeatability.

The Swedish Mammography Cohort Physical Activity Questionnaire (SMC-PAQ) was designed to estimate current (past year) as well a historical physical activity (Orsini *et al.* 2007). The historical physical activity data was collected for three age points – 15, 30 and 50 years old. The SMC-PAQ, like the LTPAQ, was also designed to cover occupational, leisure-time and household activity and was also aimed at women. The SMC-PAQ has the advantage over the LTPAQ of being self-administered increasing the practicality of the tool for large epidemiological studies, however the questions may still be too specific for accurate recall of activity levels.

These historical physical activity questionnaires are not specifically designed to investigate adherence to recognised physical activity recommendations, and currently there are no tools to investigate adherence to these recommendations in a historical/lifetime sense. Nor have these tools been developed with physical activity's relationship to falls as the objective. Therefore, there is a need for an instrument that can address these areas.

1.3. Measures of stability in older adults

Human bipedal stance is inherently unstable because a large body mass is kept in an erect posture with its centre of mass (COM) high above a relatively small base of support. Although this standing posture is potentially unstable, control mechanisms allow this stance to be maintained (Winter, 1995b). Postural stability during standing has been intensely investigated in relation to ageing and to fall risk. This research has generated considerable understanding of balance control and led to the development of several clinical and laboratory tests that are used in falls research.

Several clinical tests for balance and mobility have been designed to try and identify those at an increased risk of falling. These include the Performance Orientated Mobility Assessment (Tinetti, 1986), the Berg Balance Scale (Berg *et al.* 1989), the Physical Performance test (Reubens and Siu, 1990), the Timed-Up-and-Go (Podsiadlo and Richardson, 1991), the Multiple Tasks test (Bloem *et al.* 2001), and the Stops Talking when Walking test (Lundin-Olsson *et al.* 1997; de Hoon *et al.* 2003). In brief, these assessment tools involve tasks of balance and movement such as standing balance, standing with eyes closed, arising from a chair, retrieving an object from the floor and turning. The ability to perform these tasks is then rated by the tester or clinician. However, in healthy community-dwelling women the Berg Balance Scale appeared to have a ceiling effect showing limited predictive ability for falling in higher functioning individuals (Brauer *et al.* 2000), and was considered not sensitive enough to uncover factors that contributed to falls in active older adults (Boulgarides *et al.* 2003). So, although clinical tests of balance function are able to provide an indication of balance abilities, they are limited in the ability to detect subtle changes in postural stability and identify mechanisms of dysfunction (Brauer *et al.* 2000). This inability to detect subtle changes limits the uses of clinical balance measures in investigations into balance in healthy, physically active, community-dwelling adults, some of whom fall. The alternative to the use of such insensitive clinical assessment is the use of laboratory-based assessments, which can provide information regarding control processes and age-related biomechanical changes relevant to balance.

Many laboratory studies have relied solely on force plate measures (Thapa *et al.* 1994; Collins *et al.* 1995; Brauer *et al.* 2000; Hue *et al.* 2004; Bryant *et al.* 2005). These studies have suggested that there are increased centre of pressure (COP) sway paths in the sagittal plane in older adults compared to young adults (Laughton *et al.* 2003). However, standing balance has not been investigated in depth between groups of fallers and non-fallers in the elderly. In addition, measures of the relationship between the COM and the COP generate more useful information about the balance control systems than COP measures alone (Winter, 1995b; Yu *et al.* 2008).

Although the COM-COP relationship has been investigated in terms of balance, few published studies have compared the COM-COP separation variable between young adults and healthy older adults (Berger *et al.* 2005a; Masani *et al.* 2007), and only one (Berger *et al.* 2005b) has investigated the COM-COP relationship in different faller groups in community dwelling older persons, the majority of whom were entirely sedentary.

Stability is further challenged during walking as the area of the base of support is reduced during the swing phase when only one foot is in contact with the ground. Furthermore, walking is fundamentally unstable as the double support phase is the only part of the gait cycle where the COM is not located outside the base of support (Winter, 1995a) and this double support phase only comprises approximately 20% of the gait cycle. Dynamic stability during walking is achieved by integrating sensory inputs from the visual, vestibular and proprioceptive systems with adequate muscle strength, appropriate neuromuscular timing and free passive joint mobility (Prince *et al.* 1997). Any age-related degeneration of one or more of these sensory systems could compromise balance during gait. Therefore, the identification of gait parameters that are associated with balance control may lead to greater understanding of balance dysfunction and increased fall risk in the older population (Helbostad and Moe-Nilssen, 2003).

The majority of previous work concerning stability when walking has focussed on temporo-spatial parameters, such as gait speed, stride length and time spent in double support. These studies have shown that significant changes occur in these parameters with increasing age (Oberg *et al.* 1993; Bohannon, 1997; Blanc *et al.* 1999), increasing frailty (Kressig *et al.* 2004) and that these changes are associated with falls (Auvinet *et al.* 2003; Brach *et al.* 2005; Ko *et al.* 2007). These gait changes have been suggested to result from older adults adopting a more cautious walking pattern (Maki, 1997; Kaya *et al.* 1998; Menz *et al.* 2003; Cromwell and Newton, 2004; Chamberlin *et al.* 2005), but ironically these same changes have also been associated with increased risk of falling (Tinetti *et al.* 1986; Lipsitz *et al.* 1991; Montero-Odasso *et al.* 2004; Montero-Odasso *et al.* 2005). This paradox occurs because these temporo-spatial measures, although providing useful summary information about gait, only provide an indirect measure of stability. For example, although a slower walking speed may appear to be a compensatory strategy for balance during locomotion (Menz *et al.* 2003), a slower walking velocity has also been shown as a predictor for new falls in older adults (Montero-Odasso *et al.* 2005).

It may be more informative to investigate more direct measures of stability during walking than temporo-spatial parameters, such as COM and COP measures. Previous research has shown that peak anterior COM-COP separation is decreased in older people compared with young adults (Hahn and Chou, 2004), but there have been no comparisons made between older adults with and without a history of falling for these measures.

Most falls occur during locomotion (Keegan *et al.* 2004; Li *et al.* 2006), therefore it is important to develop a greater understanding of gait and the underlying control mechanisms that govern dynamic stability. Although the temporo-spatial characteristics have been widely investigated in terms of increasing age (Oberg *et al.* 1993; Bohannon, 1997; Blanc *et al.* 1999) and in terms of fall risk and frailty in older adults (Maki, 1997; Auvinet *et al.* 2003; Kressig *et al.* 2004; Brach *et al.* 2005; Ko *et al.* 2007), there has only been limited research conducted on more direct measures of dynamics stability during walking and often straight line walking has been considered only in reference to obstacle crossing in relation to falls in older persons (Chou *et al.* 2003; Hahn and Chou, 2004; Lee and Chou, 2006).

The mechanisms involved in turning have been largely overlooked in biomechanical research. This is despite the fact that turning steps make up 35-45% of the steps involved in common everyday tasks (Glaister *et al.* 2007). Staggering when turning has been reported to be a prominent characteristic of recurrent fallers (Tinetti *et al.* 1986), and those who are unsteady during turning are more likely to fall whilst executing a turn (Topper *et al.* 1993). From a fall outcome standpoint, individuals who fall during turning are around 8 times more likely to fracture their hip than those who fall when walking in a straight line (Cumming and Klineberg, 1994) demonstrating that falls whilst turning present a major health concern. This high fracture rate resulting from a fall when turning highlights the need to develop a better understanding of the biomechanics involved in balance control during turning to further advance knowledge about fall risk during activities of daily living.

Assessment of standing turn performance is considered of value in predicting potential fall risk in older adults (Meinhart-Shibata *et al.* 2005), and as a result has been included in many clinical tests. The 360º standing turn forms part of two regularly used clinical assessment tools for assessing balance in older persons (Tinetti, 1986; Berg *et al.* 1989), with a longer turn time and a greater number of steps associated with an increased risk of falling (Lipsitz *et al.* 1991). Despite these research findings and the widespread use of these clinical tests, the 360º standing turn has been largely ignored in biomechanical assessment particularly in terms of normal movement, changes that may be associated with increasing age, and changes that may be associated with the increased risk of experiencing a fall.

The mechanisms for stability in static and dynamic conditions have therefore previously been investigated in healthy, young adults (Nashner and Mccollum, 1985; Jian *et al.* 1993; Winter, 1995b; Hollands *et al.* 2001) and in comparison with older adults (Hahn and Chou, 2004; Berger *et al.* 2005a). These studies have provided useful information on the systems used to control upright posture, and how the changes associated with increasing age may impact on the ability of these systems to control balance. However, it remains to be determined whether changes associated with increasing age are more pronounced in those individuals who experience one or more falls, and whether tests based on those changes may be used in identification of those at risk of falling who may then benefit from specific falls prevention programmes.

There is an urgent need for increased understanding of the potential benefits of an active lifestyle for falls prevention, and for greater understanding of deficiencies that exist in the older, community-dwelling populations that may have relevance to the aetiology of falls and implications for falls prevention strategies. Research investigating the potential benefits of leading a physically active lifestyle in direct relation to the levels recommended for health and the subsequent reduced likelihood of experiencing a fall is needed to assess whether the recommendations are appropriate for falls prevention. In addition, research on the biomechanics of selected physical tasks is needed to quantify impairment magnitudes associated with ageing and fall risk, to determine which elements are critical to the impairment, and ultimately to make recommendations that could help design more effective intervention measures for falls prevention in the community-dwelling older population.

1.4. Thesis aims

The purpose of this thesis was to investigate whether achievement of recommended levels of physical activity over the life course reduces fall occurrence, and to advance the understanding of the mechanisms involved in decreased stability that put some older adults at increased risk of falling.

The specific aims of this thesis therefore were to:

1. design a new tool to measure retrospectively the long-term adherence to current physical activity recommendations issued by the Department of Health in the United Kingdom
2. evaluate whether lifetime adherence to current physical activity recommendations for health have a preventative effect against falls in community-dwelling older persons
3. consider whether there are differences in stability measures in upright erect standing associated with age and with fall status
4. investigate whether there are differences in the dynamic stability of walking associated with age and with fall status
5. assess whether there are any differences in dynamic stability of turning and turning strategy associated with age and fall status
6. make recommendations based on this work for related future research and to make suggestions for physical activity guidelines specifically aimed to reduce the risk of falling.

1.5. Thesis structure

In order to realise the above stated aims, the thesis has been structured in the following manner:

A theoretical section examines the development of physical activity recommendations for health, lifetime and current physical activity levels, and the possible associated decrease in fall risk relating to higher levels of activity (chapter 2). This is followed by an experimental chapter assessing retrospective physical activity levels with specific reference to the current recommendations for health, and self-reported history of falls (chapter 3). A second theoretical section considers the mechanisms of stability involved in the tasks of standing, walking and turning (chapter 4). This is followed by experimental work investigating stability during the tasks of standing balance, overground walking and turning in groups of non-fallers, single fallers, multiple fallers and young controls (chapters 5-7). The methods from these stability studies are presented in chapter 5, the results from these laboratory studies are presented in chapter 6 and the findings are discussed in chapter 7. These chapters will be followed with a final concluding overview (chapter 8).

Chapter 2: Physical activity and falls: review of literature

2.1. Development of physical activity recommendations

Physical activity has been advised for health benefits since the days of Hippocrates over 2000 years ago (Karvonen, 1996; Paffenbarger, Jr. *et al.* 2001). In the late 1800s, after studies involving rowers in the Harvard-Yale boat race, it was concluded that the average athlete lived considerably longer than the normal expectation (Park, 1997). Despite these observations, the medical communities in the United States and Europe were very conservative in their attitude towards physical activity in adults from around 1925-1960 (Holloszy, 1983). Interest was generated in occupational physical activity when individuals in physically active jobs appeared to be less likely to suffer from coronary heart disease than those in sedentary jobs (Morris *et al.* 1953), and this led to the systematic research on the relationship between physical activity and health that occurred in the second half of the 20th century and into the 21st century. The American College of Sports Medicine (ACSM) was an early leader in providing recommendations specifically for physical activity in the mid-1970s (Blair and Connelly, 1996). These guidelines stated that 15-60 minutes of physical activity at 60-90% of heart rate reserve on 3-5 days per week was required to develop and maintain cardiorespiratory fitness and body composition in healthy adults (American College of Sports Medicine, 1978). These recommendations were based on improving performance-related fitness levels rather than purely on health benefits, and were the result of studies that had predominantly focused on vigorous intensity physical activity to improve fitness in groups of young, healthy men. This led to the misconception that any physical activity not meeting this specific criteria was of limited or no value (Blair *et al.* 2004).

Since this early position stand from the ACSM, more research has been conducted on the effect on health of different levels of physical activity intensity in less healthy individuals. Findings from these studies led to the 1993 position stand regarding physical activity and hypertension from the ACSM which indicated that intensities of 40-70% $\dot{V}O_{2max}$ reduce blood pressure as much as higher intensity activity (American College of Sports Medicine, 1993). This demonstrated a paradigm shift towards activity recommendations for both performance- and health-related outcomes rather than exclusively performance-related fitness.

In 1995, a landmark paper was published by the ACSM. New recommendations were introduced which indicated that in order to achieve health benefits, adults were to accumulate 30 minutes or more of moderate intensity physical activity on most, preferably all, days of the week (Pate *et al.* 1995). Moderate intensity was defined as any activity with an energy cost of 3-6 metabolic equivalents (METs) and these new recommendations were intended to complement not supersede the previous recommendations. These recommendations marked a shift from the traditional fitness based to a more health-related focus. This was also the first time that *moderate* rather than *vigorous* levels of physical activity intensity were recommended in a position statement, as well as the first time intermittent activity was accepted. Many studies have investigated the benefits of continuous physical activity, but the accumulation of activity has also been identified as important for public health policy. The minimum length of each session of physical activity has been suggested to be 10 minutes (DeBusk *et al.* 1990). In 1996, the Department of Health in the UK introduced the recommendation of achieving 30 minutes of moderate intensity physical activity on at least 5 days of the week (Department of Health, 1996). These are consistent with the physical activity recommendations in Australia (Department of Health and Ageing, 1999), Switzerland (Swiss Federal Office of Sports *et al.* 2000) and from the World Health Organisation (World Health Organization *et al.* 2003).

The ACSM and the American Heart Association (AHA) have recently updated their recommendations to "all healthy adults aged 18-65 years need moderate-intensity aerobic physical activity for a minimum of 30 minutes on five days each week or vigorous-intensity aerobic activity for a minimum of 20 minutes on three days each week" (Haskell *et al.* 2007). Combinations of these activity types can also be performed to meet recommendations. These updated recommendations provide clarity to the 1995 ACSM recommendations by identifying 5 days a week to be the minimum number of days in which moderate intensity physical activity should be achieved. This is consistent with the recommendations from the UK. These new ACSM guidelines are also much more explicit in their wording. The recommendations also state that "adults will benefit from performing activities that maintain or increase muscular strength and endurance for a minimum of two days each week" (Haskell *et al.* 2007). This is the first time that muscle strengthening activity has been explicitly incorporated into physical activity guidelines.

These aerobic and muscle strengthening guidelines also apply to adults aged 65 and over, however the guidelines for this age group also incorporate a description of how these activities should be applied due to the heterogeneity of fitness levels in older adults (Nelson *et al.* 2007). In practice, this means that the recommendations are applied in prescriptive as opposed to absolute terms. In addition, older adults are also advised to incorporate flexibility exercises for at least 10 minutes on at least 2 days of the week and to perform exercises to maintain or improve balance (Nelson *et al.* 2007).

The focus of physical activity guidelines therefore, has shifted from fitness benefits to health benefits, which makes them applicable to populations as a whole rather than just those who wish to increase performance. It is therefore important not only to have recommendations in place, but also to assess physical activity levels within populations who attempt to adhere to these recommendations and to investigate their impact upon subsequent ill-health events. The remainder of this literature review will consider the evidence relating to population adherence to the physical activity guidelines, and also on fall occurrence, fear of falling, fall outcomes and the potential benefits of physical activity for falls prevention.

2.2 Physical activity levels in England

The most detailed study of physical activity in the population in England was the Allied Dunbar national fitness survey (Sports Council and Health Education Authority, 1992). This was a cross-sectional study focusing predominately on activity performed in the 4 weeks prior to interview, although the study also incorporated some historical questions. Of the study population as a whole (n = 4316), 49% of the men and 41% of the women had engaged in vigorous or moderate activity lasting 20 minutes or more on at least 12 occasions in the previous 4 weeks. There was a consistent decline in participation in vigorous activity with increasing age; however levels of light and moderate activity were consistent across the age bands based on the classification criteria. The findings suggested that home activities were the main way in which people were moderately active, emphasising the necessity for these activities to be included in any assessment of activity levels.

Data from the Allied Dunbar Fitness Survey from respondents aged 50 and over was reanalysed alongside data from the Health Education Authority National Survey of Activity and Health (combined n = 3078) in a report for the Health Education Authority (Skelton *et al.* 1999). This report re-defined moderate intensity physical activity based on age, e.g. in respondents aged 75+ moderate intensity was defined as activity of at least 4 $kcal.min^{-1}$ as opposed to 5 $kcal.min^{-1}$ in respondents aged 50-69. The re-definition of moderate intensity was to reflect that maximal exercise intensity declines in old age, and therefore scaled moderate intensity to reflect this age-related decline. In the sample population aged 50+, of those free from immobilising disease, 30% of men and 19% of women were considered frequently active.

Data from England using the current physical activity guideline criteria (30 mins of moderate intensity activity on at least 5 $days.week^{-1}$) showed that in the 16-74 years age range, 31.4% of the sample population (n = 3189) were active enough in 1995 (Hillsdon *et al.* 2001). However, based on the same representative cohort, this had dropped to 21.6% by 1997. This was despite a public awareness campaign promoting physical activity for health. There was a split by age; a greater percentage in the 16-44 age group achieved the recommendations than the 45-74 age band. However, the younger age group showed a larger decline in those active between 1995 and 1997 (37.0% to 22.8%) than the older age group (26.9% to 20.6%). This demonstrates a worrying decrease in the proportion of the population engaged in enough activity recommended for health benefits.

Cross-sectional reports by the Department of Health also show this consistent decline in the number of people achieving the physical activity recommendations and an increase in the number of people completely inactive with increasing age (Department of Health, 1999; Department of Health, 2004a). These reports show a decline in the number of people achieving the recommendations between 1998 and 2003 (table 2.1). The percentage of men achieving the recommendations dropped from 40 to 37% and women from 26% to 24%. The trends in men and women across the age bands were different. In the 16-24 age band, over 50% of the men achieved the recommendations and these levels then decreased with each chronological age band. In contrast 30-35% of the women achieved the recommendations in the 16-24 age band and this level remained consistent around the 30-35% until the 55-64 age group where it then declined continually until the final 75+ age group.

Table 2.1. Percentage of adults achieving physical activity recommendations, by sex and age group

		Age							
		16-24	**25-34**	**35-44**	**45-54**	**55-64**	**65-74**	**75+**	**Total**
1998	**Men**	62	52	46	39	32	17	7	40
	Women	35	34	34	31	22	12	4	26
2003	**Men**	53	44	41	38	32	17	8	37
	Women	30	29	30	31	23	13	3	24

Source: Department of Health (1999, 2004a)

These population studies show that generally less than half, and often less than a third (depending on the population groups of interest) of adults are engaged in sufficient physical activity for health benefits based on current recommendations. Of greater concern is that fewer and fewer adults are achieving these recommendations, which could have implications for health provision in the future.

2.3 Physical activity levels elsewhere in the World

When the figures for physical activity in England are compared with other studies from around the World, the declining levels observed with increasing age have also been detected in other population studies (Crespo *et al.* 1996; Livingstone *et al.* 2001; Chad *et al.* 2005; Muntner *et al.* 2005). This is particularly noticeable in men for whom the downward shift in occupational activity with increasing age is not compensated by an increase in leisure time or household activities. Therefore, these areas need to be targeted in future drives to increase habitual physical activity to offset the decline in occupational activity.

More than one-third of the population (aged 50 and over) assessed in a Swiss study reported that they did not take part in any sports nor achieved the recommended levels of habitual physical activity (Meyer *et al.* 2005), however this study did not appear to account for any occupational or household activities. A study in the USA found that only 32% of the sample population (aged 25-64 years) achieved physical activity recommendations (Jones *et al.* 1998), but again this only accounted for leisure time activities. This is in contrast to a study of Chinese adults (aged 35-74 years) which found 66.3% of the sample population to be physically active based on the physical activity recommendations (Muntner *et al.* 2005). This study did include occupational activity which may have accounted for a substantial portion of this difference. This is supported by the data when split into rural and urban populations where 78.1% of the rural population and 21.8% of the urban population was physically active – which is mirrored by the occupational physical activity data. The occupational, as opposed to leisure time physical activity, was the main contributor to the achievement of the recommendations in this rural Chinese population, and demonstrates the need for occupational data to be included in an study of physical activity. In Australia, 50.9% of the population in the 18-75 age range was estimated to be sufficiently active in 1997, although this had declined to 45.2% in 1999 (Bauman *et al.* 2003) mirroring the decline in activity levels observed in England. In Japan, 68.7% of men and 76.2% of women aged 40-70 spent less than 1 hour per week in sport or physical activity (Kurozawa *et al.* 2005), although no information was given on occupational or household activity. However, 49.4% of men and 50.7% of women spent over an hour a day walking and when this data was combined only 13.0% of men and 11.9% of women spent less than 30 minutes a day walking and less than 2 hours a week in any sport or physical activity. This demonstrates the importance of incorporating walking in any assessment of habitual physical activity levels.

Based on these studies, the proportion of the population in England achieving physical activity recommendations appears to lie between the American and Australian figures, although admittedly the American figures did not include occupational activity. These values are much lower than for China and Japan, which may show a cultural difference in the approach to activity, e.g. daily Tai Chi is a cultural norm in some regions (Hong Kong Sports Development Board, 2002). Although the urban population in China were less active than these Western Hemisphere figures, nearly 80% of the population live in rural locations, suggesting that declines in occupational activity either with increasing age or increasing urbanisation could have a major impact on this Chinese rural population's ability to attain sufficient physical activity.

In a study conducted in Ireland, it was found that men were twice as active in occupational and leisure-time activities, while women were three times more active in household pursuits (Livingstone *et al.* 2001). This may account for the disparities between men and women in studies that did not incorporate household pursuits in their assessments of physical activity levels (Crespo *et al.* 1996; Jones *et al.* 1998; Meyer *et al.* 2005). This highlights the importance of incorporating all types of physical activity in any study of population levels to obtain a true reflection of physical activity and to attain a thorough understanding of the epidemiology of health conditions.

These studies highlight that the adherence to sufficient physical activity based on current recommendations for health is relatively low. The trend also suggests that adherence is steadily decreasing. Occupational and household activities also need to be included in any assessment of physical activity, as the exclusion of these could underestimate the time spent in moderate or higher intensity activity. Only when these activities are accounted for in population studies can more valid levels of habitual physical activity be reported. Strategies can then be implemented to reduce inactivity and the implications of inactivity on health issues, such a falling in older people, can be explored.

2.4 Falls

There are several definitions for a fall in use in research papers. A fall has been defined simply as a sudden, unintentional change in position causing the victim to land on the ground (Nowalk *et al.* 2001; Jensen *et al.* 2002). A slight variant on this definition is as an event where an individual unintentionally comes to rest on the ground or other lower level, however if the individual comes to rest against furniture or a wall this is not defined as a fall (Bischoff *et al.* 2001; Campbell *et al.* 1999; Steinberg *et al.* 2000). This has been expanded on by stating that if the fall was caused by a major intrinsic event (such as a stroke) or overwhelming hazard (Lord *et al.* 1995; Lord and Clark, 1996; Close *et al.* 1999; Lajoie and Gallagher, 2004) that it should be classified differently as a 'hazard-related' fall. This is an important distinction, as these hazard-related falls may need environmental assessment for prevention rather than programmes related to physical activity or age-related changes that may have occurred.

The use of a fall definition relative to the particular aspect of interest of a study has its attractions. However, the use of more than one definition for falls in the literature makes comparisons between studies difficult. This is particularly important when intervention are being investigated that use falls (or lack of falls) as an outcome measure. It has been suggested that the wording of a falls definition could be one of the reasons that different fall rates are reported in similar populations (Lamb *et al.* 2005) and that future intervention studies should use a definition that is simple and can easily be understood by the people who document their falls (Hauer *et al.* 2006). A definition that is simple to understand is also of use in retrospective studies, as details of falls in the past may be difficult to recall (Cummings *et al.* 1988). Therefore, the use of a definition that simply states a fall to be a sudden, unintentional change in position causing the individual to land on the ground (Nowalk *et al.* 2001; Jensen *et al.* 2002) could be used for both retrospective and intervention studies.

A key concern in falls prevention is not simply the high incidence of falls in older persons (young children and athletes have an even higher incidence of falls) but rather the combination of high incidence and a high susceptibility to injury that is present in some older adults (American Geriatrics Society *et al.* 2001). A recent report in England found that 23% of men and 29% of women over the age of 65 had fallen at least once in the previous 12 months (Department of Health, 2007). The incidence of falls rises steadily with increasing age, but men report fewer falls than women until the aged 85+ category.

These data from England are slightly lower than the 32% of community-dwelling older adults reported to fall at least once a year in the USA (Tinetti *et al.* 1988), but very similar to the 27.7% reported in a more recent US study (Friedman *et al.* 2002). The fall rate over one year in another US study was 52% in a group of community-dwelling individuals aged 60-88 (Berg *et al.* 1997). This is significantly higher than both the data from England and from the Tinetti *et al.* and Friedman *et al.* studies, which may be due to the relatively small sample size of 96 for this type of study, and also that potential bias may exist in a volunteer sample. Berg *et al.* (1997) also found similar fall rates for men and women which could indicate a different pattern for falling in the USA to England, although there were fewer men than women involved, which also could have impacted on the findings.

Falls have been reported to occur at home more often than away from home (58 and 42% respectively), although falls at home were more likely to occur outdoors than indoors (Berg *et al.* 1997). This could be due to more hazardous terrain being encountered outdoors than indoors. Women have been reported to be more likely to fall within the home, whilst men have been reported to be more likely to fall in their garden (Campbell *et al.* 1990; Berg *et al.* 1997). Most of these falls occurred during periods of maximum activity in the morning or afternoon. As most of these falls are occurring during the daytime as opposed to at night, this suggests that physical movement is reduced in darker environments, or that low light levels are not a major factor in the majority of falls in older people. This could be partly explained by the reliance on vision for balance control increasing up to the age of 65, after which the role of vision in balance control declines (Lord and Ward, 1994). Falls have also been reported as occurring most commonly during walking (Berg *et al.* 1997; Keegan *et al.* 2004), suggesting that balance mechanisms during locomotion are important to understand for falls prevention.

Recent Department of Health data from England reported that 23% of men and 34% of women had required medical treatment after a fall (Department of Health, 2007). Fractures occurred in 5% of falls in a one-year study, with a further 9% of falls resulting in a soft tissue injury requiring medical attention (Berg *et al.* 1997). These are very similar to the findings of Tinetti *et al.* (1988) who reported that 24% of those who fell suffered serious injury, and 6% of falls resulted in fracture. If a quarter to a third of falls result in medical treatment, falls present a major financial cost to the healthcare system. This underlines the need for identification of those at risk of falling (either as a first or repeat occurrence), lifestyle habits that might either increase or decrease the likelihood of falling, and preventative measures to reduce the incidence of falls.

2.5 Physical activity history and falls

Few studies have investigated the potential relationship between habitual physical activity and fall incidence. However, studies have investigated relationships between habitual physical activity and factors such as strength, proprioception and balance which are all related to fall risk. These studies have investigated active and non-active populations as well as specific activity types.

When falls were investigated as an outcome measure, elderly women who reported regular activity in sports before the age of 40 had fewer falls than those who were less active (Bischoff *et al.* 2001). However, regular activity was only defined as "at least once weekly", which is below the current physical activity guidelines, and no occupational or household activity was accounted for. Despite these limitations, the findings give strong indications that an active lifestyle may be beneficial in reducing fall risk in later life. Although there were differences in fall incidence, no functional differences were observed, which were assessed using the Timed Up and Go (Podsiadlo and Richardson, 1991).

A prospective analysis study followed a group of post-menopausal registered nurses (n = 61 200) over a period of 12 years (Feskanich *et al.* 2002). The participants reported the number of hours per week they spent in different activities. The results suggested that this group were fairly sedentary, with the median total activity being 7 MET-hours.week^{-1}, with walking being the most popular activity. The women with 24 MET-hours.week^{-1} or more physical activity had a 55% lower hip fracture risk than those in the less than 3 MET-hours.week^{-1} of physical activity category. However, no data was given about fall occurrence or the incidence of other fall-related injury. So although a higher habitual level of physical activity appears to have benefits for hip fracture prevention, it is unclear whether this was due to a lower risk of falling in the first place or whether the higher activity level offered more protection against hip fracture in the event of a fall.

Tai Chi is one of the most commonly investigated forms of physical activity in relation to older populations. Long-term Tai Chi practitioners have been shown to have superior balance control and flexibility compared to sedentary non-practitioners (Hong *et al.* 2000). Although there were no details of any fall history presented in this study, balance is one of the components required for postural control. When Tai Chi practitioners were compared to active non-practitioners, the groups were similar in simple tests of balance but the Tai Chi practitioners were significantly better in more complex balance tasks (Lin *et al.* 2000; Wong *et al.* 2001). None of the participants had fallen in the 12 and 3 months prior to testing in the respective two studies, but no details were given for any previous falls history prior to that time, nor was any link made between the data and any potential future fall risk. However, these studies suggest that long-term Tai Chi practitioners may be better adapted to more testing environments that may challenge postural stability. Elderly Tai Chi practitioners have better knee joint proprioception and greater limits of stability than healthy non-practitioners (Tsang and Hui-Chan, 2003). Further study by the same authors found that the knee joint proprioception and limits of stability of elderly Tai Chi practitioners and elderly golfers, but not elderly controls, was comparable to young controls (Tsang and Hui-Chan, 2004). This similarity between golfers and Tai Chi practitioners may be due to the weight shifting nature of both activities and the requirement in both activities of the maintenance of balance and precise control of the posture of the head and body in relation to space. The practical implications for these findings relate to the relative participation levels in these activities in different countries. Whereas in regions such as Hong Kong and Taiwan, there may be much greater participation in Tai Chi, in the Western hemisphere habitual Tai Chi is less common but the practice of golf is widespread. As there are known ageing effects in these measures of sensorimotor function (Skinner *et al.* 1984; King *et al.* 1994; Gilsing *et al.* 1995; Tsang and Hui-Chan, 2004) utilised by Tsang & Hui-Chan (2003, 2004), the finding that older people who participate in either of the two forms of activity identified have comparable function to young adults is worthy of further investigation in relation to falls prevention.

A population of elderly women from an urban background who had been physically active for at least 20 years was compared with two control populations from the same background and a rural community (Ringsberg *et al.* 2001). The women were classified as active if they had participated in physical activity classes for at least 1 hour per week as opposed to relating activity to health recommendations. Despite the criteria for *active* being quite low, the active women had significantly greater quadriceps and grip strength, balance and gait speed than the urban control group. Quadriceps strength is important for stability during gait as they contribute to vertical support during the first half of stance as they slow forward progression of the body (Liu *et al.* 2006). The differences were not so apparent between the active women and the rural women, though this may be due to different methods adopted for these two groups due to test location practicalities or possibly due to the fact that no occupational activity was considered when classifying the participants as active or not active. Even if these women classified as active had not achieved physical activity recommendations throughout their lifetime, however, they were still demonstrating benefits from some physical activity that may reduce fall risk and maintain functional performance.

Lifetime physical activity was correlated with bone mineral density in postmenopausal women (Kriska *et al.* 1988) and in men aged 50 and over (Florindo *et al.* 2004). Although bone mineral density is not a factor in fall risk, decreased bone mineral density is a risk factor for fractures that could be the outcome of a fall. Therefore, habitual physical activity, physical activity recommendations that specifically include activities related to bone health, and intervention programmes that decrease the risk factors for fractures as well as reducing the risk of a fall occurring are worthy of further investigation.

2.6 Physical activity interventions and falls

In addition to physical activity history, research has been conducted into specific physical activity programmes, normally in the form of structured exercise, as intervention measures to reduce the risk of falling. As with the historical studies, falls themselves have often not been the outcome measure, and many of these studies have used measures of balance, gait and strength as indicators of success.

Of the studies that have used falls as an outcome measure, a 12-month general physical activity programme incorporating aerobic, strengthening and balance exercises did not result in any significant differences in fall rates between the physical activity and control groups in the follow-up period (Lord *et al.* 1995). However, there was a trend for participants who attended 75% or more of the classes experiencing fewer falls than those who attended less than 75% of the classes and the control group. As the physical activity classes were held twice weekly, it is possible that more frequent sessions, in line with physical activity recommendations, may have resulted in a significant reduction in fall occurrence. A 2-year home-based physical activity programme resulted in lower fall rates in women over 80 compared to a control group, as well as lower hazard rates for a moderate or serious injury (Campbell *et al.* 1999). This type of programme has the advantage in that it is home-based and therefore not dependent on services such as transport and local facilities. However, a home-based programme lacks a social element and may have lower adherence rates (Taylor *et al.* 2004). There were significantly fewer falls in a Tai Chi group than a stretching programme control group in the 6-month post-intervention follow-up after a 6-month intervention programme (Li *et al.* 2004), and a statistically significant 44% reduction in injurious falls after a 12-month Tai Chi intervention compared to the control group (Lin *et al.* 2006). There was a 25% reduction in falls in participants who participated in a 12-month intervention including strength, balance and flexibility exercises compared to a control group, although this reduction was not statistically significant (Shumway-Cook *et al.* 2007). A meta-analysis of intervention studies suggests that programmes that include balance training are important for the efficacy of an intervention (Sherrington *et al.* 2008). This may partly explain why Tai Chi has proved a successful activity for falls prevention studies as this modality involves a substantial balance training element.

There are some reports, however, that suggest increased physical activity can actually increase the risk of falls. In a study utilising brisk walking as an intervention to reduce osteoporotic fractures, there was a significantly higher fall rate in the walking group in the first 12 months (Ebrahim *et al.* 1997). However, despite the number of falls being higher in the walking group than the control group, the fracture rates were the same. In addition, during the following 12 months, the rate of falls had dropped below that of the control group, although the result was not significant. The definition of "brisk walking" in this study is vague; it is possible that initially the walking speed was at a pace that the participants found difficult to maintain postural control and therefore increased the likelihood of a fall. Once a training effect had been imparted, the risk of falling decreased, as can be seen by the lower rate of falls in the second year. Walking is also associated with a decreased risk of fracture in post-menopausal women (Feskanich *et al.* 2002) and a lower risk of cognitive decline in elderly women (Yaffe *et al.* 2001), therefore is clearly an important mode of activity. However, care has to be exercised when prescribing activity so as not to place individuals at a significantly increased risk of falling due to increased or inappropriate physical activity modality or intensity.

These studies suggest that physical activity intervention programmes have variable success in reducing the incidence of fall occurrence, and indicate that falls themselves are able to be used as an outcome measure in programmes of this nature. However, as falls are multifactorial in nature (Tinetti, 2003) it may not be that surprising that intervention related reductions in falls are not always statistically significant, particularly in the short-term (6-12 months). So it is important with these intervention studies to not only use falls as an outcome measure but also to utilise measures of balance, strength and mobility as secondary outcome measures, as these are associated with an increased risk of experiencing a fall and also will provide useful information on the functional changes that have occurred that may contribute to any decreased fall risk.

Of the studies that have investigated other outcome measures, Tai Chi is the most frequently investigated form of physical activity intervention programme. Six-month Tai Chi interventions have resulted in improved functional balance compared to baseline (Li *et al.* 2004), and increased concentric and eccentric strength of the knee extensors (Lan *et al.* 2000). These strength increases may have implications for activities of daily living such as rising from a chair and also stability during gait. However, the internal validity of Lan *et al.*'s study was weakened by the lack of a control group which may be due to it only being a pilot study. A 20-week Tai Chi intervention resulted in improvements in force control (Christou *et al.* 2003), which may result in more accurate body movements. A 12-month Tai Chi programme resulted in improved cardiorespiratory function, strength and flexibility compared to baseline, whilst a control group showed no changes (Lan *et al.* 1998). These studies demonstrate that Tai Chi is of value as an intervention tool for both increasing strength and balance ability which are associated with fewer falls and with lower fall occurrence as well.

Of the intervention studies that have used alternatives to Tai Chi, a 12-month general physical activity programme resulted in improved strength and reaction time compared to baseline (Lord *et al.* 1995). A 20-week community-based physical activity programme incorporating strength, postural and stretching exercise resulted in improved knee extensor strength and increased gait speed around a figure-eight circuit in a group of older women with osteoporosis (Carter *et al.* 2002). Another 20-week physical activity intervention class incorporating balance, strength, trunk stability and flexibility exercises resulted in significant improvements in balance measures and in the strength of the hip muscle, the quadriceps and the trunk extensors in community-dwelling women with osteopenia (Hourigan *et al.* 2008). A 16-week home-based intervention programme incorporating, balance, aerobic, strength and flexibility exercises improved performance on mobility tests and strength in the musculature of the ankle and reduced fear of falling (Delbaere *et al.* 2006a). A 10-week feasibility study using tango dancing resulted in gains in muscle strength demonstrated through sit-to-stand measures (McKinley *et al.* 2008). Intervention studies are often difficult to compare for efficacy as they utilise different intervention lengths, different frequencies of classes and different outcome measures. Research is needed to identify the minimum frequency and duration of intervention programmes to assess the efficacy for reducing fall risk. In addition to using falls themselves as an outcome measure, other outcome measures that are sensitive enough to discriminate between fallers and non-fallers in both healthy and frail older populations warrant further investigation. This would allow standardisation of these research trials and therefore the comparison of the relative merits of different physical activity programmes in different groups of older adults. The studies conducted to date do, however, show that significant improvements can be made through physical activity interventions that can modify associated risk factors for falling as well as reduce the associated fear of falling. The use of physical activity as a means to curb the number of falls in older people therefore warrants further attention.

Adherence to physical activity interventions is an important factor to consider when proposing the value of the programme in reducing falls and fall risk. The drop-out rate from one 12-month Tai Chi study was 26.9% (Lan *et al.* 1998). The compliance rate from a home-based physical activity programme after 2 years was 44% (Campbell *et al.* 1999), but as the population group were all over 80 this relatively low compliance rate after such a time period is perhaps unsurprising. A drop-out rate of only 12% was reported in a 20-week intervention study (Hourigan *et al.* 2008). This intervention programme was community-based with flexibility over times and days of class attendance, with emphasis on social interaction, which may have contributed to the high adherence levels observed to this programme. The drop-out of a home-based intervention was 30%, but this was attributed mainly to the participants bearing a fairly considerable financial cost (100 Euro) to take part as physiotherapists were involved at the beginning and end of the intervention period (Delbaere *et al.* 2006a). These studies indicate that many factors may be involved in the success of an intervention programme, and that it is possible that the success will be affected by the age of the target group, and that programmes that are relatively inexpensive and have a social aspect are likely to be the most successful. Six months after the intervention programme had ended, 66% of the Tai Chi group were still engaged in some Tai Chi or other exercise training (Li *et al.* 2004), and 10 years after a walking intervention participants were still walking significantly greater distances recreationally than the controls (Pereira *et al.* 1998), demonstrating that interventions can lead to permanent patterns of activity and therefore lifestyle changes.

These intervention studies show some positive results for reducing fall rates and improving functional performance. However, there has also been suggestion that physical activity and the risk of falling could have a U-shaped relationship, with those least active and most active at the greatest risk of falling (Gregg *et al.* 2000).

Therefore, care has to be exercised when encouraging increased physical activity to not expose the individual to a significantly increased risk of falling, whilst maintaining the desired benefits from the activity. In further support of physical activity, there was a reduced risk of fracture in fallers with increasing amount of physical activity in the previous year (Keegan *et al.* 2004). This suggests that not only can physical activity have a preventative effect against falling in the first place, but also those who are active and are still unfortunate enough to experience a fall may also have a decreased risk of a fracture as an outcome. Therefore, any increased risk of falling in the most active, may be partly offset by the reduced risk of fracture as an outcome. However, adherence to these programmes may not always be that high and there is limited data on whether these programmes are continued after a study has ended. Therefore, it would be more advantageous to promote a healthy active lifestyle in younger generations to achieve lifestyle changes that impact on fall risk in older age than wait until these groups are already in the "at risk" category for falls.

2.7 Fear of falling

An associated psychological symptom of falls is fear of falling. Loss of confidence in mobility tasks and fear of falling are commonly reported in older people (Hill *et al.* 1996). Fear of falling is partly due to the fear of possible resultant physical harm, but also fear of the associated social embarrassment from having a fall (Yardley and Smith, 2002). Fear of falling becomes a key public health concern if this fear results in self-imposed restrictions to activity that could lead to further loss of physical functioning and reduction of health status through inactivity (Tinetti *et al.* 1994; Yardley and Smith, 2002; Li *et al.* 2003; Zijlstra *et al.* 2007; Deshpande *et al.* 2008).

Fear of falling can be assessed by simply using the question "Are you afraid of falling?" An interest in using a tool to provide more information on the fear itself however, led to the development of an instrument to measure fear of falling in different common activities (Tinetti *et al.* 1990). The Falls Efficacy Scale (FES) uses a 10-point scale to rate the degree of perceived efficacy at avoiding a fall when involved in 10 day-to-day activities, e.g. simple shopping, reaching into cupboards and cabinets, getting in and out of a chair. Research has been conducted to compare the FES to a more situation-specific measure of balance confidence (Powell and Myers, 1995). This has been termed the Activities-specific Balance Confidence (ABC) scale, and has 16 items as opposed to 10 on the FES. Both of these scales have been used in studies investigating fear and confidence, as well as using simple fear-related questions.

In a cohort of community-living elderly persons, 43% reported a fear of falling (Tinetti *et al.* 1994). However, the mean efficacy score based on the FES (Tinetti *et al.* 1990) suggested that although the respondents in this study were afraid of falling, the majority felt confident in conducting everyday living tasks without falling. This is much higher than the 20.8% of people reporting a fear of falling in a more recent study that was also conducted in the USA (Friedman *et al.* 2002). This discrepancy may be explained as the Friedman *et al*. study did not include individuals aged 85 and over. In an English study population, 43% reported no fear of falling, 46% reported a slight fear and 11% reported a marked fear (Yardley and Smith, 2002).

Individuals reporting a higher fear of falling were engaged in fewer activities of daily living or social activities than those with low fear (Friedman *et al.* 2002; Li *et al.*

2003; Deshpande *et al.* 2008). Avoidance of activities for fear of falling also increased with increasing age and was more common in women (Yardley and Smith, 2002). This suggests that fear may impose constraints on the social functions and daily living tasks in these individuals, and has been shown to be an independent predictor for a decline in physical function (Deshpande *et al.* 2008). Older adults who have a high fear of falling may not be so willing to engage in physical activity interventions for falls prevention, despite the potential benefits of the intervention, due to this underlying fear of falling which provides additional challenge in compliance and adherence to preventative measures.

In a group of non-fallers, those who reported a fear of falling were significantly more likely to report a fall in the following 12 months than those who were not afraid (Friedman *et al.* 2002). In addition, those with no fear of falling at baseline were twice as likely to report fear 12 months later if they had suffered a fall in that period compared to those who had not fallen. Another study also suggested that fear of falling was a predictor of subsequent falls in a 6-month follow-up (Hadjistavropoulos *et al.* 2007). As these studies suggest that falling is an independent predictor of developing a fear of falling and vice versa, an individual who develops one of these outcomes is at a greater risk of developing the other.

A 3-month Tai Chi programme resulted in a reduction in fear of falling based on the FES in women living in retirement communities (Taggart, 2002). There were also improvements in balance and functional mobility, but the study was limited by the lack of a control group. A 13-week resistance training programme and an agility training programme both resulted in improved balance confidence based on the ABC scale compared to a control stretching programme group in older women (Liu-Ambrose *et al.* 2004). This is despite there being no significant improvement in physical performance, although there were trends towards increased postural stability and general physical function. A 10-week tango dancing intervention resulted in higher balance confidence measures using the ABC scale, which was accompanied by increases in lower limb muscle strength (McKinley *et al.* 2008). Caution may be necessary to ensure that physical activity does not result in individuals partaking in activities beyond their physical abilities and as a consequence increasing fall risk as an inappropriately low fear of falling can be detrimental if a falls risk is still present (Delbaere *et al.* 2006b). However, physical activity that increases confidence in a controlled way to increase or maintain independent living is worthy of further investigation.

Fear of falling is an important issue to address, as fear may prevent individuals being as integrated into their community as they would wish. A fear of falling may result in an even greater reduction in the levels of activity of an individual, therefore further increasing the risk of falling as a result of the effects of inactivity. Physical activity interventions have shown a beneficial effect on reducing fear of falling, although those most fearful of falling may not be willing to engage in these programmes.

2.8 Conclusions

The focus of physical activity has shifted since the original ACSM position stand in the 1970s from activity to improve fitness to activity for health benefits. As part of this shift, the recommendations are now concentrating on moderate as opposed to vigorous intensity activity, whilst still stating the usefulness of vigorous activity for fitness benefits. It is clear from the recent ACSM guidelines for older persons that there is also a shift from generic recommendations to an appreciation that different populations may need different health requirements and therefore different activity types for the most pertinent health benefits for a particular group of people.

Despite these recommendations and campaigns in many countries to publicise them, the adherence to these recommendations is low. This is despite population subgroups in the European Union who are significantly active reporting better self-rated health (Abu-Omar *et al.* 2004). Of greater concern are the indications that, in some countries at least, including the UK, the adherence to these recommendations are getting progressively lower. This could have health repercussions when these populations reach old age. Currently it is not known whether achieving physical activity recommendations reduces the risk of falling, but if it does, fall rates in future populations could increase above current rates as these populations would have been less active throughout their lifetimes.

Research clearly shows the benefits of an active lifestyle in maintaining cardiorespiratory fitness, strength, proprioception and balance, although the link to reduced fall risk is less clear. However, these studies have often focussed on particular activities, such as Tai Chi, rather than habitual physical activity levels per se. There is currently no research investigating the long-term achievement of physical activity recommendations on fall occurrence or fall risk. This is important as recommendations need to address falls as well as the lifestyle issues of obesity, stroke, diabetes and cardiovascular disease.

Physical activity interventions have shown positive results in improving strength, balance and confidence, which shows that some of the declines in these areas with ageing can be halted or reversed. However, long term reduction in falls through these programmes will depend on the willingness of individuals to persist with them and the accessibility of the activity.

Chapter 3: Assessment of lifetime adherence to physical activity recommendations; implications for falls in community-dwelling older adults

This experimental chapter concerns lifetime physical activity and addresses the first two aims of the thesis. Therefore, the first aim of this study chapter was to develop a self-administered questionnaire to assess the achievement of the current physical activity recommendations across the lifespan, and to assess whether the achievement of these recommendations had any preventative effect on falling. The second aim of this study was to investigate whether there were differences between those who had and had not maintained a physically active lifestyle in terms of fall outcome or fear of falling. It was hypothesised that adults who had adhered to the physical activity recommendations throughout their lifetime would have been less likely to have experienced a fall event and be less likely to report a fear of falling.

3.1 Methods

The development and testing of the Lifetime Physical Activity and Falls History questionnaire (LPAFH) involved the following five phases:

1. initial design of the instrument;
2. a first pilot in a convenience sample of 24 participants;
3. a second pilot in a different convenience sample of 11 participants;
4. a test-retest reliability check on the final version of the LPAFH with 28 participants;

5. the main study, where data were collected in a sample of 314 community-dwelling older adults using the final version of the LPAFH.

3.2.1 Phase 1: Initial design of the Lifetime Physical Activity and Falls History questionnaire

The LPAFH was designed to assess how many days per week on average a person achieved at least 30 minutes of moderate or higher intensity physical activity in each decade of their life from their 20s onwards. It was also designed to gain information about fear of falling, any fall occurrences and outcomes of any fall events.

Following demographic data collection, the first section of the questionnaire assessed fear of falling, and used the fear of falling efficacy scale (Tinetti *et al.* 1990). The second section focussed on past physical activity levels, and asked how many days per week that at least 30 minutes of moderate or higher intensity physical activity was accumulated in leisure time and in occupational time. In addition, this section also asked how many days per week those 30 minutes of moderate or higher activity were not achieved. This was to confirm any overlap between days of occupational and leisure time physical activity. This form of frequency report is considered appropriate when assessing habitual activity (Shephard, 2003). Examples of moderate and higher intensity physical activity for both leisure time and occupational activity were given for reference (Whitehead *et al.* 1995; American College of Sports Medicine, 2000). Light-intensity activities were not included as the ultimate goal was to assess the current recommendations for physical activity (Department of Health, 2004b) in relation to fall risk. These physical activity questions were split into decades from the 20s onwards, and respondents were asked to complete each decade including their current one.

The falls history questionnaire was based on a previous questionnaire (Lord *et al.* 2001) and addressed each decade from the 50s onwards. A fall was defined as a loss of balance resulting in the body, or part of the body, coming to rest on the ground (Nowalk *et al.* 2001; Jensen *et al.* 2002). A stumble was defined as a loss of balance resulting in the body, or part of the body, coming to rest against a wall, a piece of furniture or another object which may have prevented a fall. Further questions asked about locations of falls, how the falls occurred, and whether any injuries were sustained as a result.

3.1.2 Phase 2: First pilot

The purpose of the first pilot study was to check the usability of the LPAFH (see appendix II). The participants were a convenience sample of 24 cognitively intact, community-dwelling persons over 50. Thirteen participants were male; eleven were female. The mean age was 66 years (range 50-82). The participants completed the LPAFH questionnaire and gave written feedback on the time taken to complete and the ease of the questions to answer. The main concerns expressed by the respondents included that the participants felt the questionnaire took too long to complete, and that although they felt confident in their recall on number of falls and when this first occurred, if they had suffered more than one fall it was difficult to recall at what age each one occurred. As a result of this first pilot study, some revisions were made to the LPAFH (appendix III). These revisions included the fear of falling section being adjusted to include further questions (Powell and Myers, 1995; Hill *et al.* 1996), to provide more information on activities that may be of concern to individuals. The LPAFH was considered too long (20-30 minutes completion time), and was revised so the physical activity section was shortened to combine leisure time and occupational physical activity. It was concluded that these did not need to be separate questions as long as both were addressed by the questions asked, and would also reduce the incidence of double reporting (Ham *et al.* 2004). This also reflected the wording of the physical activity recommendations (Department of Health, 2004b), which do not differentiate between leisure time and occupational physical activity. The falls section was adjusted to be applicable over the lifetime rather than for each decade, as this was considered easier to answer.

3.1.3 Phase 3: Second pilot

The aim of the second pilot was to check the usability of the adapted LPAFH questionnaire, and to confirm that the changes made addressed the concerns raised from the first pilot. The participants for this second pilot were a different convenience sample of 11 cognitively intact, community dwelling persons over 63. Two participants were male; nine were female. The mean age was 71 years (range 63-84). The participants completed the revised LPAFH questionnaire and gave verbal feedback on the questions. The feedback stated that on the whole the questions were easy to understand and to answer. The only concern was raised about the number of points on the fear of falling scale and that this made it difficult to place the answer on this relatively long scale. Based on this feedback, the fear of falling efficacy scale was reduced from a 10-point to a 5-point scale.

3.1.4 Phase 4: Test-retest

The purpose was to determine the test-retest reliability of the final version of the physical activity section of the LPAFH. The fear of falling efficacy scale has previously been shown to be repeatable (Tinetti *et al.* 1990), but test-retest was conducted in this case due to the scale reduction and the additional scale items. Four participants were male; twenty-four were female. The mean age was 68 years (range 56-86). The participants completed the LPAFH twice, 2 months apart as a timeframe deemed appropriate in order to minimise 'memory of responses' and it was confirmed that none of the respondents fall status had changed in the interim two months. On the first occasion the participants completed the questionnaire with the researcher present to be able to answer any queries. The retest questionnaire was distributed through the post.

Test-retest reliability was determined using Cohen's Kappa statistic (Cohen, 1960; Sim and Wright, 2005) as an absolute measure of agreement for nominal data. The levels of agreement used were taken from Landis and Koch (1977). The physical activity responses were tested in their answered format (i.e. 0-7 days per week) and also by recoding into active and not active enough categories, based on the 5 days per week recommendations (Department of Health, 2004b). The percentage level of absolute and relative agreement for each test-retest item was also established.

Test-retest statistics for the physical activity questions can be found in Table 3.1. For number of days active per week, the Kappa statistic showed fair repeatability (Landis and Koch, 1977) for each decade (except the 50s which showed slight repeatability). No Kappa statistic was computable for the 70s and 80s due to empty categories impacting upon the essentially cross-tabulation based analysis. When the data was recoded into 'active' and 'not active' for each decade based on achievement of the current physical activity recommendations, the Kappa statistic showed better absolute repeatability ranging from 0.3 to 1.0. Similarly, percentage of agreement was also improved ranging from 68 to 100%. When participants were then identified as either achieving 'active' status over their lifetime (achieving recommendation in every decade) or 'not active' status over their lifetime (not achieving the recommendation in one or more decades) observed Kappa was 0.5 (moderate) with 75.0% same classification agreement.

Table 3.1 Test-retest statistics for the physical activity questions in the LPAFH

Decade	**Kappa**	**% Agreement**	**Kappa active/not active**	**% Agreement active/not active**
20s	0.27	75	0.73	89
30s	0.29	79	0.79	93
40s	0.35	75	0.48	75
50s	0.21	54	0.29	68
60s	0.29	68	0.39	72
70s	-	70	0.78	90
80s	-	67	1.0	100

The Kappa statistic for the question "Are you currently afraid of falling?" showed fair repeatability (Kappa = 0.34), and 88.9% answered this question the same on both occasions. Test-retest statistics for the individual items on the FES can be found in table 3.2. Some of the Kappa values were not calculated for the individual items due to empty categories impacting on the analysis. Kappa values ranged from moderate to substantial agreement, except for using public transport, and a high percentage of agreement was observed for all items.

Based on these test-retest statistics, the physical activity questions were considered reliable for categorising active or not active enough for each decade across the lifecourse. The shorter scale version of the FES and the additional individuals items were also considered reliable in general, with some caution recommended over the “using public transport” item. It was therefore concluded that the LPAFH questionnaire was suitable for use in the main study.

Table 3.2 Test-retest statistics for the revised FES

FES item	Kappa	% agreement
Cleaning the house	-	77.8
Getting dressed/ undressed	0.51	88.9
Preparing simple meals	0.65	96.3
Taking a bath/ shower	-	74.1
Simple shopping	0.65	96.3
Getting in/ out of a chair	0.78	96.3
Going up and down stairs		74.1
Walking around the neighbourhood	0.71	92.6
Reaching into cabinets or closets	-	77.8
Hurrying to answer the door or phone	-	88.9
Walking in icy conditions	0.46	59.3
Getting in/ out of a car	-	88.9
Using public transport	0.18	66.7
Crossing roads	0.42	77.8
Using front/ rear steps at home	-	85.2
Picking an item up from the floor	0.72	92.6

3.1.5 Phase 5: Main study

The modified, reliable LPAFH (appendix IV) was distributed locally through regional chapters of the University of the Third Age (U3A), Age Concern and the Women’s Institute. This involved attendance at meetings to introduce the aims of the project, and to answer any questions about the questionnaire. The LPAFH was also made available online through national and regional U3A websites to gain some nationwide responses. Eligibility requirements included that the participants be over 50 years old, community-dwelling and cognitively intact. Three hundred and fourteen respondents returned questionnaires. Seventy-four were males; two hundred and twenty-eight were females. The mean age was 70 years (range 54-94).

3.1.6 Classification of participants

The participants were classified into groups based on their questionnaire responses. Grouping variables were determined by sex (males = 78, females = 236), physical activity (active = 94, non-active = 220), fear of falling (afraid = 87, not afraid = 220), fall status (non-faller = 88, faller = 225) and faller type (non-faller = 88, single faller = 80, multiple faller = 143).

Differences between average physical activity levels for each decade were investigated between males and females using independent t-tests. Relationships between activity levels (active/ not active), sex, fear of falling (afraid/ not afraid) and fall status (faller/ non-faller and non-faller/ single faller/ multiple faller) were investigated using Chi-squared analysis. If a 2x2 Chi-square was used, Yates' value for continuity was used. Independent t-tests were used to identify any differences in the fear of falling items between activity levels, sex and fall status (faller/ non-faller). The level of significance was set $p = 0.05$.

3.2 Results

In total, 314 participants completed the LPAFH. Details of the respondents are given in table 3.3.

Table 3.3 Details of the LPAFH respondents

	Males (n = 78)	Females (n = 236)
Age (years)	71.4 ± 7.5	70.5 ± 7.4
Height (m)	1.74 ± 0.09	1.62 ± 0.07
Body weight (kg)	76.2 ± 10.8	66.4 ± 11.4
University educated	30.8% (24)	26.3% (62)
Smoker	48.7% (38)	38.1% (90)
Uses a walking aid	5.1% (4)	10.2% (24)
Diagnosed with osteoporosis	3.8% (3)	14.8% (35)

3.2.1 Lifetime physical activity levels

Physical activity levels for males and females are displayed in table 3.4. The average physical activity levels were consistently lower for males than females, apart from levels in the 20s, but this difference was only significant for the 30s ($t = -2.6$, $p = 0.01$). The average physical activity levels only dropped below the recommended 5 days a week in the 70s for the males, and the 80s for the females.

Table 3.4. Physical activity levels across the decades for males and females (n).
* indicates a significant difference from the males

Decade	Males (n = 78)		Females (n = 236)	
	Mean ± SD days per week	% Achieving PA recommendations	Mean ± SD days per week	% Achieving PA recommendations
20s	6.1 ± 1.8 (78)	62.8 (78)	6.1 ± 2.1 (233)	69.1 (233)
30s	5.7 ± 2.0 (78)	57.7 (78)	6.4 ± 2.0(233)*	76.4 (233)
40s	5.7 ± 2.0 (78)	59.0 (78)	6.1 ± 2.1 (232)	69.0 (232)
50s	5.6 ± 2.1 (77)	57.1 (77)	5.7 ± 2.2 (235)	60.9 (235)
60s	5.2 ± 1.9 (73)	43.8 (73)	5.3 ± 2.1 (213)	51.6 (213)
70s	4.8 ± 2.0 (40)	35.0 (40)	5.1 ± 2.3 (127)	46.5 (127)
80s	4.6 ± 2.6 (8)	37.5 (8)	4.9 ± 2.3 (26)	38.5 (26)

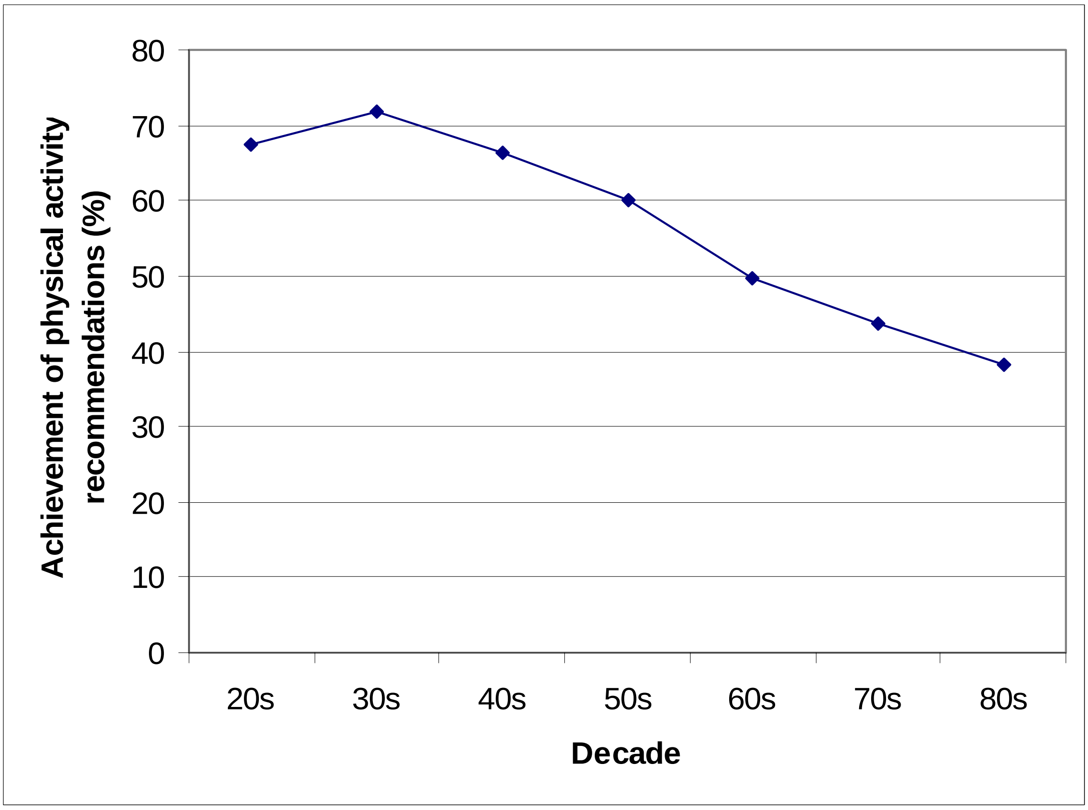


Figure 3.1 Participants achieving the physical activity recommendations in each decade

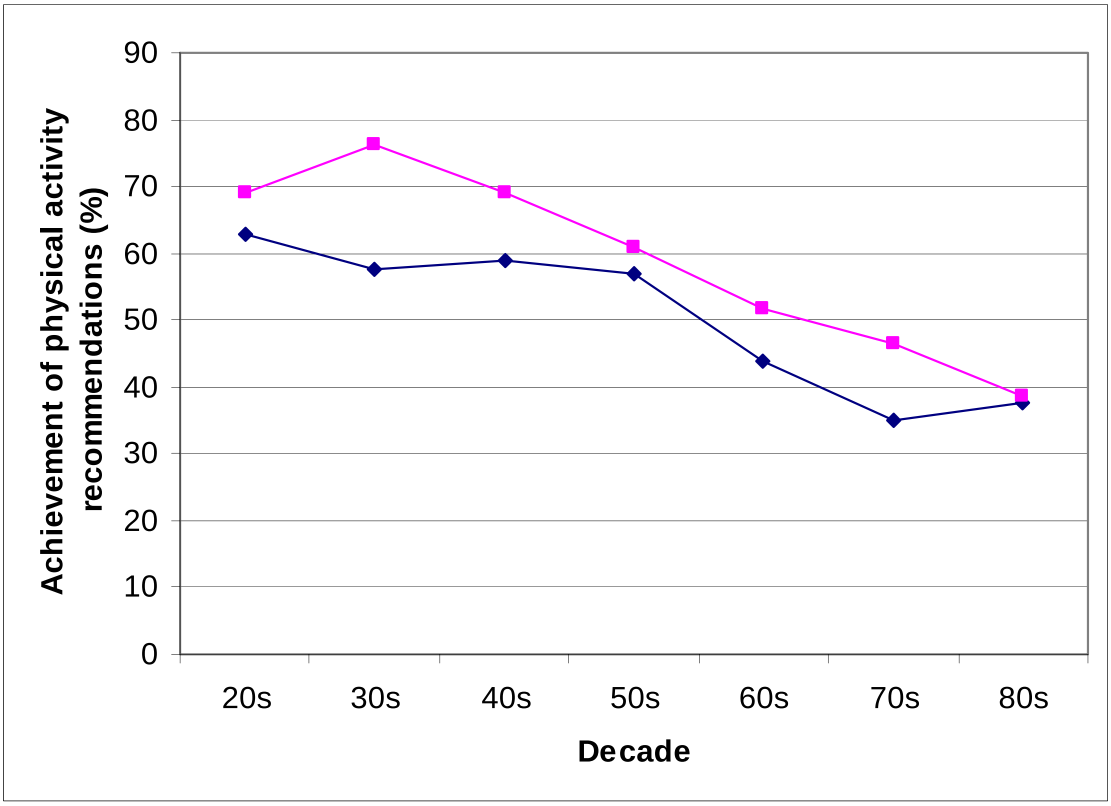


Figure 3.2 Males (♦) and females (■) achieving the physical activity recommendations

When the data was recoded into achieving the PA recommendations or not, 67.5% of participants had taken part in enough physical activity in their 20s, 71.7% in their 30s 66.5% in their 40s, 59.9% in their 50s, 49.7% in their 60s, 43.7% in their 70s and 38.2% in their 80s. This showed a gradual decrease in respondents achieving the recommendations as they got older (see figure 3.1). Nearly thirty percent of participants achieved the recommendations for every decade of their life (and were classified as the active group). There was also a higher percentage of females than males achieving the recommendations across all decades (figure 3.2), but as with the days per week values, this was only significant for the 30s ($\chi^2_{Yates} = 9.174$, $p = 0.002$).

3.2.2 Fall history

Twenty-eight percent of respondents had no history of falling, 26% reported a single fall, with the other 46% reporting multiple falls (figure 3.3). The most common number of these multiple falls reported was 2-3 falls. The mean age for the first fall was 60.66 (± 11.25) years.

Achievement of at least 30 minutes of at least moderate intensity physical activity on at least 5 days of the week during each decade of life for fallers and non-fallers can be seen in figure 3.4. As with the males and females, it was apparent that the percentage achieving the recommended levels reduced with increased age category. The only increase in physical activity attainment was for the non-fallers in the 80s, which may be due to the low participant numbers in this category ($n = 5$). There was no significant relationship between physical activity recommendation attainment and whether someone had fallen or not ($\chi^2_{Yates} = 3.762$, $p = 0.052$). When the fallers were further split into single fallers and multiple fallers, there was still no significant

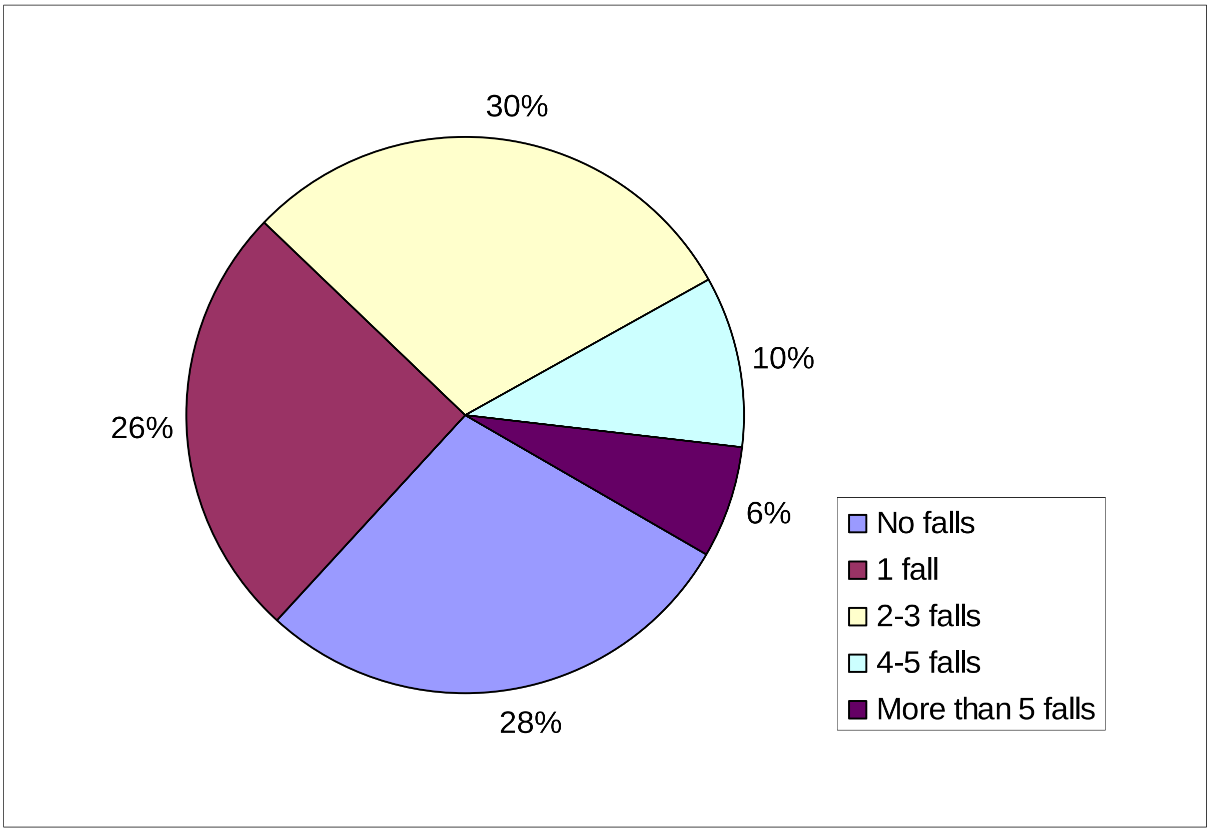


Figure 3.3 Number of falls in each category

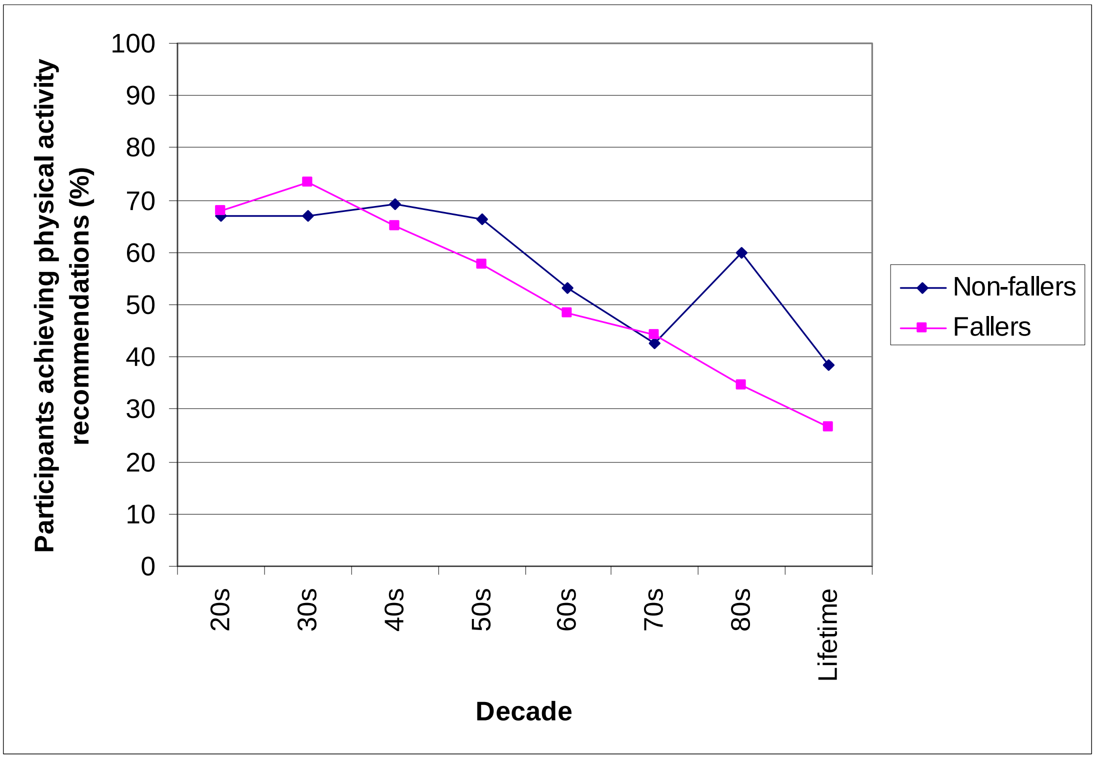


Figure 3.4 Percentage of non-fallers and fallers achieving the recommended amount of physical activity for each decade and across the lifetime

relationship between physical activity attainment and faller type ($\chi^2 = 4.591$, p = 0.101).

There was a significant relationship between sex and fall status ($\chi^2_{Yates} = 11.311$, p = 0.001), with more women having experienced a fall than the expected count. This relationship was also significant with type of fall ($\chi^2 = 12.512$, p = 0.002), with women more likely to have experienced multiple falls than expected, and less likely to have not fallen than expected.

Walking outdoors was the most common place to experience a fall or stumble (see figure 3.5), with 154 participants reporting an incidence, followed by walking in icy conditions (also normally as outdoors situation; 75 participants) and walking indoors (71 participants). When data was combined into two groups based on location, respondents reported 188 fall occurrences in the home and 421 fall occurrences outside the home.

The most common type of fall was through a trip (150 participants), followed by a slip (112) and a loss of balance (84). Forty-five participants reported that their falls resulted in no injuries. The most commonly reported injuries were bruises (155 participants) and cuts/grazes (100 participants). The most common serious injuries reported were back pain (39) and a broken wrist (26). Two respondents reported a broken hip. When injury types were split into non-serious (no injury, bruises, grazes) and serious (fractures, sprains, back pain) groups, there were no significant differences in physical activity levels for the decades leading up to the first fall.

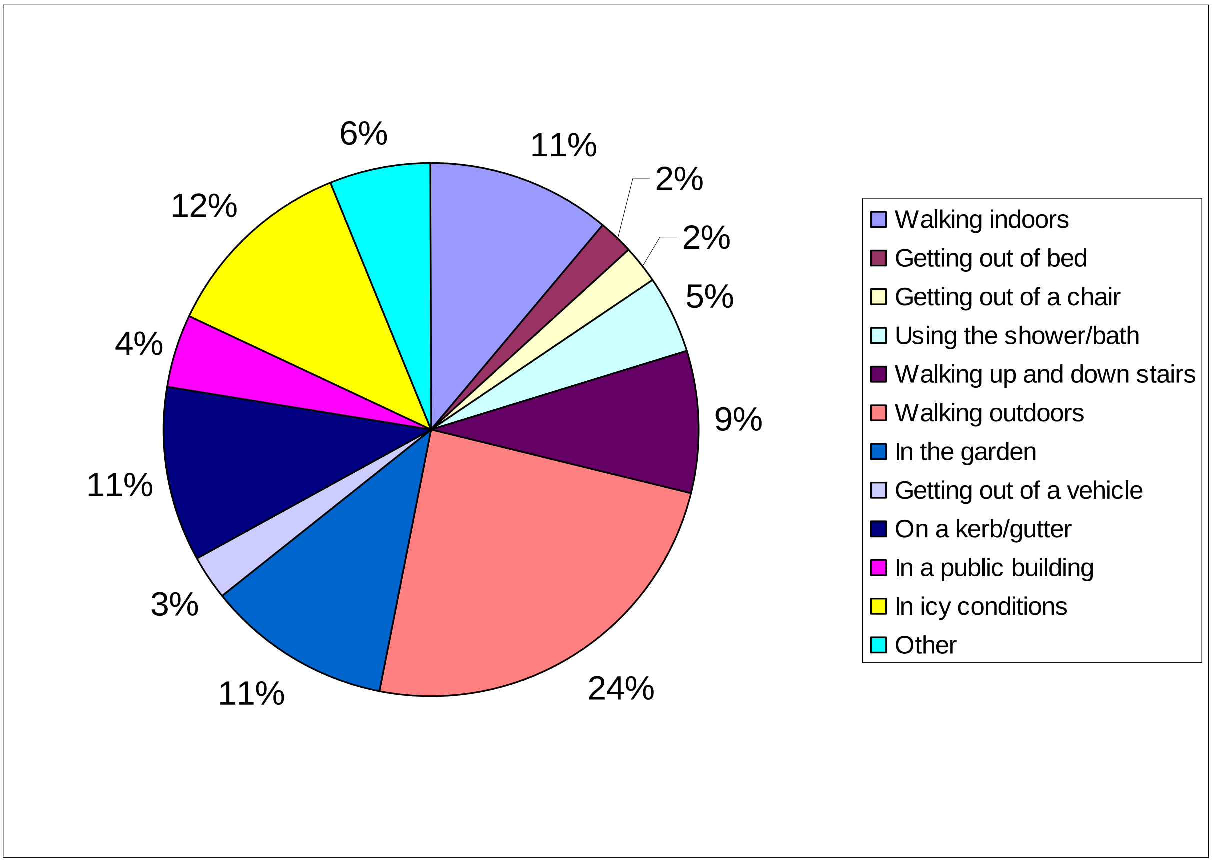


Figure 3.5 Activity at the time of a fall

3.2.3 Fear of falling

Table 3.5 contains summary data from completion of the fear of falling section of the LPAFH for the male and female categories. Data identified that 15% (12) males and 32% (75) females reported a fear of falling. Chi-squared analysis showed a significant difference between males and females reporting a fear of falling (χ^2_{Yates} = 7.416, p = 0.006), with more females and fewer males reporting a fear of falling than the expected count.

Table 3.5 FES scores per item for males and females (mean ± SD) * indicates a significant difference

	Males	Females	t-value
Cleaning the house	4.77 ± 0.73	4.48 ± 0.94	2.811*
Getting dressed or undressed	4.81 ± 0.58	4.67 ± 0.84	1.641
Preparing simple meals	4.97± 0.16	4.74 ± 0.83	4.071*
Taking a bath or shower	4.50 ± 0.84	4.23± 1.10	2.267*
Simple shopping	4.88 ± 0.51	4.64 ± 0.87	2.959*
Getting in or out of a chair	4.78 ± 0.64	4.65 ± 0.91	1.369
Going up and down stairs	4.64 ± 0.76	4.23 ± 1.13	3.608*
Walking around the neighbourhood	4.78 ± 0.62	4.41 ± 1.03	3.797*
Reaching into cupboards or closets	4.71 ± 0.65	4.38 ± 1.02	3.304*
Hurrying to answer the door or phone	4.69 ± 0.69	4.39 ± 1.07	2.799*
Walking in icy conditions	3.55 ± 1.11	2.97 ± 1.32	3.466*
Getting in/ out of a car	4.72 ± 0.62	4.43 ± 1.03	3.003*
Using public transport	4.61 ± 0.78	4.26 ± 1.19	2.959*
Crossing roads	4.67 ± 0.72	4.32 ± 1.06	3.214*
Using front or rear steps at home	4.78 ± 0.60	4.31 ± 1.12	4.665*
Picking up an item from the floor	4.62 ± 0.76	4.52 ± 1.02	0.798

When the fear of falling data was analysed by task, females had a lower mean rating across all items than males (see table 3.5), however the mean confidence rating only dropped below 3 for females in icy conditions. Significant differences were observed between males and females for all items except getting dressed/ undressed, getting in or out of a chair and picking an item up from the floor.

Table 3.6 contains summary data from completion of the fear of falling section of the LPAFH for the active and not active categories. There was no significant relationship between fear of falling and being active based on adherence to physical activity guidelines throughout the lifecourse (χ^2_{Yates} = 1.242, p = 0.265). When the fear of falling data was analysed by individual item, however, there was a significant difference between groups for all activities except picking an item from the floor.

Table 3.6. FES scores per item for the active and the not active respondents (mean ± SD) * indicates a significant difference

	Active	Not Active	t-value
Cleaning the house	4.73 ± 0.67	4.48 ± 0.97	-2.555*
Getting dressed or undressed	4.83 ± 0.60	4.65 ± 0.84	-2.072*
Preparing simple meals	4.91± 0.48	4.75 ± 0.81	-2.174*
Taking a bath or shower	4.48 ± 0.86	4.23± 1.11	-2.183*
Simple shopping	4.87 ± 0.47	4.63 ± 0.90	-2.991*
Getting in or out of a chair	4.86 ± 0.46	4.61 ± 0.96	-3.038*
Going up and down stairs	4.58 ± 0.79	4.23 ± 1.14	-3.091*
Walking around the neighbourhood	4.69 ± 0.71	4.43 ± 1.03	-2.561*
Reaching into cupboards or closets	4.67 ± 0.73	4.37 ± 1.02	-2.972*
Hurrying to answer the door or phone	4.66 ± 0.78	4.39 ± 1.07	-2.514*
Walking in icy conditions	3.35 ± 1.17	3.01 ± 1.33	-2.253*
Getting in/ out of a car	4.71 ± 0.72	4.42 ± 1.03	-2.783*
Using public transport	4.58 ± 0.87	4.25 ± 1.18	-2.668*
Crossing roads	4.58 ± 0.86	4.34 ± 1.04	-2.140*
Using front or rear steps at home	4.63 ± 0.78	4.34 ± 1.11	-2.524*
Picking up an item from the floor	4.67 ± 0.83	4.48 ± 1.01	-1.729

There was a significant relationship between fear of falling and whether an individual had experienced a fall ($\chi^2_{Yates} = 26.246$, $p < 0.001$) with more fallers expressing a fear of falling than the expected count. This was supported by the relationship between fear of falling and type of faller (non faller, single faller, multiple faller) ($\chi^2_{Yates} = 39.011$. $p < 0.001$), with single fallers showing similar fear of falling numbers to the expected count, whilst multiple fallers showed a 59% higher number of respondents who were fearful of falling than expected.

When the task data was analysed, the fallers had a lower mean rating across all items than non-fallers (see table 3.7). The mean confidence rating only dropped below 4 for the non-fallers and 3 for the fallers in icy conditions. For all other items, the rating was above 4 for both groups. Significant differences were observed between fallers and non-fallers for all items except getting dressed/ undressed, preparing simple meals and picking an item up from the floor.

Table 3.7 FES scores per item for non-fallers and fallers (mean ± SD) * indicates a significant difference

	Non-fallers	Fallers	t-value
Cleaning the house	4.75 ± 0.74	4.48 ± 0.94	-2.695*
Getting dressed or undressed	4.81 ± 0.62	4.66 ± 0.84	-1.786
Preparing simple meals	4.89 ± 0.52	4.77 ± 0.80	-1.506
Taking a bath or shower	4.61 ± 0.77	4.18 ± 1.12	-3.817*
Simple shopping	4.85 ± 0.54	4.65 ± 0.88	-2.418*
Getting in or out of a chair	4.83 ± 0.61	4.63 ± 0.92	-2.145*
Going up and down stairs	4.68 ± 0.80	4.20 ± 1.12	-4.168*
Walking around the neighbourhood	4.80 ± 0.70	4.39 ± 1.01	-4.084*
Reaching into cupboards or closets	4.69 ± 0.69	4.37 ± 1.03	-3.156*
Hurrying to answer the door or phone	4.74 ± 0.69	4.36 ± 1.08	-3.603*
Walking in icy conditions	3.72 ± 1.18	2.87 ± 1.26	-5.447*
Getting in/ out of a car	4.67 ± 0.79	4.45 ± 1.01	-2.041*
Using public transport	4.64 ± 0.78	4.23 ± 1.20	-3.554*
Crossing roads	4.67 ± 0.71	4.31 ± 1.08	-3.393*
Using front or rear steps at home	4.71 ± 0.73	4.32 ± 1.11	-3.645*
Picking up an item from the floor	4.66 ± 0.76	4.50 ± 1.03	-1.475

3.3 Discussion

3.3.1 Design of an instrument

The LPAFH was designed to be an easily administered and time-economical tool for the assessment of lifetime physical activity and fall occurrence. The focus of interest for the physical activity questions centred around the achievement of the UK recommendations of a minimum of 30 minutes moderate intensity activity on at least 5 days of the week (Department of Health, 2004b). These recommendations focus on the amount and intensity of activity as opposed to the specifics of the activity, so the LPAFH was designed to reflect this. The LPAFH, therefore, is structured differently to previous questionnaires and interviews that have investigated retrospective lifetime physical activity levels recall (Kriska *et al.* 1988; Friedenreich *et al.* 1998; Chasan-Taber *et al.* 2002; Littman *et al.* 2004; Orsini *et al.* 2007). Whilst having more specific knowledge about physical activity during the lifecourse may be of interest particularly in relation to any additional specific health-related physical activity requirements, this detailed level of information may be difficult to recall accurately from the participants' distant past.

The LPAFH considers occupation and household physical activity in addition to leisure time (as the Department of Health recommendations do not differentiate), unlike some questionnaires that do not consider all of these aspects of physical activity (Kriska *et al.* 1988; Littman *et al.* 2004). Consequently, these questionnaires that do not consider occupational or household physical activity may under-represent the amount of physical activity an individual has undertaken. This has implications for quantifying the efficacy of activity in relation to health benefits.

The test-retest of the individual items regarding the number of days per decade upon which the recommendations were achieved, using Cohen's Kappa statistic (Cohen, 1960), suggests that this information cannot be recalled reliably. This is despite the relatively simple wording of the physical activity questions and the absence of the need to recall specific details about any activity. Kriska *et al.* (1988) used the Kappa statistic and accepted values of 0.39-0.47 as a fair agreement for their test-retest on questions relating to how often respondents participated in physical activity. This shows a better reliability than the days per week question in the present study (although the levels can be classed as slight to fair agreement), but lower reliability than the recoded active enough / not active enough questions (showing substantial agreement for some decades). When the repeatability of individual decade items was analysed using percentage of correct re-classification, this method showed the repeatability to be high, only dropping below 70% for the participants recalling their physical activity levels in their 50s and 60s. This lower repeatability for the 50s and 60s may be a factor of career changes or retirement that occurred during these decades. Percentage agreement for the active enough / not active enough categories only fell below 70% in the 50s. Based on the combined information from these Kappa figures and the percentages of correct reclassification, the LPAFH can be used as a reliable measure of physical activity recall in relation to attainment of the recommended physical activity guidelines for health in studies of this nature with similar samples of participants.

The format of the LPAFH was not altered after the poor reliability measures on the questions regarding number of days per week of physical activity. The questions could have been adjusted to ask simply "Did you achieve at least 30 minutes of moderate or higher intensity physical activity on at least 5 days of the week?" This dichotomous approach was considered too leading, and it was concluded that the current format of the questions was simple to recode into "active enough" and "not active enough" categories and negated any potential to lead the responder into a particular answer.

The Falls Efficacy Scale has been investigated for repeatability previously (Tinetti *et al.* 1990), but based on a 10-point rather than a 5-point scale. Although the Kappa statistic showed only fair repeatability for the question "are you currently afraid of falling?" the finding that 88.9% of participants answered this question the same on both occasions suggests that the repeatability for this question is high. With the individual items, the repeatability was over 70% except for walking in icy conditions and using public transport. This demonstrates the reliability of a 5-point scale version of the FES.

The FES has also been modified for use in other studies. One adaptation is the FES-International (FES-I; (Yardley *et al.* 2005), which increased the items to 16 and used a shortened 4-point scale. The scale was shortened in the FES-I as the authors considered a 10-point scale to lack meaningfulness to respondents. This supports the use of a reduced scale in the LPAFH. Some of the items were re-worded so that the items were applicable to a wider geographical area, e.g. walking in icy conditions was modified to walking in slippery conditions. The FES-I may be a useful addition to the LPAFH questionnaire instead of the current modified FES, as this would allow the tool to be used in all climatic regions. However, as this current LPAFH data collection was conducted in early 2005, and the FES-I was published in November 2005 there was not the option to utilise the FES-I in this particular study.

3.3.2 Main study

There is a potential bias in using a volunteer sample such as this, as the sample may not accurately represent the community-dwelling population at large in this age group. This community-dwelling sample is probably not representative of older people as a whole, as many older people may live in restrictive, sheltered or nursing accommodation. As a result, the population in this study are likely to represent the healthier portion of the older population, and possibly also the more active.

More women (75% of sample population) than men took part in this study, and this appears to be the trend in other studies investigating falls in older people. Two-thirds of participants were women in a study by Nordell *et al*. (2000) and 75% were women in a study by Keegan *et al*. (2004), although both of these studies only used participants who had already experienced a fall or fracture rather than a general community-dwelling older population. This bias towards women respondents has implications for the summary data from these studies, as conclusions that are formed from the summary data may be more reflective of the female population than the population as a whole. Therefore, caution must be exercised when applying the findings from these female-dominated studies to the male population.

3.4.3 Lifetime physical activity

The respondents in this study have shown high physical activity levels throughout their lifetime, with the percentage of individuals adhering to current physical activity recommendations only dropping below 50% in the 60s for the men and the 70s for the women. The findings from the current study show higher adherence than population findings in England from 2003 when direct comparisons are made across each age group (Department of Health, 2004a). This is also mirrored by the finding in the present study that less than 10% of women failed to participate in any activity on any day of the week in all decades and less than 10% of men in all decades except the 80s. These are considerably lower rates of complete inactivity than the population figures which indicate that 32% of men and 40% of women across the 16-75+ age bands fail to achieve 30 minutes of moderate intensity activity on any day of the week (Department of Health, 2004a). This confirms that the volunteer population represent a very active subset of the population.

A report further investigating the data from the Allied Dunbar national fitness survey (Sports Council and Health Education Authority, 1992) also reported self-reported participation in physical activity from the age of 16 (Skelton *et al.* 1999). Although the definitions used for regular activity were different than the current physical activity recommendations, 80% of men and 64% of women reported themselves as being regularly active between the ages of 16-24. This steadily declined with increasing age, with 68% of men and 51% of women being regularly active between the ages of 25-34, and 54% of men and 45% of women being regularly active between the ages of 35-49. These findings are slightly lower than the reported level of activity in the respondents of the LPAFH, however regular activity only included sports and exercise activities, so the levels would be lower than for the LPAFH which has included occupational and household activity. Despite the Allied Dunbar data not including non-exercise related activity, the report suggests that the level of activity reported from the LPAFH is appropriate for this older population. Therefore, the more recent cross-sectional data (Department of Health, 1999; Department of Health, 2004a) showing much lower adherence to the physical activity recommendations across the 16-75+ age bands than reported here suggests that this could be due to the increasing levels of inactivity in the British population.

The number of respondents adhering to the physical activity recommendations steadily decreases with increasing age. This decrease in activity with age has been shown in cross-sectional studies (Crespo *et al.* 1996; Department of Health, 1999; Livingstone *et al.* 2001; Department of Health, 2004a; Chad *et al.* 2005), and with retrospective data (Skelton *et al.* 1999). The current study demonstrates that this decrease in activity is a process that occurs with age rather than purely a difference in behaviour across generations. This has implications for policy recommendations where the importance of maintaining physical activity levels with increasing age should also be emphasised.

In a cross-sectional study in Switzerland, 33% of 50-64 year olds and 29.1% of 65-79 year olds did no physical activity (Meyer *et al.* 2005). This shows a far greater level of inactivity than the present study. However, this Swiss study only took into account leisure time physical activity rather than including occupational or household physical activity, which may account for the difference in the age groups that may still be in regular employment and in those individuals that participate in predominantly household-based activity.

The female participants in this study were more active than the male participants in all decades, although this difference was only significant in the 30s. This is in contrast to a cross-sectional study of adults aged 18-65 in Ireland, which found males to be significantly more active than females in all age groups (Livingstone *et al.* 2001), and a cross-sectional study of adults aged 18 to over 65 in the USA, which found more males than females met the physical activity guidelines in all age groups (Jones *et al.* 1998). This study from the USA was limited by household activities not being included in the analysis, and the study from Ireland investigated energy expenditure to classify activity levels as opposed to using physical activity recommendation attainment. The types of physical activity engaged in have been demonstrated to be different between men and women. Males were more active than females in occupational and leisure time activities, whilst females were more active than males in household pursuits (Livingstone *et al.* 2001). These results were mirrored in a South African study which also found women to be far more active in household pursuits than men (Kolbe-Alexander *et al.* 2004), although this study was conducted among a lower socio-economic group. These different activity patterns indicate that men and women need different approaches to encourage a more active lifestyle.

There is an increase in the proportion of men reaching the recommendations from the 45-64 age group to the 65 and over age group in this US study (Jones *et al.* 1998). Due to the cross-sectional nature of the study, it is impossible to know whether men in this age group have been more active during their lives than the men in the younger age groups, whether there is a bias towards more active men as respondents in this age group, or whether due to retirement these men have more time to engage in physical activity and therefore have increased their activity levels.

The Allied Dunbar national fitness survey (Sports Council and Health Education Authority, 1992) found that the average duration of activity could be between 1 and 2 hours depending on the intensity. The duration was not assessed in the present study beyond the 30 minute threshold, but it is possible that there may be health benefits from longer activity sessions on less than 5 days of the week that may not be accounted for. For some individuals, it may be more practical to accumulate enough physical activity over a weekly cycle rather than a daily and weekly cycle. Further research is needed to determine whether the benefits of physical activity accumulated over a week are just as compelling as on a 5-day per week schedule.

Women have shown a tendency to overestimate their physical activity levels rather than underestimate it after a 32-year follow-up period (Lissner *et al.* 2004), however, the recall of moderate and light levels of activity after a 30-year follow-up period were more reliable than for vigorous levels of activity in both men and women (Falkner *et al.* 1999) It is possible that light and moderate levels of activity are more routine activities and therefore are easier to recall reliably from the distant past. This suggests that in studies of this nature, there may be some benefit in wording questions to reflect different intensities of activity for increased recall accuracy. The ability to accurately recall physical activity levels in the distant past will always present a limitation to studies of this nature. However, unless a study is able to be longitudinal over several decades, recall questionnaires are a necessary method to evaluate the etiological effects of physical activity on the development of subsequent chronic disease or conditions. Therefore, limitations need to be accepted and questionnaires designed to limit recall error as much as possible. In addition, questionnaires are the only feasible method of assessing habitual physical activity in larger populations (Shephard, 2003).

3.4.4 Physical activity and falls

The findings of this study suggest that the attainment of the current recommendations of 30 minutes of physical activity on five days a week (Department of Health, 2004b) does not significantly reduce fall occurrence compared to individuals who have not achieved these recommendations. However, there is a trend towards fewer falls in the more active participants which deserves further investigation. There is no preventative factor in the risk of having multiple falls compared to single falls or no falls. There are possible explanations for this non-significant finding for activity and fall occurrence. It is possible that physical activity does not have a protective effect against falling. However, there are many studies that suggest that physical activity does have benefits for fall prevention (Carter *et al.* 2001). This evidence has consisted of retrospective and intervention studies. There have been previous reports of decreased fall occurrence in those who have led an active lifestyle (Bischoff *et al.* 2001), although this was only apparent in women and not in men.

Many studies do not investigate falls directly but at characteristics associated with increased stability and mobility. For example, long-term Tai Chi practitioners have been shown to have better postural stability than non-practitioners (Hong *et al.* 2000; Wong *et al.* 2001), women who participate in lawn bowls demonstrate reduced postural sway compared to controls (Brooke-Wavell and Cooling, 2009) and Tai Chi interventions have resulted in increased muscle strength in the lower limbs (Lan *et al.* 1998). Falls can occur for many reasons, and it is fair to assume that an active lifestyle is not going to be the sole reason to protect against a fall event. However, this trend towards decreased fall occurrence in those who have been active presents another reason to continue promoting physical activity as a preventative form of medicine. Further research is needed to clarify whether the recommendations need more specification such as strengthening or balance activities to enhance this preventative trend.

A review of physical activity studies suggested that the relationship between physical activity and falling is U-shaped, with those least and most active at the highest risk of falling (Gregg *et al.* 2000). By categorising the respondents based on their adherence to the physical activity recommendations; this may have resulted in comparing the very active with the completely sedentary and therefore masked any benefits of achieving the physical activity recommendations across the lifecourse. It is possible that even if lifetime physical activity does not have a significant protective effect against falls, that lifestyle choice can influence the type of fall. Higher current levels of leisure-time physical activity have been associated with outdoor, but not indoor falls, with the highest proportion of these outdoor falls occurring during walking (Li *et al.* 2006). It is possible that individuals who engage in more leisure time activity spend more time outdoors, therefore increasing the risk of falling outdoors as opposed to individuals who spend proportionately more time indoors. Three-quarters of the outdoor falls have been reported to have been precipitated by one or more environmental causes (Li *et al.* 2006), as opposed to intrinsic factors. This suggests that physically active older persons may have different fall patterns than those less active. This has implications for the design and adoption of appropriate fall prevention strategies.

Higher current levels of physical activity are associated with the reduced risk of fracture resulting from a fall (Keegan *et al.* 2004), and regular walking is associated with a reduced risk of hip fracture in post-menopausal women (Feskanich *et al.* 2002). In terms of osteoporotic fractures, lifelong physical activity has been promoted as the most effective method of prevention as physical activity can increase bone mass, density and strength (Kannus, 1999). Although the preferable outcome would be the prevention of a fall event occurring in the first place, if falls do occur, habitual physical activity offers protection against the most serious of fall outcomes.

3.4.5 Falls

Despite the high activity levels of this study population, only 28% had no history of falling. This high fall occurrence rate shows that despite the participant population being highly independent and community-dwelling, they still represent an "at risk" group for experiencing a fall and are as noteworthy a study population for falls research as more frail populations.

A greater proportion of women than men had experienced a fall in this study. This finding may have been influenced by substantially more women than men having participated in this study, although this finding has been reported previously (Department of Health, 2007). This may be related to the different physical activity patterns observed in this and other studies between men and women. This also indicates that falls prevention programmes may require different strategies for men and women, or that women need to be targeted more by these prevention programmes.

The current study shows that the majority of falls in community-dwelling older persons occur outside the home. This is supported by earlier studies which found that only 23% of falls occurred inside the home in community-dwelling older persons (Berg *et al.* 1997), 39% of falls occurring outdoors (Nordell *et al.* 2000), 58% reporting the most recent fall occurring outdoors (Li *et al.* 2006), and 79% of falls occurring outdoors in a 12-month follow-up (Pajala *et al.* 2008). As this population is independent and community-dwelling, it follows that they are going to be in more challenging situations within the community than those who are frail and spend more time indoors. Therefore, falls prevention programmes should be designed to reflect the target population by addressing the different challenges faced in activities of their daily living.

Sixty-six percent of participants who had fallen reported at least one fall being as a result of a trip, with 50% reporting a slip. This is more than the 34% percent of falls that have been documented as resulting from a trip and 25% from a slip in community-dwelling older persons (Berg *et al.* 1997), and the 30% of falls reported from a trip or a slip in 65-74 year olds (Nordell *et al.* 2000). However, this may be due to the reporting of the figures. In the current study, the number of participants reporting a certain type of fall circumstance was reported rather than the number of falls of those types. This is because some of the respondents could not remember how many falls of different circumstances they had experienced but could recall that they had at least one fall of this type. This may cause a distortion when comparing figures to these previous studies.

Trips have been documented as resulting predominantly in forward falls, as have slips and faints at fast gait speeds (1.9 ± 0.16 m.s^{-1}) (Smeesters *et al.* 2001). The majority of falls occurring outdoors have been reported to be in the fall forward direction (Li *et al.* 2006), suggesting that the majority of falls are resulting from these circumstances. However, at slower gait speeds ($< 1.43 \pm 0.13$ m.s^{-1}), slips resulted in sideways or backwards falls, and faints resulted in a greater number of sideways falls, with impact near the hip (Smeesters *et al.* 2001). This gait speed value, however, represents a comfortable and normal walking speed (Bohannon, 1997). This study by Smeesters *et al.* was conducted on young adults in induced falls, but assuming that the findings are also valid for older adults, individuals with normal or slower gait speeds who experience falls through slipping or fainting are going to be more at risk of fracturing their hip as a fall to the side has been reported as a risk factor for hip fracture in elderly persons (Greenspan *et al.* 1998), with the impact on the hip or the side of the leg being the biggest risk factor (Hayes *et al.* 1993).

The majority of the participants in the present study reported no or minor injuries as a result of a fall, with only two reporting a hip fracture. These fall outcome figures are similar to previously reported data. During a 12-month study period, 47% of participants reported an injurious fall (Cummings *et al.* 1988). Most of these reported injuries were minor, with 51% of injuries being bruising or swelling. Four percent of participants who fell reported a fracture (Cummings *et al.* 1988), and 5% of falls resulted in a fracture in another study over a 12-month period (Berg *et al.* 1997). These findings demonstrate that fractures, although a serious outcome, only occur in a relatively low percentage of falls.

Thirteen per cent of participants who fell in the study by Cummings *et al.* (1988) did not recall those falls at the end of the 12 months, and 7% of participants stated at the end they had fallen in the 12-month period who had not fallen in that time. The study also found that of those reporting to a nurse after a fall in the 12-months, 52% did not recall having a fall and 40% did not recall having a fall-related injury in the same period. This suggests that it is not only non-injurious falls that may be forgotten, but also falls with more serious consequences. The participants forgetting injuries tended to be only those sustaining minor injuries. However, this study by Cummings *et al.* just covered a 12-month period and the recall difficulties may have had more to do with placing the fall in time rather than the fall event, i.e. the fall may not have been forgotten, but the accuracy of recall of when the fall took place may be a problem. This may have implications for the accuracy of stating when a first fall occurred in the present study.

3.4.6 Fear of falling

The prevalence of fear of falling was 28.4% in the study population. This prevalence is lower than the previously reported figures of 43% in community-dwelling older people (Tinetti *et al.* 1994), but higher than another previous report of 20.8% (Friedman *et al.* 2002). When compared to previous fear of falling data from England, the current study has lower reports of fear than the 46% who reported being a little afraid and the 11% that reported a marked fear of falling (Yardley and Smith, 2002). However, these figures from Yardley & Smith were from community-dwelling individuals aged 75 and over, as opposed to the current study population which had an average age of approximately 70, which may account for some of this difference. Of the non-faller group in the current study, only 6.9% of the respondents expressed a fear of falling. These results show that community-dwelling individuals who have not experienced a fall do not fear falling. This is supported by previous reports suggesting that those who have fallen have a higher fear of falling than those who have not fallen (Li *et al.* 2003; Scheffer *et al.* 2008). It has been previously reported that non-fallers with a fear of falling are more likely to report falls after a 20-month follow-up period than those non-fallers with no fear (Friedman *et al.* 2002). Therefore, non-fallers who do fear falling may be a suitable group to target with falls prevention programmes.

It has been suggested that using situation-specific tasks may limit the usefulness of these fear efficacy scales. In particular, walking in icy conditions may be beyond the experience of older adults living in more temperate geographical regions (Hill *et al.* 1996). However, as the present study was conducted in the UK the use of a climate-dependent item such as walking in icy conditions was appropriate. This was supported by the lowest confidence rating in all groups of participants in the present study being for this walking in icy conditions item, demonstrating it was an activity that respondents felt most at risk of falling whilst engaged in. This item has been changed to walking on slippery surfaces in the FES-I (Yardley *et al.* 2005). This could be a good compromise for future studies to keep an item that clearly causes anxiety, whilst wording the item appropriately that it is applicable in more regions of the World.

Items on the FES have been criticised for not being situation-specific enough, therefore being prone to inconsistencies with individual interpretation (Powell and Myers, 1995). The FES has also been criticised for not having the sensitivity to assess loss of balance confidence in higher functioning seniors (Powell and Myers, 1995). Although the respondents from this study gave scores from fairly confident to completely confident on the items, there were still significant differences detectable between the faller and non-faller groups, despite the respondents all being community-dwelling. These differences were apparent across a range of items, such a walking in icy conditions, cleaning the house and taking a bath, rather than being isolated to a single task. This shows a lower confidence in the ability to carry out many different everyday tasks for fallers than non-fallers, for women than men, and for the inactive respondents than the active respondents.

3.4.7 Limitations

There has never been, and never will be, a randomised, double-blind, placebo-controlled trial demonstrating that physical activity in youth, adulthood or old age reduces fall risk in older persons (Karlsson, 2004). It is not possible to conduct such a study blinded, as the participants will always know if they are randomised to physical activity or not. Even if the study was conducted un-blinded, it would be ethically unacceptable to randomise individuals to a no-physical activity group. Therefore, despite the limitations of a retrospective questionnaire such as this one, this method is the only feasible way to assess lifetime physical activity levels in a current group of older adults.

3.4.8 Conclusions

This is the first time that a questionnaire tool has been designed specifically to retrospectively assess the long-term adherence to physical activity recommendations for health in relation to fall occurrence in older adults. When the physical activity information was coded into two categories based on achieving or not achieving the recommended activity levels, this data could be collected reliably.

The sample population in this study were very active overall, and have been very active as a whole throughout their lifetime. Despite this high level of activity, a substantial proportion of this group had experienced at least one fall. This implies that although this population are highly-functioning, they are still worthy of investigation in falls prevention studies.

There was a trend towards fewer reported falls in those who had adhered to physical activity guidelines throughout their lifetime than those who had not been active enough, although this was not significant. Therefore, the findings from this study do not support the original hypothesis. This lack of significance is not too disheartening, as the aetiology of falls is multi-factorial (Tinetti, 2003) and it is unrealistic to expect falls to be prevented purely through physical activity. However, the evidence suggests that aside from the other health benefits of a physically active lifestyle, there is a tendency towards fewer falls in those that are active. Findings from interventions have shown activities such as Tai Chi (Li *et al.* 2004) to be beneficial in reducing fall rates, suggesting physical activity that incorporates balance training is of benefit. Further research is needed to identify whether physical activity guidelines need to incorporate specific types of activity to decrease fall risk as well as generic advice for health. The ACSM has recently incorporated strength and balance activities into their guidelines aimed specifically at older adults (Nelson *et al.* 2007), however, it may be of more benefit to incorporate these activities into guidelines aimed at all adults to develop habitual physical activity patterns earlier in life and to develop these strength and balance benefits throughout the lifetime rather than once people are already old.

The majority of the falls occurred during activities outside of the home, mirroring the results of previous studies in community-dwelling older adults (Berg *et al.* 1997; Nordell *et al.* 2000; Li *et al.* 2006). This suggests that falls are more likely to occur during dynamic activities such as locomotion. Research on these areas of daily activity to establish any detectable differences between those who fall and do not fall may assist in the identification of those at risk of falling and to provide a greater understanding of the mechanisms involved in placing an individual at increased risk of experiencing a fall event. This will help to identify the individuals who would benefit most from physical activity interventions, to develop interventions specifically to decrease the risk of falling based on the differences that may be present in the balance control systems, and may have implications for future physical activity recommendations both for the general and older populations.

This study shows that leading a physically active life, based on physical activity recommendations, does not have a preventative effect against experiencing a fall in older adults. Therefore, in order to re-address the recommendations for physical activity with falls prevention in mind, a greater understanding of the physical changes that may place certain community-dwelling older adults at greater risk of falling than others is required. From the literature, physical activity has been linked with increased postural stability, gait function and ability to carry out activities of daily living. Therefore, the biomechanical assessment of these activities based on falls status in older adults in the following empirical chapters of this thesis (Chapter 6-7) will provide insight into risk factors for falls in this population and also target areas for physical activity recommendations and interventions to reduce the risk of falling in the community-dwelling older population.

Chapter 4: Static and dynamic stability: implications for falls: Review of Literature

4.1 Introduction

An important prerequisite to the development of fall prevention programmes is an improved understanding of the biomechanical and neuromuscular variables that govern stability. The ability to stand upright on two feet is important in itself, and also as a precursor to the initiation of other activities of daily living (Winter *et al.* 1998). This ability to stand upright is challenged by the human body being an inherently unstable system, due to two-thirds of the mass of the body being located two-thirds of body height above the ground (Winter, 1995b). As a result the body's centre of mass (COM) is located high above a relatively small base of support (the feet), so human stance requires that a large body consisting of multiple flexible segments is kept in an erect posture (Masani *et al.* 2006). Consequently, the body has a high potential energy, leading to the priority of equilibrium control during almost all motor tasks (Gatev *et al.* 1999).

There are three major sensory systems involved in balance and posture – visual, vestibular and somatosensory – which have all been reported to deteriorate with increasing age. The visual system is primarily involved in planning locomotion and in obstacle avoidance (Patla, 1997; Marigold, 2008). Visual acuity and accommodation have been shown to decline with increasing age (Cristarella, 1977) as has visual sensitivity to motion (Wojciechowski *et al.* 1995). The vestibular system acts as a gyroscope, which senses linear and angular accelerations (Winter, 1995b).

Vestibular function declines with age through hair cell degeneration, otoconial degeneration in the otolith organs, and decreasing number of Scarpa's ganglion neurons (Rauch *et al.* 2001). The somatosensory system consists of a multitude of sensors that sense the position and velocity of the body segments, their contact with external objects, and the orientation of gravity (Winter, 1995b). Age-related declines in proprioception (Skinner *et al.* 1984; Shaffer and Harrison, 2007) and in tactile sense in the big toe (Tanaka *et al.* 1996) have been reported which may have implications for the ability of the somatosensory system to contribute to the maintenance of balance.

As a consequence, this reported degeneration of the balance control system with increasing age has encouraged further research to understand more about how the system works and how to quantify its status at any point in time. This could help the understanding of the factors that place some older adults at an increased risk of suffering a fall event during what would appear to be relatively non-problematic everyday tasks. Therefore, this literature review will focus on the control of balance in three such tasks – standing, walking and turning.

4.2 Postural control when standing

It is impossible to stand motionless as even when standing quietly on both feet (Stevens and Tomlinson, 1971), the body sways over its base of support. This is termed postural sway and is the corrective body movement resulting from the control of body position (Sheldon, 1963). Postural stability can be defined as the ability of an individual to maintain the position of their COM within specific boundaries of space, which are termed stability limits (Lord *et al.* 2001). The ability to control postural balance is a prerequisite to performing many of the activities of daily living and underpins the ability to maintain an independent lifestyle (Bryant *et al.* 2005).

4.3 The inverted pendulum model for standing

Postural sway during quiet stance has been modelled as an inverted pendulum, where the body sways above the base of support using the ankle joint as the pivot in the sagittal plane, and as a parallelogram pivoting around both the hip and ankle joints in the frontal plane (Winter, 1995b). This inverted pendulum model relates the controlled variable (COM) with the controlling variable of the centre of pressure (COP). The COP is the point location of the ground reaction force vector and represents a weighted average of all the pressures over the surface of area in contact with the ground (Winter, 1995a). The inverted pendulum model assumes that the body above the ankle joint is rigid and rotates about the ankle, whereas in reality, the body is actually multi-segmented. The presence of joints and soft tissues make it difficult to move the body as a completely stiff inverted pendulum. However, the antero-posterior (AP) and medio-lateral (ML) movements of the whole body COM are highly correlated with the COM of the individual body segments (Gage *et al.* 2004), and the angular motions of the ankle are correlated with the COP excursions in the AP direction with no similar correlations of hip or knee angle (Gatev *et al.* 1999). These findings suggest that despite the body being comprised of multi-linked segments, there is almost synchronous sway of the body parts, further supporting the inverted pendulum model.

A uniform offset between the COP and COM positions of sufficiently long duration would imply accelerations and displacements inconsistent with quiet standing, therefore the COP and COM positions must vary about each other (Benda *et al.* 1994). The COP amplitude is slightly larger than the COM in both the AP and ML directions (Winter *et al.* 1998) as the COP tracks the COM and oscillates either side of the COM to stabilise it around a central position (see figure 4.1). This is consistent with the inverted pendulum model.

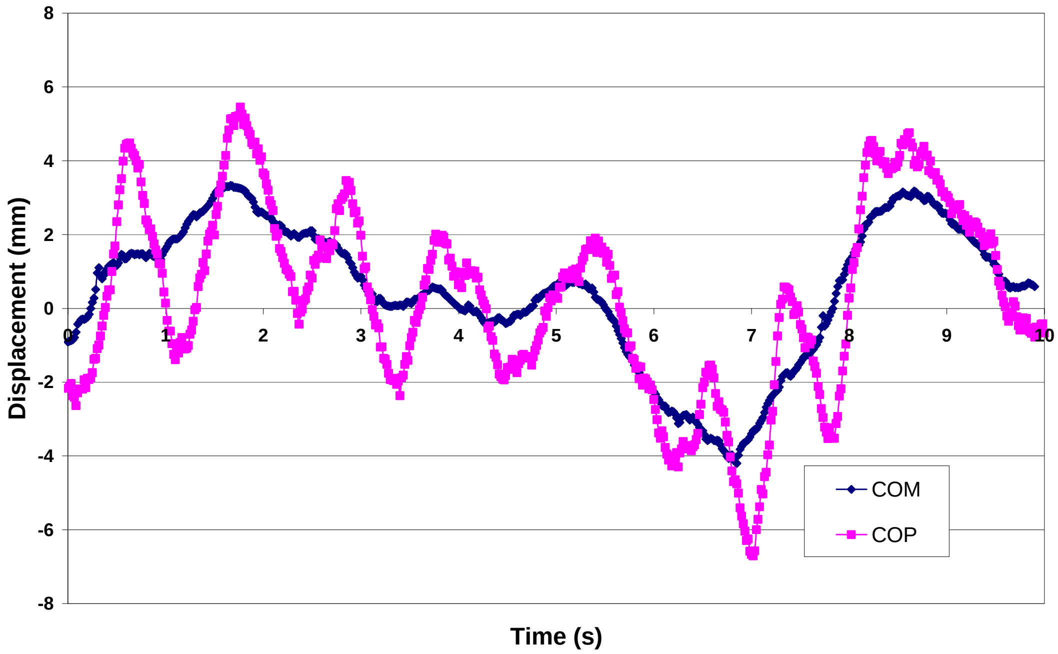


Figure 4.1. Representative data of the COM and COP positions during quiet standing

The difference between the COP and the COM during quiet standing has been shown to be a reliable variable (Corriveau *et al.* 2000; Corriveau *et al.* 2001), and reflects the relationship between the controlling and controlled variables in the balance mechanism of quiet standing when approximated using an inverted pendulum model (Masani *et al.* 2007). The COM-COP variable has been shown to be proportional to the horizontal acceleration of the COM (Winter, 1995b). This high correlation of the acceleration of the COM with the COM-COP separation further supports the inverted pendulum model in quiet standing (Gage *et al.* 2004). The COM-COP separation may be viewed as the “error” signal in the balance control system which causes the COM’s horizontal acceleration. This high negative correlation between the COM-COP separation and the COM acceleration means that when the COP is anterior to the COM the acceleration is backward, and vice versa when the COP is posterior to the COM (Winter, 1995b). The same negative relationship between the COM-COP separation and the COM acceleration applies in the ML direction. However, the excursions of the COP and the COM are greater in the AP than the ML direction in normal standing and in young, healthy adults (Hasan *et al.* 1996).

It is hypothesised that the postural control system adopts a control strategy that relies primarily on velocity information and can modulate the muscle activity in an anticipatory manner (Masani *et al.* 2003). Any change in the velocity of the COM indicates the direction and intensity with which the current COM position will change. The COM velocity information is therefore important for anticipating how COM position will change and what corrective measures need to be taken by the central nervous system (CNS) to compensate for these positional changes (Masani *et al.* 2003). There are no specific receptors for detecting the COM, so the CNS must integrate multi-sensory information to obtain information on the COM position and velocity (Morasso and Schieppati, 1999), for these compensations for balance control to occur.

Differences in the COM-COP magnitude have been reported between young (age 22.9 ± 4.0 years) and elderly adults (age 81.2 ± 6.3 years) in both the AP and ML directions, but not between young and senior adults (age 69.2 ± 2.4 years) (Berger *et al.* 2005a). There were also significant differences in the mean velocity of the COM between the young and the older populations, but the COM velocities were not separated into AP and ML directions. This study was conducted only in the eyes open condition to correspond to normal life situations. However, by also conducting the study with eyes closed, this may have given information about the ability to adapt balance control in low-light conditions, which is also a normal life situation.

Berger *et al.* (2005b) further investigated standing balance in elderly fallers and non-fallers in a subsequent study with community dwelling but highly inactive (walked less than 1 $km.day^{-1}$) and fairly old (mean age of over 84 years) participants. Significant differences were observed between groups for the area and amplitude of COM-COP separation, with larger values observed for the faller group. The larger amplitude in the faller group was interpreted to be caused by increased neuromuscular activity during quiet stance compared to the non-fallers (Berger *et al.* 2005b). It remains to be determined, however, if these differences between fallers and non-fallers are also present in more active community-dwelling populations.

Computer modelling of COM and COP relationships during standing show that a person can tolerate higher anterior velocities of the COM at more posterior COM positions without initiating a fall (Pai and Patton, 1997). As the COM moves to a more anterior position, the anterior velocity of the COM has to be reduced for balance to be maintained. This suggests that balance is not based so much on COM position limits, as COM velocity-position limits. Very few studies, however, have investigated the velocity and acceleration of the COM variable during different tasks, including quiet standing.

4.4 The ankle and hip strategies for balance control

The ankle strategy was first proposed for balance control in the sagittal plane in 1985 by Nashner & McCollum. The ankle strategy applies during quiet standing and predicts that the ankle plantarflexors and dorsiflexors control the inverted pendulum. The ankle plantar/ dorsiflexor mechanisms have been shown to be dominant when standing with a natural stance width (Gatev *et al.* 1999), with the ankle plantarflexors activating to overcome the destabilising torque of gravity on the COM (Runge *et al.* 1999). This stabilisation potential of the ankle plantarflexion torque has limitations, because the moment of inertia of the whole body around the ankle joint is quite high and significant plantarflexion torque will cause the heel to rise (Kuo, 1995). Consequently, in response to a perturbation, if the ankle muscles could not act, a hip strategy would respond to either flex the hip to move the COM posteriorly or extend the hip to move the COM anteriorly (Winter, 1995b). This hip strategy moves the body as a double-segment inverted pendulum with counter-phase motion at the ankle and hip, whereas the ankle strategy moves the body as a single-segment inverted pendulum by producing torque at the ankle. In the circumstance that the base of support is very narrow, in the outermost regions of postural sway, the forces generated by ankle muscles will be insufficient to move the body on any trajectory towards the origin and a pure hip strategy will be adopted (Nashner and Mccollum, 1985).

Activity of the lateral gastrocnemius muscle anticipates the AP motions of the COM and the COP suggesting a predictive manner of the ankle strategy of quiet stance (Gatev *et al.* 1999). There is increased activity of the lateral gastrocnemius muscle when the COM is moving anteriorly to the ankle joint and decreased activity when the

COM is moving posteriorly to the ankle joint. As the COM moves anteriorly to the ankle, this falling forward movement of the COM leads to an increased forward bending force and therefore a loading of the ankle plantarflexors. Contrary, when the COM is moving posteriorly to the ankle, this results in a decreased forward bending force and unloading of the ankle plantarflexors. This is supported by the finding that ankle extensor activity was positively correlated with, and temporally preceded displacement of both the COP and the COM (Masani *et al.* 2003).

In the frontal plane, an ankle strategy for balance control is limited by the small width of the foot. As a consequence, the maximum moment that could be generated by the invertors or evertors would be about 10 Nm, in excess of this would cause the foot to roll over its medial or lateral borders (Winter, 1995b). However, the hip abductors and adductors could generate in excess of 100 Nm (Winter, 1995b), so a combined hip and ankle strategy is generally observed in the frontal plane. A high positive correlation has been observed between the ML motions of the knee and shoulder and a significant negative correlation of the hip position and the hip angle motions indicates that both ankle and hip mechanisms control sway in the frontal plane (Gatev *et al.* 1999).

Elderly women with a history of falling have demonstrated a reduced ability to recover balance from a forward leaning posture using the ankle strategy when compared to healthy young women (Mackey and Robinovitch, 2006). This has been attributed to both a reduction in peak ankle torque and a reduction in the speed of response to regain balance. However, no comparison was made with a group of older women without a history of falling, which may have provided information on whether these were purely age-related changes or whether these measures could differentiate between those with low and high risk of falling.

Significantly increased muscle activation and co-activation of antagonistic muscle groups in the lower limb in the older adults compared to young adults have been demonstrated in quiet standing (Laughton *et al.* 2003). These could be, in part, a compensation for age-related declines in muscle strength. Any weaknesses in the muscle groups of the lower limb could potentially impair the ability to correct for COM movement and effectively prevent a fall. It may be that maintaining these muscles in an activated state, thereby increasing muscle co-contraction, is an attempt to provide additional stability as compensation for increased muscle weakness. Ankle dorsiflexor strength has been shown to be significantly weaker in fallers compared to non-fallers in community-dwelling older women (Skelton *et al.* 2002), which may have implications for the ability to control postural sway by the ankle strategy in these individuals.

When postural control has been challenged by adopting the Romberg stance or one-legged stance, older adults have employed significantly greater rectus femoris and semitendinosus muscle activity than young adults, with no differences shown between the groups for ankle muscle activity (Amiridis *et al.* 2003). This suggests that as greater demands are placed on the postural control system, the older adults will employ a mixed hip and ankle strategy whereas the young adults could accommodate the increased postural requirements by increasing the activity of the ankle muscles alone. The older adults demonstrated significantly greater ankle, knee and hip joint excursions than the young adults (Amiridis *et al.* 2003).

In summary, postural sway characterises normal standing and needs to be controlled to maintain balance. This has been modelled as an inverted pendulum, with the pivot around the ankle joint in the sagittal plane and around both the hip and the ankle joints in the frontal plane. This inverted pendulum can be investigated by examining the COM and COP relationship, and control of this pendulum can be described using ankle and hip strategies. However, although standing balance has been extensively researched, and age-related differences have been reported, there are very few studies examining balance control of quiet standing using COM and COP measures between older persons of different faller status.

4.5 Walking gait

Walking is one of the most common of all human movements and consequently is an integral part of many activities of daily living. Walking has also been reported as one of the most popular forms of physical activity (Feskanich *et al.* 2002; Kurozawa *et al.* 2005). Walking has been reported as the activity at the time of falling in several falls studies (Lipsitz *et al.* 1991; Berg *et al.* 1997; Keegan *et al.* 2004), indicating that increasing the understanding of stability mechanisms during walking are important for identification of those at risk of falling during locomotion.

4.6 Temporo-spatial characteristics of walking

Temporal and spatial variables, such as walking speed, cadence and stride length, are the most common values reported in gait analysis. The ability to maintain adequate walking speeds for reasonable time periods without undue fatigue is important for the maintenance of an independent lifestyle in old age (Bendall *et al.* 1989). Gait speed does not differ between sexes (Smith *et al.* 2002; Helbostad and Moe-Nilssen, 2003; Tirosh and Sparrow, 2004), but there is an age effect with older adults walking on average slower than younger adults (Oberg *et al.* 1993; Smith *et al.* 2002; Menz *et al.* 2003; Gérin-Lajoie *et al.* 2006). Elderly female participants have been shown to walk significantly slower than young female participants (Buzzi *et al.* 2003; Tirosh and Sparrow, 2004). Gait speed appears to get progressively slower across the decades (Lord *et al.* 1996), with a reported ~7% decline per decade after the age of 65 (Bendall *et al.* 1989). Walking speed is associated with fall risk as elderly fallers have been shown to walk slower than elderly non-fallers (Lee and Kerrigan, 1999; Auvinet *et al.* 2003). A gait velocity of <0.8 m.sec^{-1} has been suggested as a cut-off for those community-based individuals who are at risk of falling, with 35% of participants having reported a fall in the previous 6 months (Montero-Odasso *et al.* 2004). However, in all these cases, whether this slower gait was present before the fall, or was a result of having fallen previously, remains to be determined.

A reduction in gait speed may have implications for tasks of everyday living. In one study, 20% of elderly women were found to walk at a slower speed than that required to negotiate a Pelican crossing (Bendall *et al.* 1989). This may limit their confidence and ability to walk around the local community and to conduct activities of daily living that may involve crossing a road. A reduced walking speed may also be more strongly associated with a fear of falling than with the risk of future falls (Maki, 1997). This slowing of walking may allow a greater reaction time to obstacles or other environmental factors that may impinge on walking. For example, older adults who walked at 1.44 ± 0.10 m.s^{-1} were less likely to recover balance after a trip than those walking at 1.13 ± 0.19 m.s^{-1} (Pavol *et al.* 2002). A person walking with a slower gait may have lower initial momentum of the body in the event of a loss of balance, increasing the probability of recovery (Maki, 1997).

Walking speed is a composite of cadence and stride length. Women have been shown to walk at a higher cadence than men when walking at the same speed (Oberg *et al.* 1993; Smith *et al.* 2002). Cadence decreases with increasing age (Lord *et al.* 1996), and elderly fallers have been shown to have a lower cadence than elderly non-fallers (Lee and Kerrigan, 1999; Auvinet *et al.* 2003). When fallers were separated further, multiple fallers have been shown to have a slower cadence than non-fallers or single fallers, with the single fallers showing similar results to the non-fallers (Lord *et al.* 1996). This suggests there is value in dividing faller groups into single and multiple falls as these groups may show different patterns.

Stride length has also been shown to decrease with increasing age (Winter *et al.* 1990), which alongside decreasing cadence will contribute to a decrease in walking speed. Stride length is shorter in women than men (Tirosh and Sparrow, 2004), although the increased cadence observed in women accounts for the walking speed of men and women being comparable. In elderly men, walking speed was ~9.3% slower than young males due to a reduced stride length (Watelain *et al.* 2000). Stride length is shorter in those afraid of falling than those who are not afraid (Maki, 1997). This decreased stride length may promote stability by minimising the forward excursion of the COM beyond the base of support provided by the stance foot (Maki, 1997), however this decreased stride length would still need to be long enough to adequately decelerate the COM at heel strike to maintain stability whilst walking.

Elderly females spend significantly longer in the double support phase than young females (Tirosh and Sparrow, 2004), and again this time in double support appears to gradually increase across the decades (Lord *et al.* 1996). Individuals who are fearful of falling spend longer in double support than those who are not afraid (Maki, 1997). This increased time in double support reduces the amount of time spent balancing on one leg, and therefore reduces the time the COM is outside the base of support (Winter, 1995a). This represents a conservative strategy for balance control and may also increase confidence in older people when walking.

In one study, swing duration was found to be the only spatial-temporal variable that was significantly different between young and elderly participants, with the swing duration being less in the elderly participants than in the young (Mills and Barrett, 2001). This was accredited to shorter stride duration by the elderly participants, and has been shown previously (DeVita and Hortobagyi, 2000). This is consistent with the increased time spent in the double support phase discussed above, and again is representative of a conservative strategy for balance control in older people during walking.

Increased step width has been described as a common feature in elderly gait (Rogers and Mille, 2003). Step width measures have not shown differences between those who have and have not fallen previously (Brach *et al.* 2005), although step width was significantly narrower in those that had fallen sideways previously than those who had fallen in other directions (Ko *et al.* 2007). Increased step width has been associated with fear of falling and also with an increased risk of falling during walking (Maki, 1997). This increased step width may be a result of lateral instability, but may also be increasing lateral instability as this would increase the COM-COP separation and the COM acceleration in the frontal plane. These research findings are slightly contradictory, which may suggest that measures of step width are not that reliable in assessing fall risk.

A paradox occurs because the gait changes, such as a slower walking speed and a decreased stride length and step width, that are thought to represent the adoption of a more stable gait pattern (Maki, 1997; Kaya *et al.* 1998; Menz *et al.* 2003; Cromwell and Newton, 2004; Chamberlin *et al.* 2005) have also been shown to be risk factors for falls (Tinetti *et al.* 1986; Lipsitz *et al.* 1991; Montero-Odasso *et al.* 2004; Montero-Odasso *et al.* 2005). So to take reduced walking speed as an example, although this may appear to be a compensatory strategy, reduced walking speed is also associated with people who fall, suggesting that there is another aspect of their gait that predisposes them to an increased chance of losing balance when walking (Menz *et al.* 2003). This paradox can be explained by the fact that temporo-spatial parameters provide only indirect measures of stability. As a result, these temporo-spatial parameters can only provide limited insights into balance control during walking, and more sensitive measures are needed to gain further understanding on these balance mechanisms and any possible age-related changes that occur which may affect stability during walking.

4.7 The inverted pendulum during walking

In standing, the aim for balance is to keep the COM within the base of support. The body only has to make minor corrective accelerations in the horizontal plane to maintain a near equilibrium. The condition for balance, however, changes with walking as the COM has to move outside the base of support to initiate motion in a particular direction. In steady state walking the COM is always outside the base of support, except during the short double support period (Winter, 1995a). To initiate a forward step, the COM has to be accelerated in an anterior direction, effectively initiating a forward fall. This forward fall is averted by placement of the swing foot, decelerating the forward momentum of the COM. The COM has been shown to move posteriorly with respect to a fixed point in the pelvis at heel strike (Whittle, 1997). Thus, the COM is in a state of dynamic balance during walking, with the COP moving behind and then ahead of the COM in the sagittal plane (see figure 4.2), resulting in the total body gravity force vector passing forward through the COP four times in one gait cycle (Jian *et al.* 1993).

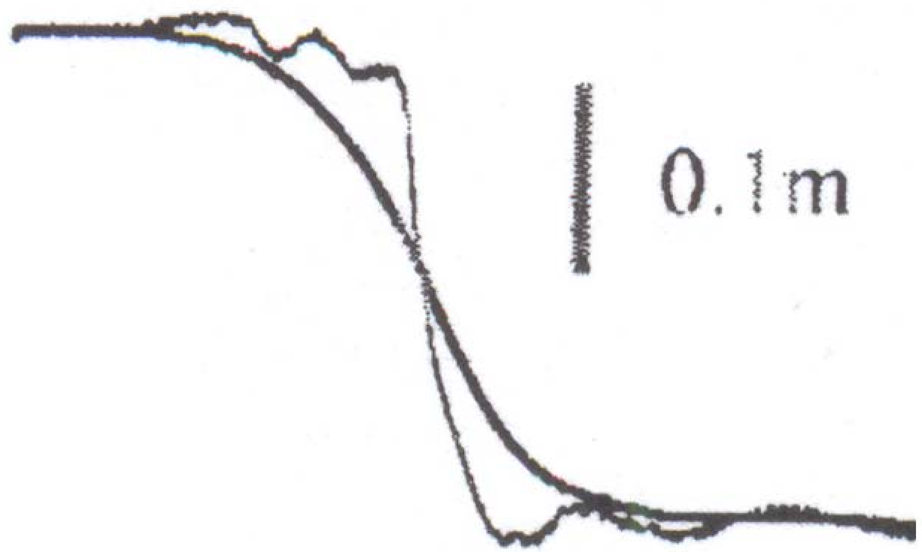


Figure 4.2. The antero-posterior positions of the COM (thick line) and the COP (thin line) against time during walking (Lyon and Day, 1997)

Balance can be controlled during walking by placement of the foot. Any change in foot placement would result in a change in the COP, thus controlling COM-COP separation. This strategy is dominant in both the sagittal and frontal planes during walking, where the placement of the foot is determined by the previous step length and width (Jian *et al.* 1993). Once the foot is placed, the boundaries of the COP are defined. However, the exact position of the COP under the foot can be controlled by the musculature achieving the final trajectory of the COM (Jian *et al.* 1993).

In a model of human gait in the sagittal plane, if a muscle contributed to support during the first half of stance, it concurrently reduced forward progression (Liu *et al.* 2006). In the same model, if a muscle contributed to support during the second half of stance, it concurrently increased forward progression (Liu *et al.* 2006). This is in accordance with the inverted pendulum model. However, in a simple inverted pendulum, forward motion would be hindered by gravity from heel strike to mid-stance (when the pendulum is vertical), whereas after mid-stance, gravity would assist forward motion. In Liu et al's model, they demonstrated that gravity started assisting progression just after the end of double support (~18% of the gait cycle, as opposed to mid-stance at ~32% of the gait cycle). This can only have occurred by dynamic interactions of the segments permitted by the joints of the legs, suggesting that the inverted pendulum model is too simplistic to describe the entire gait cycle.

In this model of human gait in the sagittal plane, the dorsiflexors support the COM of the body whilst slowing forward progression for foot strike to foot-flat, with the hip and knee extensor muscles (vastus lateralis, vastus intermedius, vastus medialis and gluteus maximus) providing vertical support during the first half of stance as they slow forward progression (Liu *et al.* 2006). The plantarflexors generate both support and progression from mid-stance to foot off (Lacquaniti *et al.* 1999; Neptune *et al.* 2004; Liu *et al.* 2006), with the gastrocnemius being more responsible than the soleus for increasing walking speed (Liu *et al.* 2006). The ankle muscles, therefore, are important for control of COM motion in the sagittal plane in walking as well as in standing.

The greatest separation between COM and COP occurs at either the initial (posterior COM-COP distance) or final (anterior COM-COP distance) moment of the single support phase in the sagittal plane (Chou *et al.* 2001; Hahn and Chou, 2004). At heel strike, therefore, the COM is in front of the COP whereas at toe off the COP is in front of the COM. Therefore, during the double support phase, the COP moves rapidly ahead of the COM, and as a result, the COM is decelerated during this transfer of the body weight from one limb to another. (Jian *et al.* 1993). As a result, the foot and the stance leg must provide stability to permit the COM to move in front of the base of support (Judge *et al.* 1996).

Frontal plane balance during walking poses a difficult challenge due to the narrow width of the base of support during the single support phase, which represents the largest portion of the gait cycle. Therefore, frontal plane balance requires precise control of the trajectory of the COM (MacKinnon and Winter, 1993). An inability to control whole body motion in the frontal plane could result in a loss of balance and consequently a sideways fall. This is of particular concern to the older population as a fall to the side is associated with an increased risk of hip fracture (Greenspan *et al.* 1998).

In the frontal plane, the position of the COM shows a sinusoidal pattern (see figure 4.3), in phase with the alternating left-right square-wave pattern of the COP (Hof *et al.* 2007). The COM is located outside or slightly within the medial border of the supporting foot throughout walking, and therefore medial to the COP (MacKinnon and Winter, 1993; Jian *et al.* 1993). The COM approaches the trajectory of the COP from heel strike until the mid-stance; the COM-COP separation then increases as the COM follows the movement of the swing leg (Xu *et al.* 2004). The body gravity vector, therefore, passes through the COP twice in a gait cycle, one in each double support period (Jian *et al.* 1993).

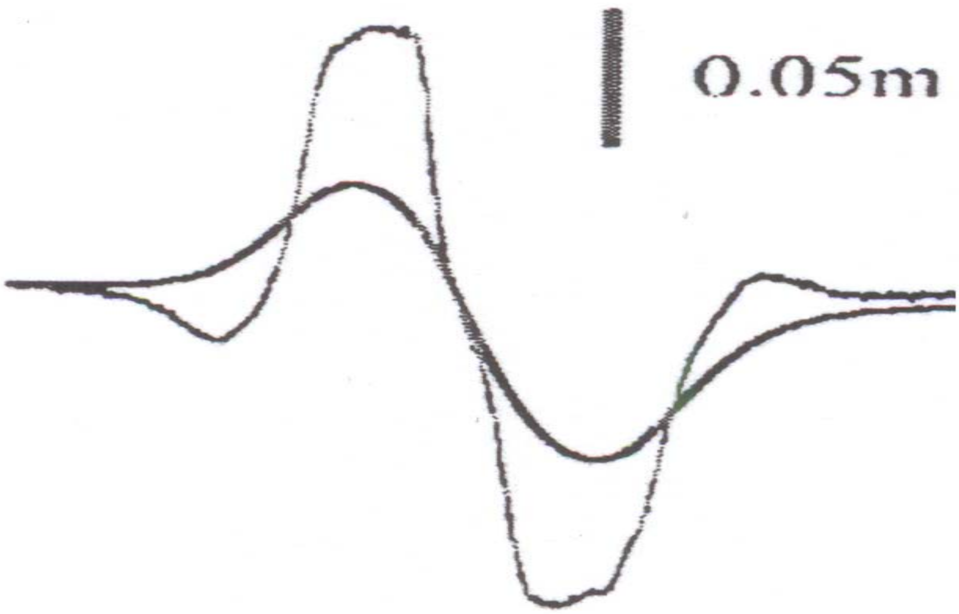


Figure 4.3. The medio-lateral positions of the COM (thick line) and the COP (thin line) during walking (Lyon and Day, 1997)

Peak COM velocity in the frontal plane occurs during the double support phase (Chou *et al.* 2001). Balance in the frontal plane has been shown to be regulated from mid-double support to the next mid-double support (MacKinnon and Winter, 1993). This is achieved by directing the horizontal acceleration of the COM towards the centre line of the plane of progression. Consequently, the polarity of the acceleration of the COM changes during the double support period. The hip abductors, particularly gluteus medius, are proposed to play a significant role in maintaining ML stability as the COM shifts rapidly between each foot (Hahn *et al.* 2005).

As the balance control system declines with age, it is reasonable to expect that a reduced ability to maintain dynamic stability would be evident in the coordination of the COM with the COP. Older persons have demonstrated significantly less maximal AP COM-COP separation than young adults, but there was no significant difference in maximal values in the ML direction (Hahn and Chou, 2004). This suggests that a conservative strategy is adopted by these elderly participants in order to reduce the distance between the COM and the COP in the sagittal plane. However, these participants were also able to adequately maintain frontal plane stability compared to the younger participants.

In young, healthy participants, displacement of the COM in the ML direction showed a decreasing trend with increased walking speed (Orendurff *et al.* 2004), so age-related reductions in walking speed may present additional challenges to the balance control system due to this observed increase in ML COM motion.

Although no significant differences between young and older adults for peak COM velocity in either the AP or ML directions were found, Hahn & Chou (2004) reported a trend of greater COM velocities for the younger adults in the sagittal plane. This may be related to the trend of greater walking velocities for the younger adults that were also observed in this study. This significantly reduced COM-COP separation and the observed reduction in COM velocity in the sagittal plane in the older adults could reduce the mechanical challenge of walking in these older adults (Hahn and Chou, 2004).

In summary, although temporo-spatial variables such as walking speed and stride length have been widely reported in the literature and age-related differences have been observed in these measures, few differences have been observed between those at risk or not at risk of falling unless those who have fallen are particularly frail. There is also an apparent paradox between changes associated with increased stability and changes associated with increased risk of falling. This arises partly because temporo-spatial measures, such as walking speed and stride length, only give an indirect measure of stability and are in all probability not sensitive enough to detect differences in stability between those at low-risk and at high-risk of falling in groups of otherwise healthy older adults. To obtain more direct measures of stability, COP and COM values need to be taken. These have demonstrated age-related effects, and sensitivity to changes in balance control, but have not been extensively studied in healthy older adults to try and obtain a better biomechanical understanding of why some people are more at risk of suffering a fall event.

4.8 Turning

Nearly all research involving human gait is focused on walking in a straight line. This is despite turning being identified as one of the fundamental components of mobility (Berg *et al.* 1989) and that 35-45% of steps involve turning in common everyday tasks (Glaister *et al.* 2007). Staggering when turning is a prominent characteristic of recurrent fallers (Tinetti *et al.* 1986), and those who are unsteady during turning are more likely to fall whilst turning (Topper *et al.* 1993). If an individual does experience a fall during turning, they are 7.9 times more likely to fracture their hip than if the fall occurred when walking in a straight line (Cumming and Klineberg, 1994). These findings suggest that turning could be a greater challenge to older people at risk of falling than walking straight ahead, and often results in more serious consequences.

Improving the current understanding of the biomechanics of turning could lead to the identification of those at increased risk of a fall during turning, and the development of interventions designed to improve mobility and reduce the risks of falling whilst turning in older adults. However, there is currently only limited research available on turning. The published research in relation to non linear walking and turning that is reviewed in the following sections has been divided into three main categories: walking a circular path, changing direction during walking and turning on the spot.

4.9 Walking a circular path

Turning in the context of walking a circular path is defined as a change in the COM trajectory in the horizontal plane with the simultaneous rotation of the trunk to maintain its orientation to the new direction of travel (Orendurff *et al.* 2006). So instead of turning a corner to re-orientate the direction of travel, the direction of travel itself follows a curved trajectory.

The head has been shown to oscillate in the horizontal plane during walking in a circle in synchronisation with the bipedal locomotor cycle (Grasso *et al.* 1996). However, this head oscillation has been found to be less than the oscillations in walking direction, indicating a form of head stabilisation. Head stabilisation has also been observed in other locomotor tasks such as walking, running and hopping (Pozzo *et al.* 1990). The head orientates itself toward the inner part of the curved trajectory, and as this was observed in the eyes open but not eyes closed condition, this head orientation is believed to be of visual origin (Grasso *et al.* 1996). This head yaw was also found to be anticipatory (100-200ms prior to the changes in the direction of locomotion with respect to walking directional changes). Therefore, vision is important in walking along non-linear travel paths, shown by this anticipatory head orientation to the new direction of travel, so age-related differences in turning may be observed due to the age-related changes in the visual system (Cristarella, 1977).

During walking on a 180° circular path, the COM shifted directly over the inside limb during foot contact at a self-selected turning speed (see figure 4.4b), and was well inside the inside limb during foot contact at faster speeds (~1.2 $m.s^{-1}$) in young healthy adults (Orendurff *et al.* 2006). Where in straight line walking, the COM trajectory oscillates in a sinusoidal pattern between the feet from supporting foot to supporting foot (figure 4.4a), when walking on a circular path (1m radius) the COM remained over the inside foot even when the outside foot was providing all the support. However, at slower speeds (~0.6 $m.s^{-1}$), the trajectory of the COM oscillated between the inside foot (during support) and midway between the two feet when the outside foot was giving support (Orendurff *et al.* 2006). During the faster turns, the lean of the trunk counteracting the centripetal force of the turn resulted in the COM following the path of the inside foot throughout. At these faster turning speeds, therefore, the inside foot placement is particularly important in maintaining stability during the turn. At slower speeds, however, less trunk lean was observed during turning resulting in the COM following a more oscillatory trajectory. This allowed the COM to be accelerated back towards the outside foot when this foot provided the support (Orendurff *et al.* 2006). This slower pace of turning, therefore, may be preferable for maintaining stability.

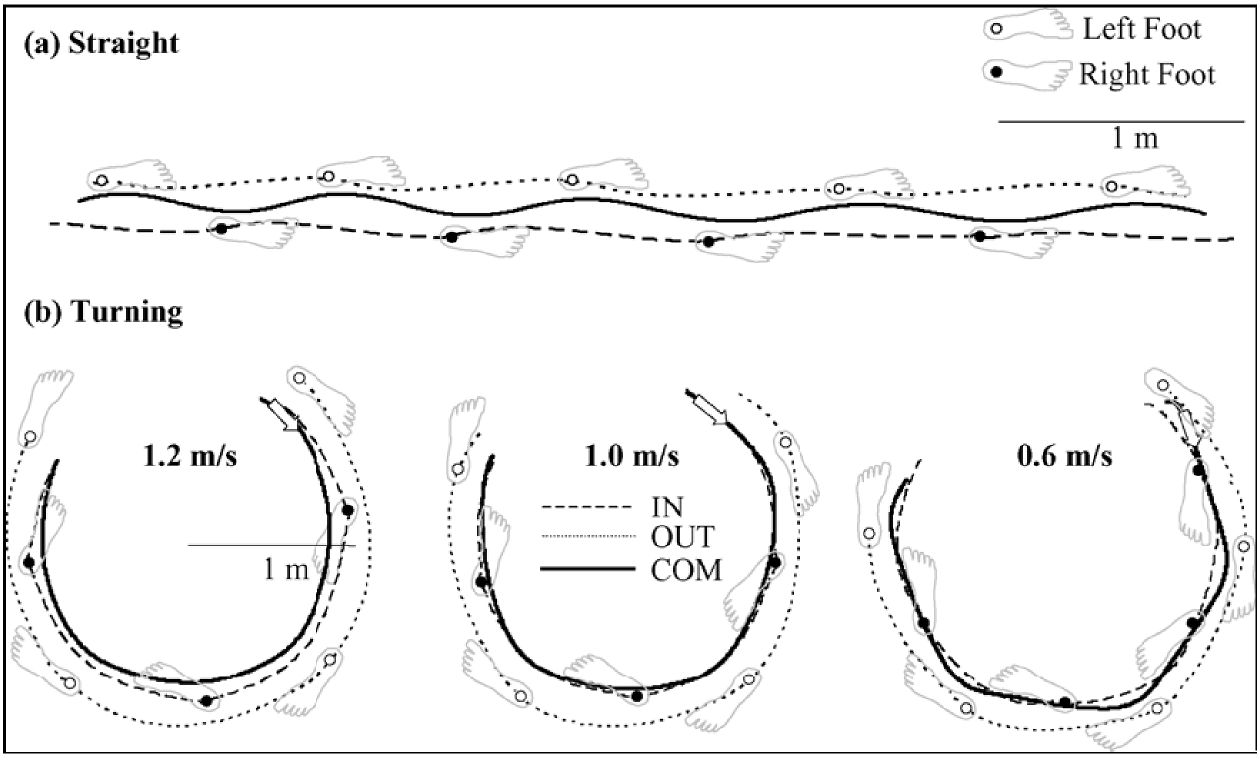


Figure 4.4 COM trajectory (bold line) in relation to ankle joint centre paths during straight line walking (a) and during walking a circular path (b) at 3 different speeds (Orendurff *et al.* 2006)

4.10 Changing direction during walking

In order to change direction during walking, a person has to translate and rotate their body to a new orientation. This process does not involve stopping to re-orientate, instead it represents a transition period between two phases of walking. As a result, the process of turning consists of decelerating the forward motion, rotating the body, and stepping out toward the new direction (Hase and Stein, 1999).

Two strategies have been identified for turning 180º when walking – a spin turn and a step turn (Hase and Stein, 1999). The stance leg in the spin turn plays a major role in decelerating the body and acting as the axis for turning. This strategy cannot be used if the initiation of turning occurs after the COM passes over the stance foot, as the stance foot would subsequently be unable to decelerate the COM sufficiently for the turn. In the step turn, both feet continue to step and each can serve as the axis for part of the turn. The step turn strategy is easier and more stable due to the wider base of support during the direction change than in the spin turn (Hase and Stein, 1999). This may make the step turn strategy a preferable option than the spin turn strategy in individuals with balance impairments. However, in a study of turning during activities of daily living, the spin turn was not observed suggesting that the step turn is the choice in everyday tasks (Glaister *et al.* 2007).

Multiple fallers have been found to take more time and more steps to turn during a 180º turn taken during gait. The participants who had experienced multiple falls in the previous 6 months took on average an extra two steps to complete the turn compared to those who had only experienced one fall (Dite and Temple, 2002). This could be a conservative strategy adopted by the multiple fallers for balance control.

In a study involving a 40º turn during walking, the use of two steps as opposed to one to turn was significantly related to balance confidence (Fuller *et al.* 2007). So this increased number of steps could be viewed as adopting a conservative approach to turning to provide more time to re-orientate the body into a new travel direction.

In both the spin and the step turns, the ankle plantarflexors generate greater moments during the braking phase of the turn than walking in a straight line (Xu *et al.* 2006). This suggests that the plantarflexors act eccentrically to arrest the forward momentum of the COM during the turning stride. Reductions in the strength and power of the plantarflexors have been observed in older compared to young adults (Perry *et al.* 2007), which may affect the ability of older adults to control the forward momentum of the COM during this turning stride. There were also significant decreases in the knee and hip extensor moments during the propelling phase of the turn compared to straight line walking (Xu *et al.* 2006). This suggests that there is less demand for forward momentum during the turn, as the body is stabilised to its new direction.

The spin turn creates greater ankle invertor moments than the step turn (Xu *et al.* 2006). This greater stabilisation demand on the ankle muscles may make the spin turn less preferable than the step turn in individuals with weaker ankle muscles. The spin turn also creates greater hip abductor moments than the step turn (Xu *et al.* 2006).

Changing direction during walking involves the rotation of the body towards the new direction and lateral translation of the COM, which are superimposed onto the normal forward progression of the COM (Hollands *et al.* 2001). The trajectory pattern of the

COM and the COP and the COM-COP distance changes during the prior and ongoing steps when a turn is incorporated into walking (Xu *et al.* 2004). In the step prior to the turn, the COM starts to shift in anticipation towards the direction of the new path of travel. The participants lean into the turn which results in the COM being positioned lateral to the COP, whereas in straight line walking the COM would remain medial to the COP. This shows an anticipatory strategy before and during the turn action.

Hollands *et al.* (2001) found in young participants that the head and trunk rotate to the direction of the turn to re-orientate the body in the direction of travel. The COM also displaces to the direction of the turn, which reflects a lateral translation of the body in the direction of the turn. A clear sequence of reorientation onset is demonstrated; first head yaw, then trunk yaw, trunk roll, COM, and finally ipsilateral foot ML displacement (Hollands *et al.* 2001). This "top-down" segmental sequence of reorientation was also observed in healthy older adults executing a 40º turn during walking (Fuller *et al.* 2007). This change of direction of the COM is achieved through the ML hip strategy (Patla *et al.* 1999), and is quantitatively described through measurements of trunk roll (Hollands *et al.* 2001).

In a condition where the head was immobilised to the trunk, this resulted in a significant change to the sequence of orientation onset during the turn. The head and trunk yaw onsets were the same, as a result of them being fixed, but trunk roll now followed COM (Hollands *et al.* 2001). As a result, trunk roll could not have been responsible for reorientating the COM in the new travel direction. A wider step width strategy was used instead prior to the onset of the turn step to initiate the acceleration of the COM in the new travel direction. This results in a greater COM-COP separation and therefore greater COM acceleration as the COM-COP separation is related to the COM acceleration (Winter, 1995a), although this may have implications for stability during the turn in individuals who may use a COM followed by a trunk roll turning strategy.

In participants who had suffered from stroke, the sequence of the segment reorientation onset was altered as a 90º turn was initiated from straight line walking. In these participants, the onset of head reorientation tended to be more synchronous with that of the thorax and pelvis (Lamontagne *et al.* 2007). Similar patterns were also observed in participants with Parkinson's disease when executing 60 and 120º turns during walking (Huxham *et al.* 2008). These studies show that turning strategies may be altered by some medical conditions, resulting in a more en-bloc turning strategy. As both of these patient groups are considered at risk for falling, the investigation of segment reorientation onset at turn initiation is of considerable importance in faller populations.

4.11 Turning on the spot

Turning not only occurs during walking, but also occurs from a stationary position both to achieve a new stationary position and also to then initiate walking. This is important for many activities of daily living.

Turning on the spot is utilised in some clinical tests to delineate fallers from non-fallers in older adults. The 360º turn is an item on the Performance Orientated Mobility Assessment (Tinetti, 1986) and the Berg Balance Scale (Berg *et al.* 1989), and is concerned with the ability of an individual to maintain their equilibrium whilst in motion. Normal turning movement has been rated as the ability to complete a 360º turn in under 4 seconds (Berg *et al.* 1989). Fallers have been shown to take longer to turn and use more steps than non fallers (Lipsitz *et al.* 1991), however the participants in this study were particularly frail so the findings may not be applicable to a healthy, community-dwelling older population.

Elderly adults need to use more steps when turning 180° than young adults, with young adults employing a predominantly pivot method of turning rather than a stepping and weight shifting strategy (Thigpen *et al.* 2000). Some elderly adults also display the pivot turn, and these individuals also do not report problems walking when turning. Elderly adults took longer to complete the turn than young adults, with the adults who reported difficulties turning taking the most time (Thigpen *et al.* 2000).

There are only a limited number of studies of turning on the spot, and of these, none investigate dynamic stability by investigating COM velocity and acceleration or COM-COP relationships. Further research using these measures will therefore further knowledge and enhance understanding of the mechanisms involved in stability during turning from a stationary position.

In summary, it is clear from the literature that turning is a motor skill that is required for mobility and when performing activities of daily living. There are many ways that turning is incorporated into activities from both a static position and also in locomotion. The majority of the research conducted in this area appears to have focussed on the incorporation of a turn into walking, and also in healthy young adults.

There is scope for further investigation in many areas with turning, particularly in the investigation of age related differences that may exist in turning strategies, and to investigate whether differences exist that may place some individuals at a greater risk of experiencing a fall.

4.12 Conclusions

Biomechanical measures of dynamic stability in these areas of standing balance, gait and turning could not only provide further information about any age-related differences, but also provide information on differences that may exist between faller groups of older persons. This could provide valuable information for both diagnostic and intervention strategies with the aim of reducing the risk of falling. Therefore, research is needed in groups of older adults with and without a history of falling using measures such as COM-COP separation to evaluate whether these variables can detect differences between those who fall and those who do not. Such research should provide insight into what places certain individuals at risk, and also enable the identification of key variables that can be used to detect risk and to assess the efficacy of intervention measures for fall prevention.

Chapter 5: Methods for the standing, walking and turning studies

This chapter reports the methods used to collect data from the laboratory testing sessions. Measures of stability were obtained in three study conditions – quiet standing, walking and turning in groups of young and community-dwelling older adults. The results are reported in chapter 6 and discussed in chapter 7.

These chapters aim to investigate whether any differences are apparent in the dynamic stability measures of COM and COP during these standing, walking and turning tasks, and also to investigate segmental reorientation onset during turning, based on age and fall status. For quiet standing, it was hypothesised that the older adults would demonstrate greater sway paths of these variables and faster sway of their COM than the young adults, and that older adults who had fallen would have greater sway paths and faster motion than the older adults who had not experienced a fall.

During walking, it was hypothesised that the older adults would walk more slowly than the young adults and use a shorter stride length. It was also hypothesised that there would be differences in dynamic stability between the faller groups, with the multiple fallers showing greater COM-COP separation and larger COM velocities and accelerations than the non-fallers.

For the turning study, it was hypothesised that the older adults would take longer to turn and utilise more steps than the young adults. It was also hypothesised that the older adults, particularly the multiple fallers, would demonstrate a more en-bloc strategy at the initiation of the turn than the young adults and less dynamic stability indicated by increased COM-COP separation and increased COM motion.

5.1 Participants

Ninety respondents were randomly selected from the LPAFH study and invited to take part in further testing. Forty-two replied and took part in the biomechanical elements of this thesis. Thirteen participants were male (age 72.9 ± 3.7 years; height 175.6 ± 6.9 cm; mass 79.6 ± 17.3 kg) and twenty-nine were female (age 69.8 ± 7.1 years; height 162.5 ± 7.1 cm; mass 69.3 ±10.8 kg). All of the older participants reported themselves free from any neurological or musculo-skeletal impairment prior to the laboratory session, and were able to walk at least 100 m without the use of a gait aid at the time of testing. The older participants were split into 3 groups (table 5.1) – non fallers (NF), single fallers (SF) and multiple fallers (MF) – based on their fall history as reported in the LPAFH (chapter 3). The older participants were asked further questions on the day of testing to confirm that they had not experienced a fall between completing the LPAFH and laboratory testing that would influence the faller group into which they were assigned. The older adults were also asked to complete the 7-day recall Physical Activity Scale for the Elderly (PASE) questionnaire (Washburn *et al.* 1993; Schuit *et al.* 1997; Dinger *et al.* 2004) to give an indication of their physical activity level at the time of testing. Fifteen young participants (8 males, age 24.9 ± 3.7 years, height 176.7 ± 5.6 cm, mass 76.2 ± 11.3 kg; 7 females, age 26.7 ± 2.4 years, height 171.2 ± 3.8 cm, mass 62.6 ± 8.7 kg) were also recruited from the local community to act as a young control group. All participants completed a pre-test health-screening questionnaire (appendix VI) in accordance to the laboratory's standard operating procedure and gave written informed consent (appendix VII). Ethical approval was granted through Institutional procedures at Department level. Participants were requested to wear shorts, and either shirtless (males only) or short-sleeved/ sleeveless tops. Participants wore shoes throughout, as this is more representative of "real life" conditions than bare foot. These shoes were requested to be "typical everyday shoes", with no higher than a low heel and therefore did not bear characteristics associated with an increased risk of falling (Tencer *et al.* 2004).

Table 5.1. Participant details

	Young adults (n=15)	Non-fallers (n=15)	Single Fallers (n=13)	Multiple Fallers (n=14)
Age (years)	25.7 ± 3.2	70.7 ± 6.2	70.0 ± 6.3	71.5 ± 6.9
Height (m)	1.74 ± 0.06	1.68 ± 0.08	1.65 ± 0.10	1.67 ± 0.12
Mass (kg)	69.8 ± 12.0	70.5 ± 11.5	70.3 ± 12.3	73.3 ± 11.6
Active days in current decade	N/A	4.0 ± 1.9	4.2 ± 1.7	3.2 ± 2.2
PASE score	N/A	131.4 ± 45.0	142.8 ± 64.8	123.1 ± 63.9

Two older participants, who formed part of the single faller group, were unable to take part in the final part of testing due to time constraints. Therefore, the single faller group for the turning study consisted of 11 older adults (age 70.2 ± 6.1 years, height 1.66 ± 0.10 m, mass 70.0 ± 12.8 kg).

5.2. Laboratory set-up

The laboratory space measured 17 x 12 m, and the capture volume was defined in accordance with the International Society of Biomechanics recommendations (Wu and Cavanagh, 1995). Whole body motion data were collected at 60 Hz using a 14-camera Vicon M2 (624) system (Vicon Peak, Oxford Metrics Ltd., UK; for camera positions please see appendix VIII). The system was calibrated prior to testing for each participant and a mean calibration residual value of <1.5 mm was accepted.

Forty-two retro-reflective markers (14 mm) were placed on specific anatomical landmarks on the participant to represent a full body marker set. The markers were applied directly to the skin (where possible), onto clothing or on elasticated bands (e.g. the head markers were placed on a headband). The full-body marker set was adapted from the Vicon Plug-in Gait (PiG) marker set (see appendix IX). Additional markers were placed on the left and right 5th metatarsals, so that 4 markers were used to define each body segment. Additional markers were temporarily placed on the inside of the left and right knees and ankles for the static trial and then removed prior to the standing balance trials. This was to provide a measure of knee and ankle widths for the subject parameter files required within the Vicon software.

Ground reaction forces were collected by two force plates (AMTI BP400600NC, Watertown, USA), embedded in the floor of the laboratory with their top surface flush with the laboratory floor. The force plates were in parallel for the standing trials and the starting position of the turning trials, and in series for the gait trials. The force plate data were captured at 120 Hz and time-synchronised to the motion capture system.

5.3 Test protocols

Participants were instructed to take up a comfortable posture of quiet erect standing with feet side-by-side, with a foot placed on each force plate, with their arms by their sides and facing straight ahead. No further direction was given to foot placement to encourage the participant to adopt as close to their normal standing posture as possible. This was to reflect actual performance of the individuals (Pajala *et al.* 2008). Data were collected for 30s with the participant either having their eyes open

(EO) or their eyes closed (EC). The order of application of EO and EC conditions was randomised among the participants. Two minutes rest was given between trials, where the participant was free to move around, and three trials were conducted in each condition.

For the walking study, participants were instructed to walk at their self-selected velocity across the laboratory. The participants were not given instructions on foot placement across the force plates, so that they would not alter their stride pattern to strike the force plates. Walking trials were conducted until there was a minimum of three trials with clean foot strikes on both force plates.

For the turning study, the participants were instructed to start with one foot placed on each of the two force plates in a side-by-side stance. They were then asked to turn 360^{o} at their own speed, and participants self-selected their turning direction to make the movement as natural as possible. After the opportunity to practice was given, a minimum of 3 trials were conducted, and a minimum rest period of 2 minutes was given in between trials.

5.4 Data processing

Vicon Workstation software (Vicon Peak, Oxford Metrics Ltd., UK) was used to reconstruct the data from each camera into three-dimensional trajectories. Gaps of below 0.1 seconds were filled in Workstation using a cubic spline interpolation (Meng *et al.* 2006).

5.4.1. Centre of mass

The position of the whole body centre of mass (COM) was computed in Vicon Bodybuilder software (Vicon Peak, Oxford Metrics Ltd., UK) using a model based on Vicon's Golem model. Whole body COM was the weighted sum of each body segment's COM using a 13-link biomechanical model (Dempster, 1955). The validity of COM estimation from the PiG marker set has been demonstrated previously (Gutierrez-Farewik *et al.* 2006).

5.4.2 Centre of pressure

Centre of pressure data was combined from both force plates to provide a single centre of pressure:

$$COP = COP_1 \frac{Fz_1}{Fz_2 + Fz_1} + COP_2 \frac{Fz_2}{Fz_1 + Fz_2}$$

where COP_1 and COP_2 are the COPs on the 2 separate force plates and Fz_1 and Fz_2 are the ground reaction forces on force plate 1 and force plate 2.

During the standing trials, the positions of the COP and the COM were then computed within Bodybuilder based on a local coordinate system that used the central point between the two feet as the origin and a horizontal X-Z plane. This was to account for the fact that there was no standardisation of foot placement, due to the focus being placed on a normal standing position. This data was then exported from the Vicon software in ASCII format.

The COM and COP data were then filtered using a 2nd order, multi-pass Butterworth filter with a cut-off frequency of 10 Hz (Winter *et al.* 1974; Giakas, 2004). Any gaps in the data (due to marker occlusion) greater than 0.1 seconds were still present in the data. Where a gap in the data appeared, a multi-pass filter such as Butterworth would introduce artefacts into the data at the edges of the missing data sections (see appendix X). To prevent this, any gaps were filled prior to filtering using a spline interpolant. These interpolated data were then removed from the filtered data, so only actual recorded data entered the data analysis stage.

The range of motion (ROM) of the COP and the COM was calculated in both the AP and ML directions. The root mean square (RMS) of the COP and COM signals were also calculated. The horizontal distance between COM and COP was calculated. The peak velocity and acceleration of the COM was calculated as was the RMS of the velocity and acceleration signals.

5.4.3. Temporo-spatial parameters during walking

Foot strike and foot off positions were determined in Workstation based on force plate data. When the participant was not on the force plates, the foot strike and foot off timings were determined by correlation of the movement pattern of the ankle marker trajectories recorded during contact with the force plates. The times that these gait events occurred were used to calculate swing time, double support duration and single support duration, and the percentages of swing time that were spent in both single and double support. Stride time was calculated as the time from foot strike to the next foot strike of the same foot. Stride times were calculated separately for left and right feet.

Stride length and step width were also calculated. The positions of the ankle markers at foot strike were used and the cosine rule was utilised to calculate the required distances.

5.4.4 Body segments for the turning trials

The head, thorax and pelvis were modelled as segments using the PiG model and exported with Vicon Workstation software in ASCII format. Each segment was defined by 4 markers placed in accordance with the PiG marker set. The head segment was defined by 2 markers placed on the anterior surface of the head and 2 markers placed on the posterior surface of the head equidistant from the midline. The thorax segment was defined by markers place on the 7th cervical vertebra, the 10th thoracic vertebra, the jugular notch and the base of the sternum. The pelvis segment was defined by markers on the left and right anterior and posterior superior iliac spines.

The velocity of the segments was calculated. These segment velocities were then used to define the start and finish of the turn. The turn was initiated from a standing position, and during standing, participants' body segments naturally oscillate around a fixed position. This introduced a problem in the correct identification of the start of the turn. The turn was therefore defined as a single, continuous, rotational movement in one direction. This approach allowed an objective isolation of the turn segment of the data by mathematical analysis. It was assumed that the greatest rotational velocity of the segments would occur during the actual turn event. This maximal rotational velocity was identified and the area of interest in the data was expanded forward and backward from this point until rotational velocity reached zero. The turn was then identified as the point where the first of the three measured body segments started turning until the point when the rotational velocity of the last of those segments returned to zero (for further details, see appendix XI).

The absolute times and percentages of total turn times were calculated for segment latencies. Thoracic, pelvic and foot off onset latencies were calculated with respect to head rotation onset. Pelvic and foot off onset latencies with respect to thoracic rotation onset, and foot off latency with respect to pelvic rotation onset were also calculated.

5.5 Statistical analysis

All statistical analysis for the standing data was conducted with a mixed model (group x condition) ANOVA. Any differences between groups were investigated through post-hoc analysis using t-tests with a Bonferroni correction.

For the walking study, temporo-spatial data for the four groups were analysed for all measures using a one-way ANOVA. Post hoc analysis using t-tests with a Bonferroni correction identified the location of any differences between the groups. The COM and COP data were analysed using an ANCOVA using walking speed as a covariate, as there was a significant difference between groups for walking speed ($F = 9.135$, $p < 0.001$, Eta Squared = 0.341). Contrast analysis using t-tests with a Bonferroni correction identified the location of any differences between the groups.

For the turning study, turn time, number of steps and segment latencies were analysed using a one-way ANOVA. Post hoc analysis using t-tests with a Bonferroni correction identified the location of any differences between the groups. The COM and COP data were analysed using an ANCOVA using turn time as a covariate. Contrast analysis using t-tests with a Bonferroni correction identified the location of any differences between the groups.

If a significant difference was detected, the effect size was also calculated. The level of significance was set at $p = 0.05$.

Chapter 6: Results for the standing, walking and turning studies

This chapter presents the results from the laboratory testing described in chapter 5. The results are split into sections based on task, first the standing balance study, followed by the walking study and finally the turning study. These results are then discussed in chapter 7.

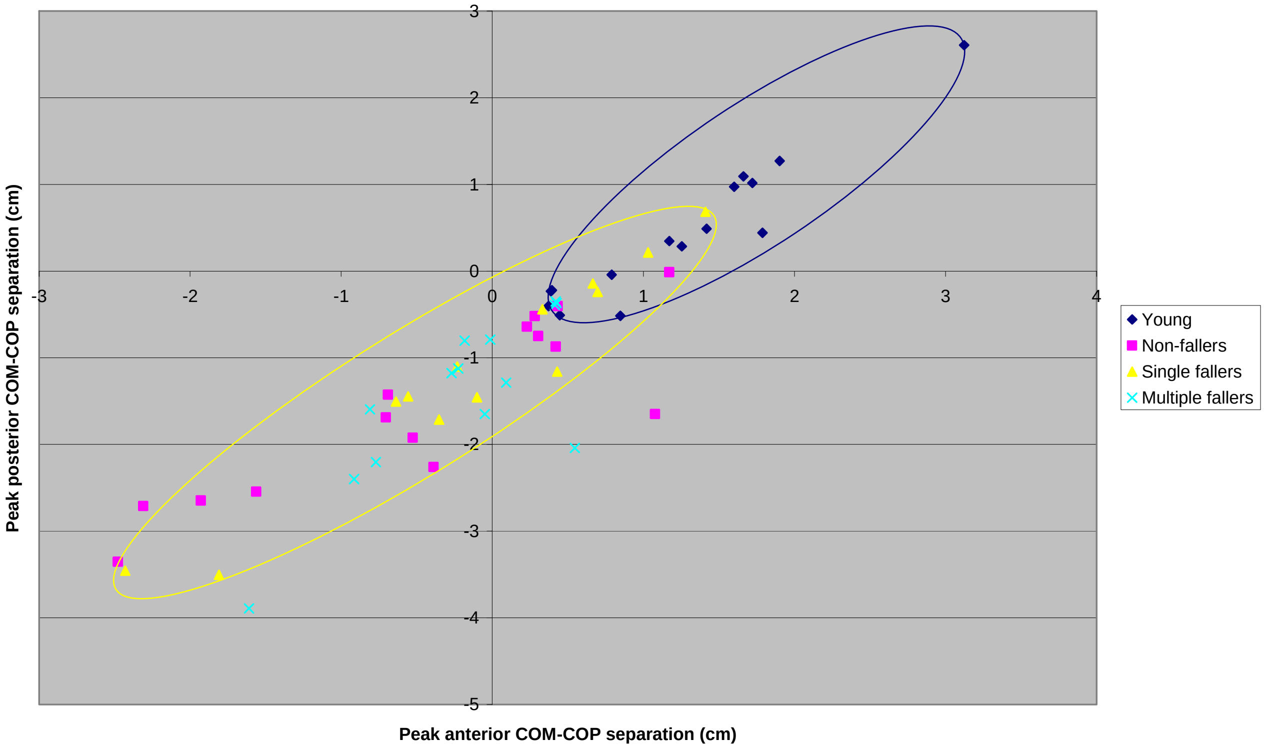
6.1 Quiet standing

Details of the range of motion (ROM) and amplitudes of the COM and the COP and the separation between them are displayed in table 6.1. There was a significant main effect for the EO/EC condition for both ROM ($F = 4.287$, $p = 0.043$, Partial Eta Squared = 0.075) and amplitude ($F = 4.683$, $p = 0.035$, Partial Eta Squared = 0.081) of the COP in the AP direction, but not in the ML direction (ROM $F = 1.003$, $p = 0.321$; RMS $F = 0.884$, $p = 0.351$). This shows an increase in both the range of the sway path and the amplitude of the COP in all groups in the EC condition compared to EO. There were no significant differences between the groups for ROM (AP $F = 1.634$, $p = 0.193$; ML $F = 2.086$, $p = 0.113$) or for the amplitude (AP $F = 0.739$, $p = 0.534$; ML $F = 1.936$, $p = 0.135$) of the COP.

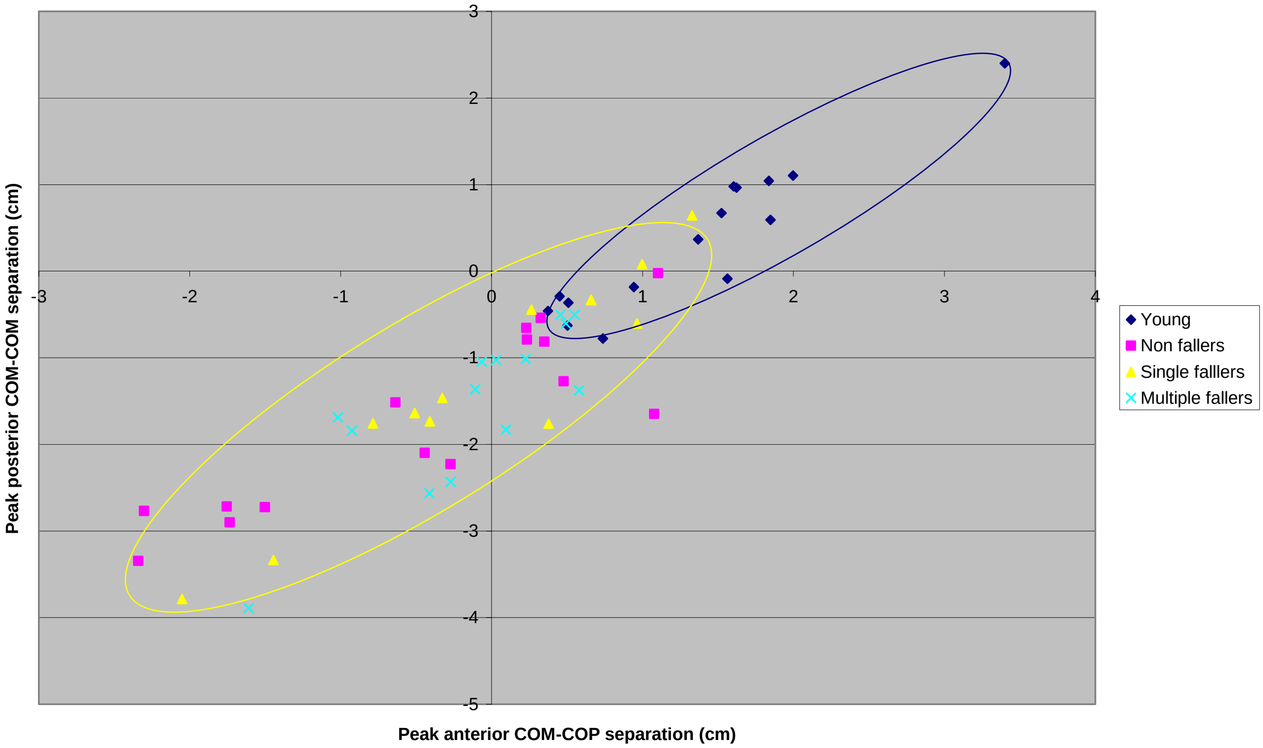
There was a significant difference between groups in COM amplitude in the ML direction ($F = 7.518$, $p < 0.001$, Partial Eta Squared = 0.299). Post hoc analysis revealed the young adults to have significantly greater amplitude of the COM in this direction than the non-fallers ($p = 0.001$), the single fallers ($p = 0.038$) and the multiple fallers ($p = 0.001$).

Table 6.1. COP and COM displacement values for the young adults and the older non-fallers, single fallers and multiple fallers. *indicates a significant difference from the young adults,

	Young Adults		Non-fallers		Single fallers		Multiple fallers	
	EO	EC	EO	EC	EO	EC	EO	EC
AP COP ROM (cm)	2.35 ± 0.80	2.66 ± 0.77	2.89 ± 0.76	3.29 ± 1.30	2.77 ± 0.95	3.10 ± 1.14	3.11 ± 1.05	3.44 ± 2.07
RMS AP COP displacement (cm)	0.48 ± 0.19	0.54 ± 0.18	0.48 ± 0.19	0.68 ± 0.42	0.57 ± 0.14	0.61 ± 0.21	0.56 ± 0.19	0.62 ± 0.34
AP COM ROM (cm)	1.92 ± 0.73	2.03 ± 0.67	2.24 ± 0.65	2.60 ± 1.34	2.12 ± 0.77	2.26 ± 0.94	2.14 ± 0.64	2.22 ± 0.86
RMS AP COM displacement (cm)	1.20 ± 0.66	1.11 ± 0.63	1.31 ± 0.79	1.39 ± 0.78	1.21 ± 0.77	1.21 ± 0.75	1.05 ± 0.70	1.04 ± 0.69
Peak anterior COM-COP separation (cm)	1.26 ± 0.76	1.35 ± 0.80	-0.45 ± 1.17*	-0.48 ± 1.17*	-0.12 ± 1.09*	-0.02 ± 1.01*	-0.21 ± 0.62*	-0.14 ± 0.66*
Peak posterior COM-COP separation (cm)	0.44 ± 0.85	0.36 ± 0.87	-1.56 ± 1.01*	-1.74 ± 1.03*	-1.17 ± 1.26*	-1.23 ± 1.29*	-1.43 ± 0.98*	-1.55 ± 0.94*
AP COM-COP ROM (cm)	0.82 ± 0.26	1.00 ± 0.30	1.12 ± 0.56*	1.26 ± 0.56*	1.06 ± 0.33*	1.25 ± 0.46*	1.22 ± 0.61*	1.41 ± 0.56*
ML COP ROM (cm)	0.93 ± 0.36	1.04 ± 0.51	1.47 ± 0.70	1.46 ± 0.88	1.29 ± 0.52	1.42 ± 0.79	1.46 ± 0.75	1.51 ± 0.73
RMS ML COP displacement (cm)	0.17 ± 0.08	0.19 ± 0.11	0.28 ± 0.15	0.28 ± 0.18	0.26 ± 0.11	0.27 ± 0.16	0.26 ± 0.12	0.28 ± 0.14
ML COM ROM (cm)	0.65 ± 0.30	0.71 ± 0.46	1.21 ± 0.69	1.05 ± 0.78	0.95 ± 0.36	1.02 ± 0.72	1.04 ± 0.47	1.04 ± 0.53
RMS ML COM displacement (cm)	0.70 ± 0.34	0.72 ± 0.30	0.37 ± 0.17*	0.36 ± 0.19*	0.47 ± 0.25*	0.46± 0.24*	0.36± 0.14*	0.37 ± 0.16*
Peak ML COM-COP separation (cm)	0.92 ± 0.32	0.94 ± 0.32	0.48 ± 0.18*	0.56± 0.32*	0.63± 0.33*	0.58 ± 0.27*	0.51± 0.22*	0.56 ± 0.29*

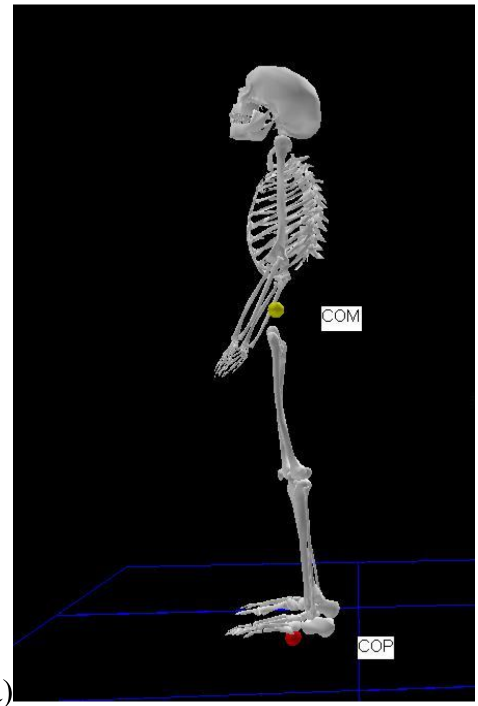


a)



b)

Figure 6.1. a) Peak anterior COM-COP separation (x-axis) plotted against peak posterior COM-COP separation (y-axis) for the young adults (blue oval) and the older faller groups (yellow oval) in the EO and b) the EC condition.

a) 

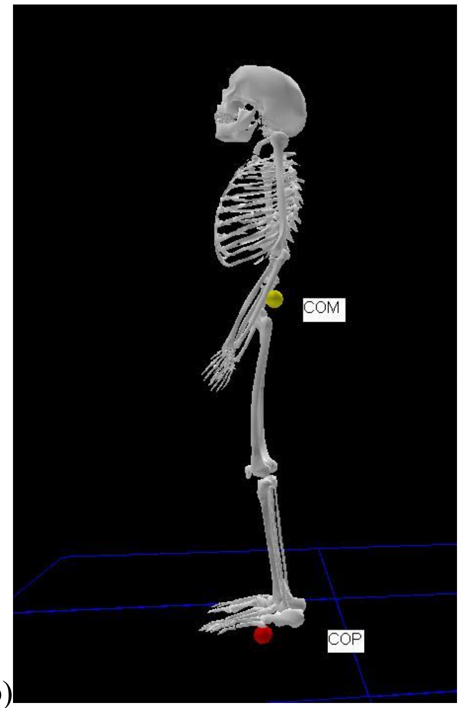
b) 

Figure 6.2. Example animation of COM and COP positions (pelvis removed in order to visualise COM position) in a) a young participant and b) an older participant

Different patterns of COM-COP separation were observed between the young and older adults in the sagittal plane (see figures 6.1 and 6.2). The young adults predominantly kept their COM anterior to their COP, with 9 (60%) young adults in the eyes open condition. Eight (53.3%) young adults in the eyes closed condition kept their COM anterior to their COP throughout the 30-second trial, and the position of the COM in the other young adults oscillated posteriorly and anteriorly with respect to the COP throughout the trial. In contrast, the older adults predominantly kept their COM posterior to their COP, with 25 (59.5%) older adults in the eyes open condition. Twenty-one (50%) older adults in the eyes closed condition kept their COM posterior to their COP throughout the 30-second trial. In the other older adults, the COM oscillated from a posterior to an anterior position with respect to the COP throughout the trial.

There was a significant difference between the groups for peak anterior COM-COP separation ($F = 11.091$, $p < 0.001$, Partial Eta Squared = 0.386). Post hoc analysis revealed the young adults to have significantly greater peak anterior COM-COP separation than the non fallers ($p < 0.001$), single fallers ($p = 0.001$) and multiple fallers ($p < 0.001$). There was a main effect for the EO/EC condition for peak posterior COM-COP separation ($F = 6.656$, $p = 0.013$, Partial Eta Squared = 0.112) with the COM being placed in a more posterior position with respect to the COP in the EC condition compared to EO. There was also a significant difference between the groups ($F = 12.803$, $p < 0.001$, Partial Eta Squared = 0.420), and post hoc analysis revealed the young adults to have significantly less separation between their COM and COP than the non fallers ($p < 0.001$), single fallers ($p = 0.001$) and multiple fallers ($p < 0.001$). There was a main effect for the EO/EC condition for the ROM of the COM-COP separation in the sagittal plane ($F = 8.904$, $p = 0.004$, Partial Eta Squared = 0.144) with greater separation demonstrated in the EC condition compared to EO. There was no significant difference between the groups for ROM of the COM-COP separation in the sagittal plane ($F = 2.438$, $p = 0.075$), but there was a significant difference between groups for peak COM-COP separation in the frontal plane ($F = 7.662$, $p < 0.001$, Partial Eta Squared = 0.303). Post hoc analysis revealed the young adults to have significantly greater COM-COP separation in the frontal plane than the non fallers ($p = 0.001$), the single fallers ($p = 0.014$) and the multiple fallers ($p = 0.001$).

Details of COM velocity and acceleration for the young adults and the older non-fallers, single fallers and multiple fallers are displayed in table 6.2. There was a main effect for the EO/EC condition for peak COM velocity (anterior $F = 6.721$, $p = 0.012$, Partial Eta Squared = 0.113; posterior F = 4.369, p = 0.041, Partial Eta Squared = 0.076), with higher peak velocities shown for the EC condition compared to EO. There were significant differences between the groups for both peak anterior (F = 3.433, p = 0.023, Partial Eta Squared = 0.163) and peak posterior COM velocity (F = 4.555, p = 0.007, Partial Eta Squared = 0.205). Post hoc analysis revealed the young adults to have significantly lower peak velocities than the non-fallers (anterior p = 0.020; posterior p = 0.007). There was a main effect for the EO/EC condition for the amplitude of COM velocity in the AP direction (F = 4.587, p = 0.037, Partial Eta Squared = 0.080). There was a significant difference between groups (F = 3.142, p = 0.033, Partial Eta Squared = 0.151), and post hoc analysis revealed the young adults to have lower amplitude of their COM velocity in the AP direction than the non-fallers (p = 0.037).

There was a significant difference between groups for both peak anterior (F = 6.553, p = 0.001, Partial Eta Squared = 0.271) and peak posterior COM acceleration (F = 7.244, p < 0.001, Partial Eta Squared = 0.291). Post hoc analysis revealed the young adults to have significantly lower peak acceleration of their COM than the non-fallers (anterior p = 0.006; posterior p = 0.002), single fallers (anterior p = 0.002; posterior p = 0.001) and the multiple fallers (anterior p = 0.009; posterior p = 0.008). There was a significant difference between groups for the amplitude of the COM acceleration in the AP direction (F = 3.452, p = 0.023, Partial Eta Squared = 0.163). Post hoc analysis revealed the young adults to have a lower amplitude of COM acceleration than the older non-fallers (p = 0.033).

There was a significant difference between groups for peak ML COM velocity ($F = 7.904$, $p < 0.001$, Partial Eta Squared = 0.309). Post hoc analysis revealed the young adults to have significantly lower peak COM velocity in the frontal plane than the non-fallers ($p < 0.001$), the single fallers ($p = 0.002$) and the multiple fallers ($p = 0.009$). There was also a significant difference between groups for the amplitude of the COM velocity in the frontal plane ($F = 4.722$, $p = 0.005$, Partial Eta Squared = 0.211). Post hoc analysis revealed the young adults to have significantly lower amplitude of their COM velocity than the non-fallers ($p = 0.007$), single fallers ($p = 0.049$) and the multiple fallers ($p = 0.043$).

There was a significant difference between groups for peak ML COM acceleration ($F = 10.919$, $p < 0.001$, Partial Eta Squared = 0.382). Post hoc analysis revealed these differences the young adults to have significantly lower peak COM acceleration in the frontal plane than the non-fallers ($p = 0.012$), the single fallers ($p < 0.001$) and the multiple fallers ($p < 0.001$). There was a significant difference between groups for the amplitude of ML COM acceleration ($F = 4.544$, $p = 0.007$, Partial Eta Squared = 0.205). Post hoc analysis revealed these differences the young adults to have significantly lower amplitude of their COM acceleration than the non-fallers ($p = 0.032$) and the single fallers ($p = 0.009$).

Table 6.2. COM velocity and acceleration values for the young adults and the older non-fallers, single fallers and multiple fallers. * indicates a significant difference from the young adults

	Young Adults		Non-fallers		Single fallers		Multiple fallers	
	EO	EO	EC	EO	EC	EO	EC	EC
Peak anterior velocity (cm.s^{-1})	1.32 ± 36	1.51 ± 0.38	1.98 ± 0.64*	2.28 ± 1.08*	1.94 ± 0.76	1.99 ± 0.63	1.78 ± 0.52	2.00 ± 0.91
Peak posterior velocity (cm.s^{-1})	-1.34 ± 0.28	-1.43 ± 0.30	-2.01 ± 0.59*	-2.35 ± 1.25*	-2.02 ± 0.80	-2.03 ± 0.70	-1.85 ± 0.39	-2.14 ± 0.87
RMS AP velocity (cm.s^{-1})	0.41 ± 0.11	0.46 ± 0.10	0.61 ± 0.20*	0.69 ± 0.40*	0.59 ± 0.20	0.61 ± 0.17	0.56 ± 0.14	0.65 ± 0.31
Peak anterior acceleration (cm.s^{-2})	20.21 ± 4.87	20.22 ± 4.11	30.21 ± 10.18*	29.23 ± 10.19*	30.23 ± 7.95*	32.17 ± 8.71*	28.32 ± 7.03*	30.81 ± 10.64*
Peak posterior acceleration (cm.s^{-2})	-19.76 ± 4.77	-19.57 ± 4.22	-30.91 ± 10.42*	-29.38 ± 10.30*	-29.84 ± 8.66*	-32.69 ± 8.91*	-28.01 ± 7.23*	-30.40 ± 10.46*
RMS AP acceleration (cm.s^{-2})	5.26 ± 1.17	5.46 ± 1.32	9.02 ± 4.75*	9.17 ± 5.07*	8.80 ± 5.14	8.90 ± 4.44	6.97 ± 1.88	8.08 ± 3.01
Peak ML velocity (cm.s^{-1})	0.81 ± 0.20	0.83 ± 0.21	1.34 ± 0.40*	1.35 ± 0.57*	1.30 ± 0.40*	1.28 ± 0.34*	1.18 ± 0.32*	1.27 ± 0.44*
RMS ML velocity (cm.s^{-1})	0.22 ± 0.07	0.23 ± 0.07	0.35 ± 0.11*	0.35 ± 0.17*	0.34 ± 0.11*	0.32 ± 0.09*	0.32 ± 0.09*	0.35 ± 0.13*
Peak ML acceleration (cm^{-2})	17.34 ± 3.91	17.06 ± 3.29	25.45 ± 6.59*	24.55 ± 6.70*	29.61 ± 8.45*	30.30 ± 9.98*	27.18 ± 7.23*	30.16 ± 10.25*
RMS ML acceleration (cm^{-2})	4.46 ± 1.18	4.53 ± 1.23	7.01 ± 2.65*	6.89 ± 2.80*	7.61 ± 3.88*	7.19 ± 2.69*	6.14 ± 1.50	7.03 ± 2.47

6.2 Walking

6.2.1 Temporo-spatial characteristics

Details for the young and older participant groups are given in table 6.3. There was a significant difference between groups for walking speed ($F = 9.135$, $p < 0.001$, Eta Squared = 0.341), and post hoc analysis revealed these differences to be between the young adults and the non-fallers ($p < 0.001$), the single fallers ($p = 0.002$) and the multiple fallers ($p = 0.001$), with the young adults walking faster than the older adult groups. There was no significant difference between groups for cadence ($F = 0.905$, $p = 0.445$), stride time ($F = 0.971$, $p = 0.413$), stance time ($F = 2.023$, $p = 0.122$) or swing time ($F = 0.921$, $p = 0.437$). There was a significant difference between groups for the percentage of time spent in stance ($F = 5.139$, $p = 0.003$, Eta Squared = 0.225), and post hoc analysis revealed the young adults spent a lower percentage of their stride time in the stance phase than the multiple fallers ($p = 0.002$). There was also a significant difference between groups for the percentage of time spent in swing ($F = 6.590$, $p = 0.001$, Eta Squared = 0.272), and post hoc analysis revealed the young adults spent a significantly greater percentage of their stride time in the swing phase than either the single fallers ($p = 0.041$) or the multiple fallers ($p < 0.001$).

There was a significant difference between groups for stride length ($F = 9.651$, $p < 0.001$, Eta Squared = 0.353), post hoc analysis revealed the young adults to have a significantly longer stride length than the non-fallers ($p < 0.001$), the single fallers ($p < 0.001$) and the multiple fallers ($p = 0.001$). There were no significant differences between groups for step width ($F = 0.883$, $p = 0.456$).

Table 6.3. Temporo-spatial values for the young and older adult groups (mean ± SD) * denotes a significant difference from the young adults

	Young	Non-fallers	Single fallers	Multiple fallers
Velocity ($m.s^{-1}$)	1.41 ± 0.08	1.16 ± 0.16*	1.20 ± 0.15*	1.16 ± 0.17*
Cadence ($steps.min^{-1}$)	114.06 ± 6.41	106.32 ± 10.79	113.87 ± 6.36	111.63 ± 10.88
Stride time (s)	1.05 ± 0.06	1.10 ± 0.11	1.06 ± 0.06	1.08 ± 0.11
Stance time (s)	0.65 ± 0.03	0.70 ± 0.07	0.67 ± 0.04	0.69 ± 0.07
Time in stance (%)	61.77 ± 1.12	62.96 ± 2.15	63.17 ± 2.03	64.06 ± 1.41*
Swing time (s)	0.41 ± 0.03	0.41 ± 0.05	0.39 ± 0.03	0.39 ± 0.04
Time in swing (%)	38.44 ± 1.10	37.03 ± 2.07	36.91 ± 1.84*	36.12 ± 1.29*
Stride length (m)	1.49 ± 0.07	1.28 ± 0.14*	1.28 ± 0.16*	1.28 ± 0.13*
Step width (m)	0.21 ± 0.03	0.20 ± 0.04	0.20 ± 0.02	0.19 ± 0.02

6.2.2 COM and COP measures

Details of the COM-COP separation and COM velocities and accelerations are given in table 6.4. At toe off, the COM is located behind the COP and results in a maximum posterior COM-COP separation in the sagittal plane (figure 6.3). As the gait cycle continues the COM moves anteriorly with respect to the COP, with a peak anterior COM-COP occurring just prior to heel strike. During double support, there is a rapid shift of the COP from the trailing foot to the leading foot resulting in the COM being behind the COP for toe off. In the frontal plane, the COM moves medially to the COP during the single support period, and then the COM-COP separation rapidly decreases and increases again during double support as the COP shifts from the trailing foot to the leading foot. The COM-COP separation is at a maximum at the beginning and end of the single support phase, with a slight dip occurring at midstance. These patterns were similar for all participants.

As a significant difference was observed between the groups for walking speed, this was added as a covariate into the analysis for the COM and COP data. There was a significant difference between groups for the COM-COP separation in the AP direction at heel strike ($F = 6.898$, $p = 0.001$, partial Eta Squared = 0.285), contrast analysis using the Bonferroni correction found the young adults had greater COM-COP separation at heel strike than the non fallers ($p = 0.001$) and the single fallers ($p = 0.048$), and also the multiple fallers had greater COM-COP separation at heel strike than the non fallers ($p = 0.011$). There was no significant difference between groups for the COM-COP separation in the AP direction at toe off ($F = 0.232$, $p = 0.873$), nor for COM-COP separation in the ML direction at heel strike ($F = 0.342$, $p = 0.795$) or toe off ($F = 0.797$, $p = 0.501$).

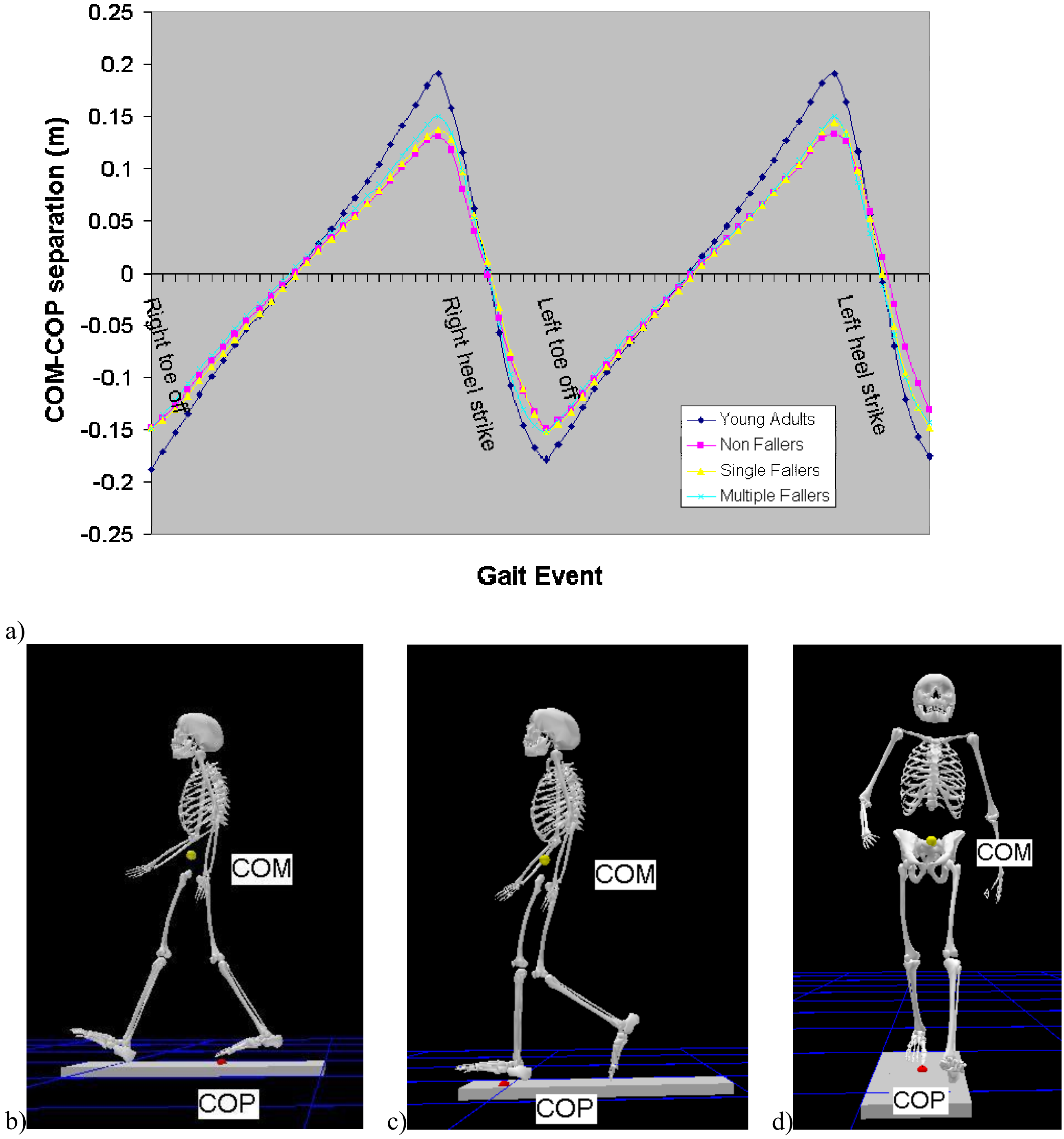


Figure 6.3. a) COM-COP separation in the sagittal plane for the 4 groups normalised over a gait cycle; schematic diagrams of b) COM-COP separation at heel strike in the sagittal plane; c) COM-COP separation at toe off in the sagittal plane and d) COM-COP separation in the frontal plane (heel strike).

There was no significant difference between groups for COM velocity in the sagittal plane at heel strike (F = 0.847, p = 0.475) or toe off (F = 1.550, p = 0.213) or in the frontal plane at heel strike (F = 0.480, p = 0.697) or toe off (F = 0.543, p = 0.655). There was a significant difference between groups for COM acceleration in the AP direction at heel strike (F = 4.285, p = 0.009, partial Eta Squared = 0.198), contrast analysis showed both the young adults (p = 0.041) and the multiple fallers (p = 0.047) had a greater COM acceleration at heel strike than the non fallers. There was no significant difference between groups for COM acceleration in the AP direction at toe off (F = 2.597, p = 0.062), nor for COM acceleration in the ML direction at heel strike (F = 0.855, p = 0.470) or toe off (F = 0.839, p = 0.479).

Table 6.4. COM-COP separation values and COM velocity and acceleration for the young and older adult groups (mean ± SD) * denotes a significant difference from the young adults, ** denotes a significant difference from the non-fallers

	Young	Non-fallers	Single fallers	Multiple fallers
AP COM-COP separation at heel strike (m)	0.18 ± 0.02**	0.12 ± 0.03*	0.14 ± 0.03*	0.15 ± 0.02**
AP COM-COP separation at toe off (m)	-0.17 ± 0.01	-0.15 ± 0.02	-0.15 ± 0.02	-0.15 ± 0.03
AP COM velocity at heel strike ($m.s^{-1}$)	1.47 ± 0.08	1.21 ± 0.17	1.26 ± 0.16	1.23 ± 0.18
AP COM acceleration at heel strike ($m.s^{-2}$)	1.80 ± 0.22**	1.34 ± 0.19*	1.42 ± 0.28	1.60 ± 0.28**
AP COM velocity at toe off ($m.s^{-1}$)	1.48 ± 0.08	1.24 ± 0.17	1.26 ± 0.15	1.24 ± 0.19
AP COM acceleration at toe off ($m.s^{-2}$)	-1.77 ± 0.21	-1.49 ± 0.27	-1.73 ± 0.31	-1.64 ± 0.31
ML COM-COP separation at heel strike (m)	0.06 ± 0.01	0.05 ± 0.02	0.05 ± 0.02	0.06 ± 0.01
ML COM-COP separation at toe off (m)	0.06 ± 0.02	0.05 ± 0.02	0.05 ± 0.02	0.05 ± 0.01
ML COM velocity at heel strike ($m.s^{-1}$)	0.08 ± 0.01	0.09 ± 0.01	0.08 ± 0.01	0.08 ± 0.02
ML COM acceleration at heel strike ($m.s^{-2}$)	0.91 ± 0.14	0.80 ± 0.17	0.89 ± 0.16	0.84 ± 0.13
ML COM velocity at toe off ($m.s^{-1}$)	0.11 ± 0.02	0.11 ± 0.02	0.11 ± 0.02	0.10 ± 0.01
ML COM acceleration at toe off ($m.s^{-2}$)	-0.86 ± 0.19	-0.92 ± 0.18	-0.89 ± 0.21	-0.97 ± 0.15

6.3 Turning 360º

Details of temporal parameters and COM velocities and accelerations are displayed in table 6.5. There was a significant difference between groups for time to turn ($F = 3.636$, $p = 0.019$, Eta Squared = 0.176). Post hoc analysis revealed the young adults completed the turn in significantly less time than the multiple fallers ($p = 0.024$). There was also a significant difference between groups for the number of steps taken to turn ($F = 3.693$, $p = 0.018$. Eta Squared = 0.178). Post hoc analysis revealed the young adults took significantly fewer steps to complete the turn than the multiple fallers ($p = 0.024$).

As there was a significant difference between some of the groups for turn time (see above), this was added as a covariate for analysis of COM velocity and acceleration. There was a significant difference between groups for peak anterior COM velocity ($F = 6.362$, $p = 0.001$, Partial Eta Squared = 0.276). Contrast analysis revealed these differences to be between the young adults and the non-fallers ($p = 0.002$) and between the non-fallers and the multiple fallers ($p = 0.013$). There was also a significant difference between groups for peak posterior COM velocity ($F = 7.153$, $p < 0.001$, Partial Eta Squared = 0.300). Contrast analysis revealed these differences to be between the young adults and the non-fallers ($p < 0.001$) and the multiple fallers ($p = 0.049$). There were no significant differences between groups for peak anterior COM acceleration ($F = 1.047$, $p = 0.380$) or peak posterior COM acceleration ($F = 0.575$, $p = 0.634$).

As there was no instruction to which direction the 360º turn was conducted, some participants initiated the turn to the right side whilst others initiated the turn to the left.

Table 6.5. Temporal turn parameters and COM velocities and accelerations for the participant groups *indicates a significant difference from the young adults; ** indicates a significant difference from the non-fallers

	Young	Non-Fallers	Single Fallers	Multiple Fallers
Time to turn (s)	3.86 ± 0.73	5.05 ± 1.11	4.64 ± 1.21	5.24 ± 1.69*
Number of steps	6.50 ± 0.78	7.61 ± 1.61	7.70 ± 0.85	7.89 ± 1.44*
Peak anterior COM velocity ($m.s^{-1}$)	0.12 ± 0.02**	0.08 ± 0.02*	0.09 ± 0.02	0.10 ± 0.03**
Peak posterior COM velocity ($m.s^{-1}$)	-0.12 ± 0.03	-0.08 ± 0.01*	-0.09 ± 0.02	-0.09 ± 0.02*
Peak anterior COM acceleration ($m.s^{-2}$)	1.47 ± 0.44	1.18 ± 0.47	1.30 ± 0.38	1.39 ± 0.36
Peak posterior COM acceleration ($m.s^{-2}$)	-1.41 ± 0.30	-1.18 ± 0.46	-1.22 ± 0.31	-1.28 ± 0.31
Peak ML COM velocity towards centre of turn ($m.s^{-1}$)	0.07 ± 0.01	0.06 ± 0.02	0.07 ± 0.01	0.07 ± 0.02
Peak ML COM velocity towards outside of turn ($m.s^{-1}$)	0.09 ± 0.01**	0.06 ± 0.01*	0.07 ± 0.01	0.07 ± 0.02
Peak ML COM acceleration towards centre of turn ($m.s^{-2}$)	1.30 ± 0.18	1.19 ± 0.20	1.31 ± 0.34	1.28 ± 0.26
Peak ML COM acceleration towards outside of turn ($m.s^{-2}$)	1.32 ± 0.23	1.13 ± 0.24	1.35 ± 0.33	1.30 ± 0.18

Therefore, the COM velocities and accelerations in the frontal plane were analysed as peak values towards the centre of the turn and peak values towards the outside of the turn. There were no significant differences between groups for peak ML COM velocity towards the inside of the turn ($F = 1.079$, $p = 0.367$). There was a significant difference between groups for peak ML COM velocity towards the outside of the turn ($F = 4.200$, $p = 0.010$, Partial Eta Squared = 0.201). Contrast analysis showed this difference to be between the young adults and the non-fallers ($p = 0.008$). There were no significant difference between groups for peak ML COM acceleration towards the inside of the turn ($F = 0.037$, $p = 0.527$) or the outside of the turn ($F = 2.132$, $p = 0.108$).

It was common for the participants to step at least partly off one of the force plates during the turn. As a result, the COP data could not be used for the portion of the trials where this occurred. As a consequence, the COM-COP separation was only calculated for the initiation of the turn, the point where the first foot was lifted in the turn and the subsequent foot contact of the step as at these points all the participants still had their base of support placed completely on one or both force plates (table 6.6).

There was a significant difference between groups for COM-COP separation in the sagittal plane at the initiation of the turn ($F = 7.244$, $p < 0.001$, Partial Eta Squared = 0.303). Contrast analysis revealed the young adults to have a far larger COM-COP separation than either the non-fallers ($p = 0.004$), the single fallers ($p = 0.002$) or the multiple fallers ($p = 0.001$). There was no difference between groups for COM-COP separation in the frontal plane at the initiation of the turn ($F = 1.650$, $p = 0.190$).

Table 6.6. COM-COP separation in the participant groups *indicates a significant difference from the young adults

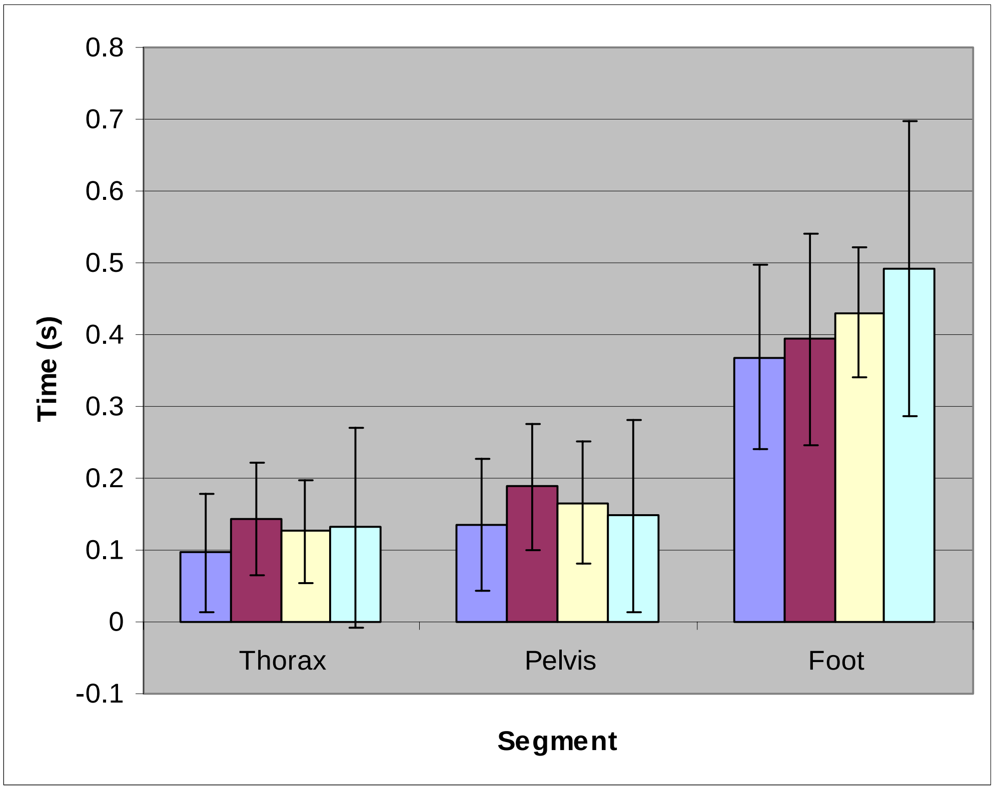
	Young	Non-fallers	Single fallers	Multiple fallers
AP COM-COP separation at turn initiation (cm)	1.01 ± 0.88	-0.46 ± 1.04*	-0.65 ± 1.07*	-0.65 ± 1.19*
AP COM-COP separation at first foot off (cm)	2.95 ± 1.28	0.66 ± 1.91*	0.99 ± 1.21	1.14 ± 2.08
AP COM-COP separation at first foot strike (cm)	3.09 ± 3.47	0.38 ± 2.15	0.10 ± 1.45	1.11 ± 2.99
Peak anterior COM-COP separation between turn initiation and first foot strike (cm)	4.05 ± 1.45	1.54 ± 1.68*	1.79 ± 1.24	2.35 ± 2.61
Peak posterior COM-COP separation between turn initiation and first foot strike (cm)	-0.22 ± 0.92	-1.50 ± 1.11	-1.49 ± 1.25	-1.77 ± 2.06*
ML COM-COP separation at turn initiation (cm)	2.89 ± 1.31	2.45 ± 2.67	1.74 ± 0.67	1.46 ± 0.94
ML COM-COP separation at first foot off (cm)	8.74 ± 2.24	6.14 ± 2.16	7.24 ± 1.50	6.75 ± 2.92
ML COM-COP separation at first foot strike (cm)	9.18 ± 2.73	7.62 ± 2.35	8.65 ± 1.66	7.83 ± 2.41
Peak ML COM-COP separation between turn initiation and first foot strike (cm)	10.60 ± 2.57	8.47 ± 2.76	9.74 ± 2.45	8.78 ± 2.53

Due to two participants adopting a turning strategy where they executed a spin rather than a step to move their foot initially, these two participants were excluded from analysis at foot off and foot strike events. Therefore, there were 14 non-fallers and 10 single fallers for the subsequent analyses of COM-COP separation. There was a significant difference between groups for COM-COP separation in the sagittal plane at the first toe off ($F = 3.267$, $p = 0.029$, Partial Eta Squared = 0.170). Contrast analysis showed the young adults to have a greater COM-COP separation than the non-fallers ($p = 0.043$). There were no significant differences between groups in the frontal plane ($F = 1.309$, $p = 0.282$). There were no significant differences between groups in the sagittal plane ($F = 2.400$, $p = 0.079$) or the frontal plane ($F = 0.215$, $p = 0.885$) at the subsequent heel strike.

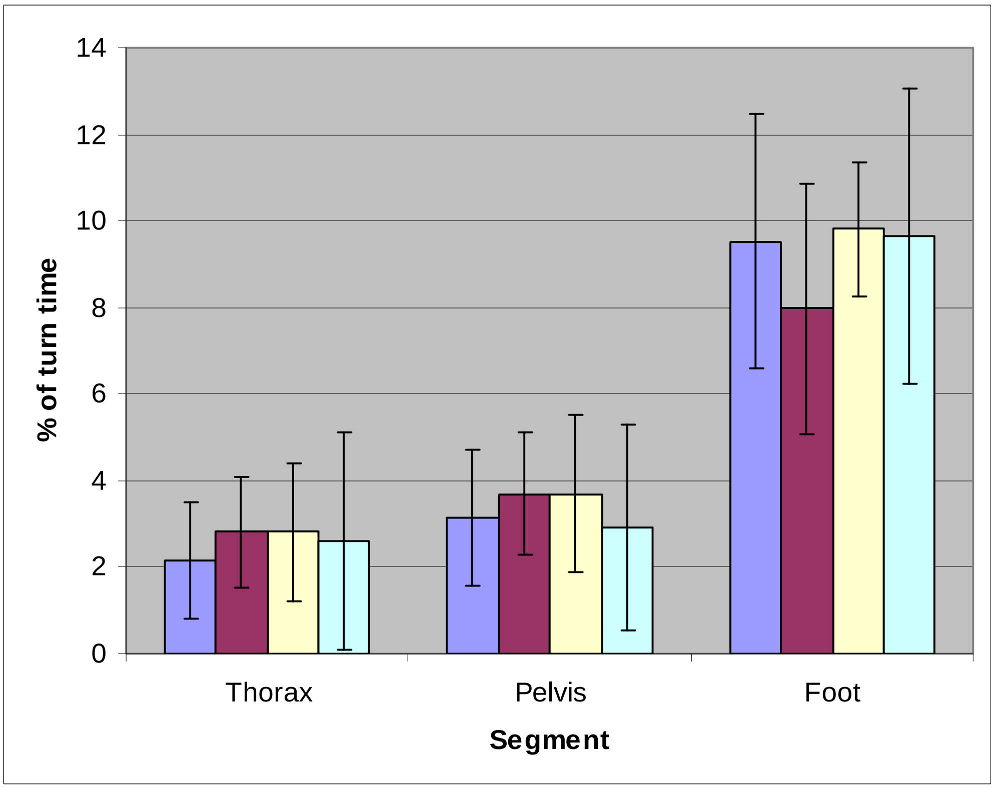
There was a significant difference between groups for the peak anterior COM-COP separation occurring between turn initiation and first heel strike ($F = 3.663$, $p = 0.019$. Partial Eta Squared = 0.186). Contrast analysis showed the young adults to have a significantly greater COM-COP separation than the non-fallers ($p = 0.031$). There was also a significant difference between groups for peak posterior COM-COP separation ($F = 3.367$, $p = 0.026$, Partial Eta Squared = 0.174). Contrast analysis showed the young adults to have significantly lower COM-COP separation than the multiple fallers ($p = 0.026$). There were no significant differences between groups ($F = 2.010$, $p = 0.125$) for peak COM-COP separation in the frontal plane between turn initiation and first foot strike.

In all participants, movement of the head initiated the turn. There was no significant difference between groups for thoracic or pelvic turn onset latency with respect to the head movement onset (figure 6.4), either expressed as time (thorax $F = 0.632$, $p = 0.598$; pelvis $F = 0.748$, $p = 0.528$) or percentage of turn time (thorax $F = 0.433$, $p = 0.730$; pelvis $F = 0.635$, $p = 0.596$). There was a significant difference between groups for pelvic turn onset latency with respect to the thorax (figure 6.5) both in absolute time ($F = 5.968$, $p = 0.001$, Eta Squared = 0.250) and expressed as percentage of turn time ($F = 7.369$, $p < 0.001$, Eta Squared = 0.302). Post-hoc tests showed the multiple fallers to have significantly shorter latency between the thorax and the pelvis than the young adults (time $p = 0.029$; percentage $p = 0.001$), the non fallers ($p = 0.001$; $p = 0.002$) and the single fallers ($p = 0.025$; $p = 0.010$).

There was no significant difference between groups for latency of foot off with respect to turn onset of the head (time $F = 1.734$, $p = 0.172$; percentage $F = 1.186$, $p = 0.325$) or thorax ($F = 2.011$, $p = 0.125$; $F = 2.411$, $p = 0.078$). There was a significant difference for latency of foot off with respect to pelvic turn onset ($F = 3.285$, $p = 0.028$, Eta Squared = 0.168; figure 6.6). Post hoc analysis showed these differences to be between the non fallers and the multiple fallers ($p = 0.047$).

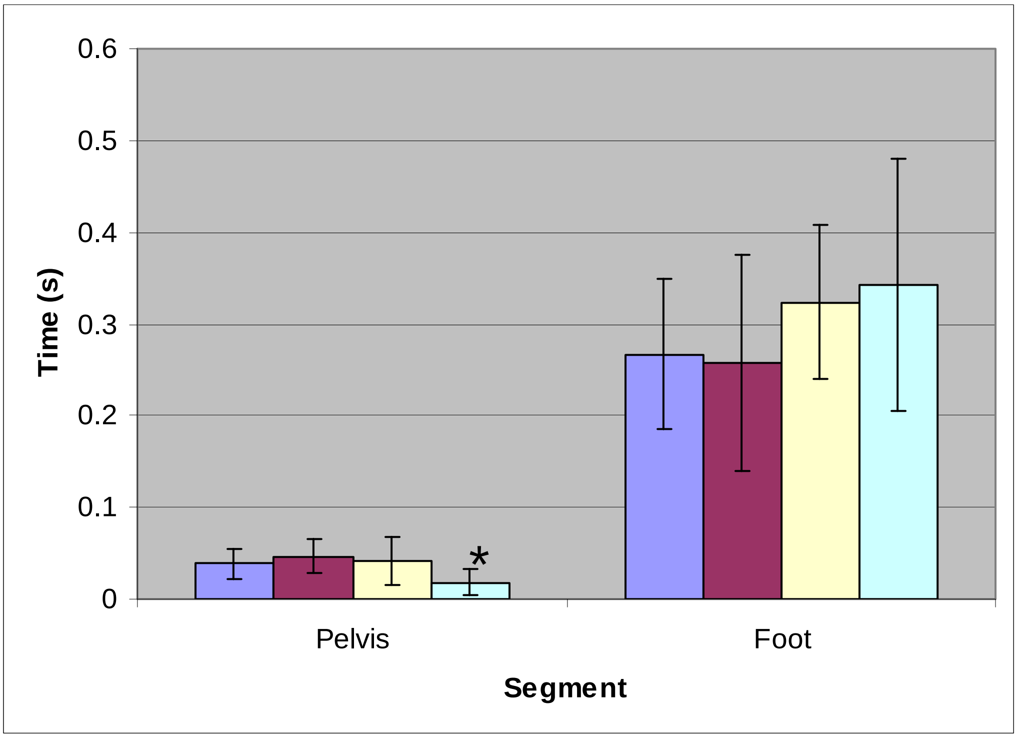


a)

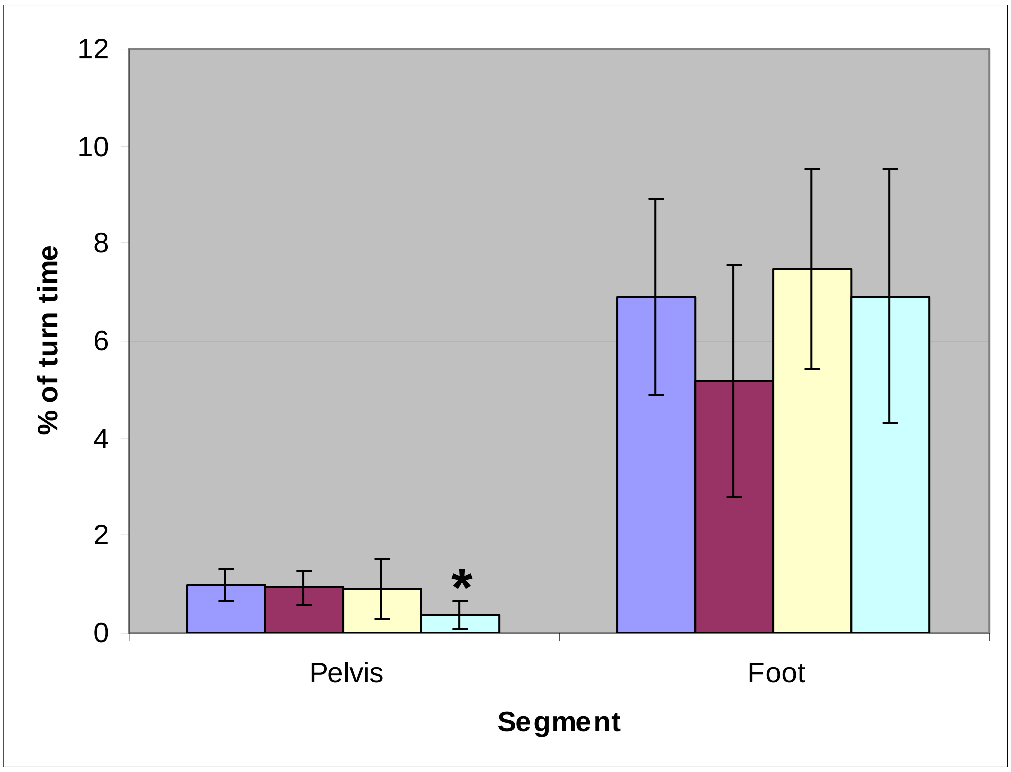


b)

Figure 6.4. Reorientation onset of body segments with respect to the head (mean ± SD) in absolute time (a) and percentage of turn time (b) for the young adults (■), non fallers (■), single fallers (■) and multiple fallers (■)

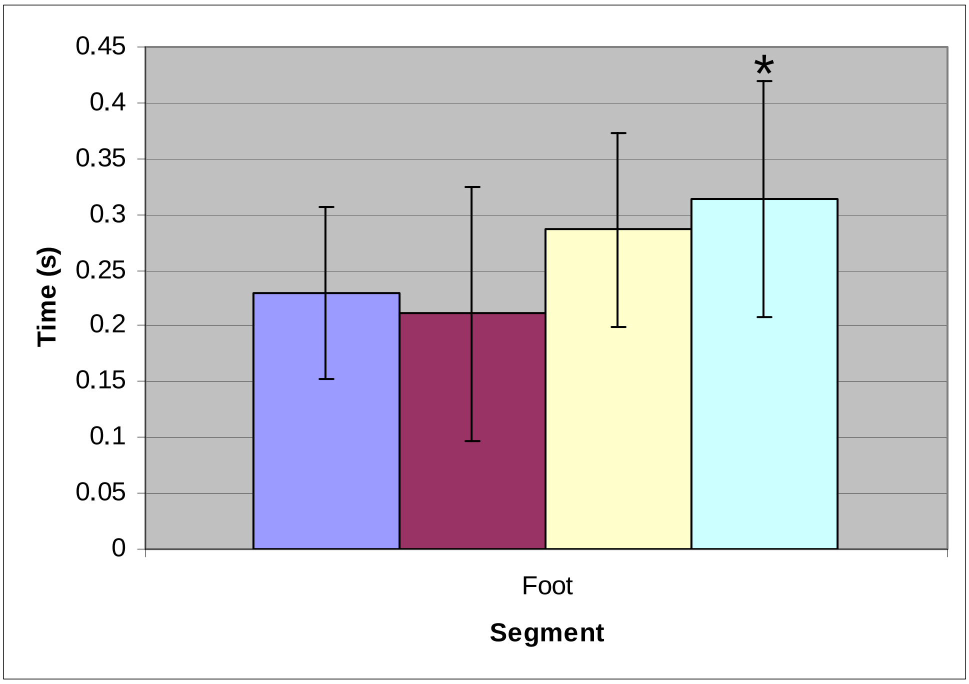


a)

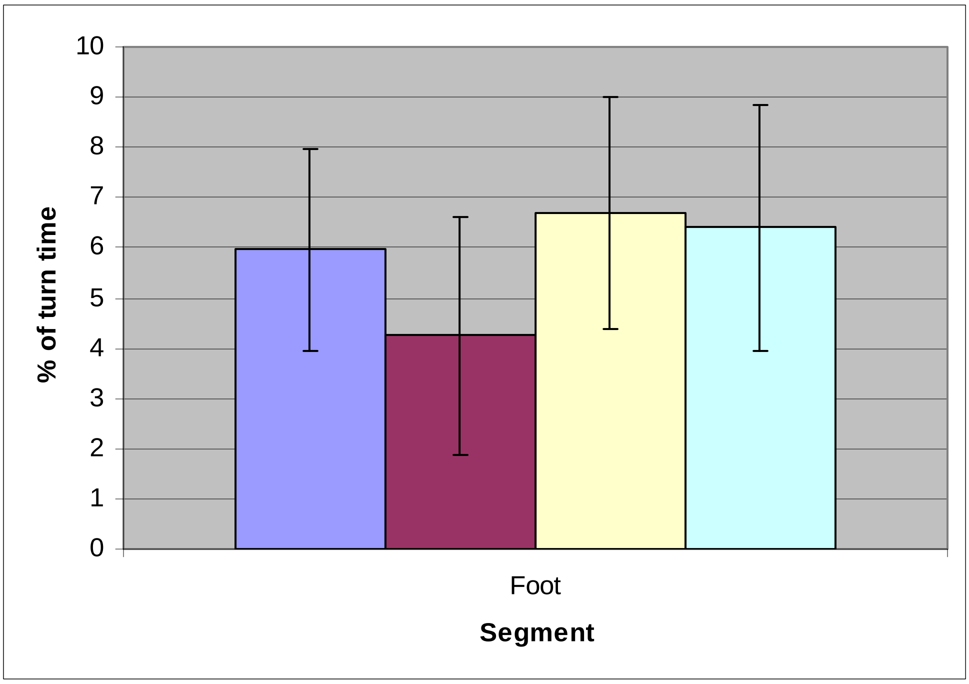


b)

Figure 6.5. Reorientation onset of body segments with respect to the thorax in absolute time (a) and percentage of turn time (b) for the young adults (■), non fallers (■), single fallers (■) and multiple fallers (■) * indicates a significant difference from all other groups



a)



b)

Figure 6.6. Reorientation onset of the foot with respect to the pelvis in absolute time (a) and percentage of turn time (b) for the young adults (■), non fallers (■), single fallers (■) and multiple fallers (■) * indicates a significant difference from the non-fallers

Chapter 7: Discussion of the standing, walking and turning studies

This chapter discusses the results from the quiet standing, walking and turning studies, following on from the methods in chapter 5 and the results presented in chapter 6.

7.1 Quiet standing

The purpose of the quiet standing study was to compare COP and COM variables in an eyes open and eyes closed condition during quiet standing in groups of young adults and older adults with a history of no falls, a single fall or multiple falls. Few studies to date have compared the COM-COP separation variable between young adults and healthy older adults (Berger *et al.* 2005a; Masani *et al.* 2007), and only one (Berger *et al.* 2005b) has compared faller groups amongst higher functioning older persons using this variable.

The key findings of the standing study are as follows:

1. no group differences in COP displacement, but a significantly greater sway path for the EC compared to the EO condition;
2. no group differences in COM displacement in the sagittal plane, but a significantly larger magnitude of the COM displacement in the frontal plane for the young compared to the older adults;
3. young adults place their COM more anterior with respect to the COP than the older adults;

4. older adults have a significantly greater ROM of their COM-COP separation in the sagittal plane than young adults, but young adults have a significantly greater peak COM-COP separation in the frontal plane than older adults;
5. older adults have significantly greater peak COM velocities and accelerations than young adults.

Many studies have used the displacement of the COP in isolation as a variable to investigate balance (Collins *et al.* 1995; Brauer *et al.* 2000; Benjuya *et al.* 2004; Cornilleau-Pérès *et al.* 2005; Mackey and Robinovitch, 2005; Raymakers *et al.* 2005). The advantages of using the COP variable include that it is directly measured and easily quantified. Previous studies have shown a significantly greater COP range of sway in the AP direction for older adults compared to young controls, (Collins *et al.* 1995; Prieto *et al.* 1996; Amiridis *et al.* 2003; Laughton *et al.* 2003; Onambele *et al.* 2006), and also in the ML direction (Prieto *et al.* 1996; Raymakers *et al.* 2005; Onambele *et al.* 2006). However, this current standing study suggests that either the COP is not a sensitive enough variable to distinguish between young adults and groups of high-functioning older adults, or alternatively that there are no differences between these groups. A review article of prospective studies using COP data in isolation also found the results of studies were conflicting for predicting future falls and suggests there could be a ceiling effect for these measures (Piirtola and Era, 2006). This further supports the current finding that COP in isolation is not a suitable measure for detecting differences between fallers and non-fallers in community-dwelling populations.

It has been reported that lateral sway range is the best single predictor of falling risk (Maki *et al.* 1994). However, there were no significant differences between the sway ROM in the frontal plane between the faller groups in the present study. This may be due to the older population in this study being particularly healthy and mobile, and the lateral sway range may only become significant when non fallers are compared to frail fallers.

The consistent increase in COP displacement observed in the EC condition compared to the EO condition in the sagittal plane is consistent with previous findings (Panzer *et al.* 1995; Benjuya *et al.* 2004; Doyle *et al.* 2004). This increase was very similar between the young adults (13.2% increase in the EC condition) and the non-fallers (13.8% increase), with the single fallers (11.9% increase) and the multiple fallers (10.6% increase) showing slightly smaller increases. Benjuya et al (2004) found the increases in the COP path with EC were much larger in young adults than older adults, although this was the elliptical path of the COP rather than the ROM in the individual planes. This led to the suggestion that young adults rely more on visual input during the EO condition than the older adults, and is supported by evidence that reliance on vision for balance control increases up to the age of 65 and then the role of vision in balance control declines (Lord and Ward, 1994). There is also evidence that the visual contribution to postural stability is significantly greater in non-fallers than fallers (Turano *et al.* 1994). No significant differences were observed between faller groups in the current study, but there was a trend towards a lower increase in sway, in the EC condition compared to the EO condition, for the multiple fallers compared to the non-fallers. This suggests that the multiple fallers in this study were also less reliant on visual input for balance during standing than the non-fallers.

As there was no concurrent significant increase in the range of motion of the COM in the eyes closed condition, this may not be an indicator of decreased stability when the eyes are closed. However, this increased COP movement may indicate that the accelerations of individual body parts are used to achieve COM stability comparable to that achieved in the eyes open condition (Panzer *et al.* 1995).

The range of motion of the COP was larger than the range of motion for the COM for all groups. This is due to the COP oscillating either side of the COM to stabilise the COM around a neutral position, and is consistent with previous findings and with the inverted pendulum model (Hasan *et al.* 1996; Winter *et al.* 1996; Winter *et al.* 1998).

Few studies have investigated COM displacement during quiet standing than COP displacement. The position of the COM has been estimated in many different ways, including the principles of dynamics based on force plate data (Shimba, 1984), a gravity line projection method (Masani *et al.* 2007) and by assuming that the COM is coincident with the position of a marker fixed to the pelvis (Thirunarayan *et al.* 1996). However, as the accurate estimation of small movements of the COM (as may be observed in quiet standing) requires precise measurements of displacements of all individual body segments so that the COM can be derived through anthropometric modelling (Winter *et al.* 1998), many previous studies have used methods that may not be sensitive enough to measure differences based on the COM displacement. Through using a full body marker set, such as Plug-in Gait, and the precision of a 14-camera motion capture system; the present study demonstrates advantages over previous studies that have used these variables in falls research. Additionally, when the COM falls outside the base of support, such as in dynamic tasks such as walking and turning described later, force plates cannot be used to accurately estimate the position of the COM (Allum and Carpenter, 2005). Therefore, the same anthropometric method for calculating COM was used throughout this thesis.

As the difference between the COM and the COP has been shown to be related to the movement of the COM (Winter, 1995b), it is logical that measuring the difference between the two rather than either in isolation will give more useful information with regard to balance control. There were different patterns demonstrated by the older compared to the young adults for COM-COP separation in this present study. The younger adults predominantly placed their COM anterior to their COP, whilst most of the older adults predominantly placed their COM posterior to their COP throughout the trials. This placement of the COM in a more posterior position in the older adults compared to the young adults suggests that the older adults employ more of a hip strategy or a combined hip and ankle strategy for balance control in the sagittal plane than the young adults (Winter, 1995a). This is supported by the finding that older adults have been shown to have significantly more activation of the hamstrings than young adults during quiet standing (Benjuya *et al.* 2004). It is also possible that the older adults keep their COM in a more posterior position than the younger adults during standing to reduce the forward bending force and the loading of the ankle plantarflexors (Gatev *et al.* 1999). This is supported by older women with a history of falling having reduced muscle strength (peak ankle torque) measured in a forward leaning posture than young healthy women (Mackey and Robinovitch, 2006). The elderly women also had reduced speed of response (reaction time and rate of ankle torque generation) than the younger women in balance recovery using the ankle strategy from a forward leaning posture (Mackey and Robinovitch, 2006). Older adults adopt a co-contraction pattern of the soleus and tibialis anterior during quiet standing whilst young adults rely predominantly on soleus activity (Benjuya *et al.* 2004). This co-contraction would stiffen the ankle joint. As a consequence, the older population in this current study maintain their COM in a less anterior position to the younger population as a conservative strategy for balance control.

The relatively posterior positioning of the COM demonstrated in the older adults, compared to the young adults, has implications for the ability of these participants to recover from a perturbation. In the occurrence of a large forward perturbation, the COM would move quickly posteriorly. Older adults have been shown to have a later onset in postural muscle activation as a result of a perturbation than young adults resulting in the COM moving closer to the edge of the base of support (Lin and Woollacott, 2002). With the COM already located in a posterior position in these older adults, any perturbation that resulted in the backward movement of the COM would mean that a quicker response to this perturbation would be required to prevent the COM passing outside the base of support and a compensatory step needed to avoid a fall occurring. If there is an increased latency in muscular response to this type of perturbation, and there is already less distance to travel within stability limits, this will increase the risk of a fall occurring in these older adults compared to the young adults.

The older adults have a significantly greater range of motion of COM-COP separation in the sagittal plane than the young adults, supporting previous findings (Masani *et al.* 2007). This increase in the COM-COP separation observed in the older adults may be due to an age-related change in the control strategy employed in quiet standing. The current study has the advantage over the study by Masani *et al.* (2007) in that COM in the current study is calculated through segmental masses rather than using the gravity line projection method. Another study that used the COP to estimate COM did not find significant differences between young and healthy older adults (Berger *et al.* 2005a), which may be due to the method employed not being sensitive enough to detect any differences. In addition, the Masani *et al.* study only conducted the analysis in the sagittal plane, whereas the current study also investigated these variables in the frontal plane.

This increased ROM of the COM-COP separation in the sagittal plane observed in the older adults could be linked to the reduced proprioception reported as a consequence of ageing (Skinner *et al.* 1984; Shaffer and Harrison, 2007). In the occurrence of reduced proprioception, the COM will drift further before detection and corrective feedback mechanisms are applied.

There were no significant differences in the COM-COP separation between any of the faller groups in this study, although there were trends towards a larger ROM of the COM-COP separation in the multiple fallers compared to the single and non-fallers. Significant differences have been observed previously between fallers and non-fallers (Berger *et al.* 2005b), although these were area and amplitude measures of COM-COP separation rather than measures that were comparable to this study. The participants in the study by Berger *et al.* (2005b) although community dwelling, were also very sedentary, so they are unlikely to be comparable to the relatively active participants in the present study.

The velocity of the COM can play a significant role in anticipating changes in body position as it can provide information about the subsequent body position (Masani *et al.* 2003). The older adults had higher peak and amplitude of COM velocity than the young adults in the sagittal plane, although this was only significant between the young adults and the non-fallers. As the older adults have a larger posterior COM-COP separation than the young adults, a proportionally large anterior COM velocity would be required to direct the COM back over the base of support for balance control (Pai and Patton, 1997). In addition, a more posterior COM position allows a person to tolerate higher anterior velocities without initiating a fall (Pai and Patton, 1997).

There were significantly higher acceleration values in the sagittal plane for the older adult groups compared to the young adults in this study, supporting previous findings (Masani *et al.* 2007). These higher acceleration values are related to higher COM-COP separation values in the older adults and are consistent with the inverted pendulum model (Winter, 1995b). If the COM is further away from the COP, larger COM accelerations are needed to direct the COM back towards the COP. However, these larger COM accelerations also need to be controlled and may further challenge the balance control system in these older adults.

The older adults had a significantly lower peak COM-COP separation in the frontal plane than the young adults. The young adults may be able to tolerate higher ranges in sway in the frontal plane without challenging their stability control mechanisms, whereas the older adults may be employing tighter regulation of sway in this direction as a conservative strategy to maintain stability.

In the frontal plane, the amplitude and peak values of the COM velocity were significantly higher for all older groups compared to the young adults. This is despite the peak COM-COP separation in this plane being smaller for the older adults compared to the young adults. So unlike the findings in the sagittal plane, where a larger COM velocity would be expected as there is a larger COM-COP separation for the older adults, in the frontal plane the COM and COP did not separate as far in the older adults compared to the young adults, but the COM moves at a far greater rate. This demonstrates that far more postural adjustment is occurring in the older adults in order to maintain a tighter coupling of the COM to the COP.

The significant differences observed between the young and older adults in this study show that there are measurable age-related differences occurring in the way upright standing is maintained. These differences are apparent despite the older population in this study being community-dwelling and physically active. These age-related differences may be more apparent in comparison with less independent living and less physically active older people, but further study is needed in relation to COM-COP variables to confirm this. Differences may be detected between faller groups in less healthy individuals, although differences in balance ability between frail fallers and non-fallers may be apparent with more simple testing procedures.

In spite of the epidemiological evidence that most falls occur during one form of locomotion or another (Winter, 1995b), it is valuable to start with research into quiet standing as this can yield considerable information about stability and the postural control systems that can then be investigated in locomotion studies.

The absence of significant differences between non-fallers and the two faller groups in the current study suggests that standing with and without visual input is not an activity that is challenging enough to detect differences in postural control that may be responsible for their faller status. Therefore, activities that may provide a greater challenge to stability were subject to further investigation in these groups of community-dwelling older adults. Also, as most falls occur during dynamic tasks rather than standing still (Campbell *et al.* 1990), investigation into dynamic stability should yield more relevant information for falls prevention strategies.

7.2 Walking

This is the first study that has investigated dynamic stability measures such as COM-COP separation during straight-line walking in groups of community-dwelling, older non-fallers, single fallers and multiple fallers as well as young adults. The main findings from this study are:

1. the young adults walk significantly faster with a longer stride length than the older adult groups
2. the multiple fallers spend significantly longer in the stance phase than young adults
3. the single fallers and the multiple fallers spend significantly less time in the swing phase than the young adults
4. COM-COP separation was significantly greater in the sagittal plane at heel strike for the young adults compared to the non fallers and the single fallers, and for the multiple fallers compared to the non fallers
5. COM acceleration was significantly greater at heel strike in the sagittal plane for young adults and multiple fallers compared to the non fallers.

7.2.1 Temporo-spatial characteristics

The older adults walked significantly slower than the younger adults, supporting previous findings (Bohannon, 1997; Buzzi *et al.* 2003; Menz *et al.* 2003; Gérin-Lajoie *et al.* 2006; Granata and Lockhart, 2008) and the first hypothesis of the study. There were no significant differences between the faller groups for walking velocity. Previous findings have been inconclusive as velocity differences for fallers and non-fallers have been reported in some studies (Lee and Kerrigan, 1999; Auvinet *et al.* 2003), but not in others (Brach *et al.* 2005). However, the faller group in the study by Auvinet *et al.* (2003) consisted of individuals hospitalised for falls in recent months prior to testing, which may have resulted in a more cautious gait than typical. The participants in the other study (Lee and Kerrigan, 1999) consisted of individuals who walked far more slowly (fallers $0.41 \pm 0.03 m.s^{-1}$; control 0.82 ± 0.02 $m.s^{-1}$) than the participants in the present study, suggesting that the older participants were tending to frailty far more than those in the present study who were community-dwelling and who had been relatively active over their lifetime (according to the LPAFH) and recently (according to PASE). It has been suggested that a walking velocity of $<0.8 m.s^{-1}$ could be used as a screening cut-off for those with a mobility impairment and increased risk of falling (Montero-Odasso *et al.* 2004). In the present study, the gait velocity was above this for all groups despite there being a group of individuals who had experienced multiple falls. This slow walking velocity may therefore be more of an indication of frailty and fall risk associated with frailty, than a good indicator of fall risk itself. However, a slower walking velocity has been associated with decreased stability at slip onset (Bhatt *et al.* 2005), suggesting that older adults may be more prone to this type of loss of balance than young adults. Slower gait speeds at the time of a slip or faint have also been associated with an increased probability of impact on the hip (Smeesters *et al.* 2001), increasing the likelihood of a hip fracture as a result of a fall (Hayes *et al.* 1993; Schwartz *et al.* 1998).

There was no cadence difference for young and older adults, and the values are similar to those previously reported (Watelain *et al.* 2000; Menz *et al.* 2003). There was no cadence difference for the faller groups. Fallers have been previously reported as having a lower cadence during walking than non-fallers (Lee and Kerrigan, 1999; Auvinet *et al.* 2003). However, as discussed above, the faller groups in these previous studies are considered far more frail than the single and multiple faller groups used in this present study. A decreased cadence may be an indicator of frailty in older adults, and is unlikely to be an early risk factor for falling in healthy, community-dwelling older adults such as the participants in the present study.

There were no differences between the groups for stride time, but there were significant differences between the young adults and the multiple fallers for the percentage of stride time spent in the stance phase, and between the young adults and the single and multiple fallers for percentage of stride time spent in swing. The trunk's angular acceleration is under the control of both limbs, so the only effective control can occur during stance (Winter, 1987). Although these differences were only small, they were significant, so this greater percentage of stride time spent in stance in the multiple fallers represents a compensatory strategy for improving balance control.

The older adult groups all had a shorter stride length than the young adults. The difference in walking velocity between the young and older adults can be explained by the significantly longer stride length displayed by the young adults. This relationship between stride length and gait velocity has been demonstrated previously (Winter *et al.* 1990; Moxley Scarborough *et al.* 1999; Watelain *et al.* 2000). Stride length has been shown to be correlated with quadriceps (Moxley Scarborough *et al.* 1999) and ankle dorsiflexion strength (Lord *et al.* 1996). As the strength of these muscle groups declines with increasing age (Hurley *et al.* 1998; Perry *et al.* 2007), it is unsurprising that there is a decreased stride length with the older groups in this study.

There were no differences in step width between young and older adults, or between the faller groups. Increased step width has been described as a common feature in elderly gait (Rogers and Mille, 2003), but an increased step width was not a feature here. Step width measures have not shown differences between those who have and have not fallen previously (Brach *et al.* 2005), although step width was significantly narrower in those that had fallen sideways previously than those who had fallen in other directions (Ko *et al.* 2007). In the present study, step width was narrower for the multiple fallers but the result was not significant.

7.2.2 COM and COP measures

As the visual (Cristarella, 1977; Wojciechowski *et al.* 1995), vestibular (Rauch *et al.* 2001) and proprioceptive (Skinner *et al.* 1984; Shaffer and Harrison, 2007) inputs into the balance control system decline with age, it is reasonable to expect that a reduced ability to maintain dynamic stability would be evident in the coordination of the COM with the COP. These differences in the present study occurred at heel strike in the sagittal plane. Results from this study show that young adults have a greater separation between their COM and COP at heel strike than the older non-faller and single faller groups. A decreased peak COM-COP separation with increasing age has previously been demonstrated in the sagittal plane (Hahn and Chou, 2004). The current study also shows there is greater separation between the COM and COP at heel strike for the multiple fallers compared to the non-fallers, despite there being no difference between these two groups for any of the temporo-spatial characteristics. Consequently, the COM-COP separation difference between these two groups of older adults can not be explained by differences in variables such as walking speed (which was a covariate in the analysis) or stride length.

The reduced COM-COP separation observed in the older non-faller and single faller groups compared to the young adults could demonstrate the adoption of a conservative strategy to reduce the body gravity moment around the COP of the feet (Jian *et al.* 1993) at heel strike. The multiple fallers were not significantly different from the young adults, although their actual COM-COP separation was smaller than the young adults.

This is the first time that COM-COP separation has been compared between faller groups. It is possible that the non-fallers adopt a more conservative approach to balance control during gait resulting in a decreased COM to COP distance at heel strike. A greater distance between the COM and COP is expected to result in larger moment arms for the body weight about joints of the supporting limb (Hahn and Chou, 2004).

To initiate a step during walking, the COM has to be accelerated in a forward direction. To achieve this, the body is effectively initiating the start of a fall forward to take the COM ahead of the base of support, with the fall then averted by the safe placement of the swing foot (Winter, 1995a). Consequently a fall is, in effect, initiated and averted repeatedly throughout gait. The multiple fallers in the present study, through their increased COM-COP separation and COM acceleration at heel strike, are effectively falling faster than the non-fallers and single fallers at the point the swing foot is placed. This is despite there being no differences in either walking speed or stride length between these groups. As a result, the multiple fallers are demonstrating less control of their posture during gait than the non fallers, which will result in decreased stability in the sagittal plane. Although this may appear to suggest that the young adults are demonstrating even less postural control than the older adult groups, as they have an even greater COM-COP separation at heel strike (although also a greater walking speed and stride length), these values are more critical in terms of stability in older adults due to age-related declines in muscle strength (see below). A compensation for this increased COM-COP separation at heel strike in the multiple fallers is likely to be the increased percentage of stride time spent in the stance phase observed in this group, which allows more time for the deceleration of the forward momentum of the COM following placement of the swing leg, and stability during stance to subsequently move the COM in front of the base of support again for the next step (Judge *et al.* 1996).

The dorsiflexors have been modelled to support the body whilst slowing forward progression from heel strike to foot-flat (Liu *et al.* 2006), and the ankle muscles produce a small dorsiflexor moment to lower the foot to the ground (Winter *et al.*

1990). Reductions in the strength (Pääsuke *et al.* 2000; Perry *et al.* 2007) and power (McNeil *et al.* 2007; Perry *et al.* 2007) of both the dorsiflexors and plantarflexors have been observed in older adults compared to young adults. Furthermore, reductions in the strength (Skelton *et al.* 2002; Perry *et al.* 2007) and power (Perry *et al.* 2007) of the dorsiflexors have also been detected in community-dwelling fallers compared to non-fallers , so any reduced strength of the ankle musculature associated with ageing or fall status will limit the body's ability to curb the greater forward acceleration of the COM observed in the multiple faller group in this study during the heel strike to foot flat phase of the gait cycle. The hip and knee extensors, primarily the vasti and gluteus maximus, also provide vertical support during the first half of stance as they slow forward progression (Liu *et al.* 2006). Reductions in knee extensor strength have been observed in older adults compared to young adults (Hurley *et al.* 1998) and knee extensor strength has been shown to reduce with increasing age from the fourth decade (Lindle *et al.* 1997) with loss of strength reported at ~3% per year in adults aged over 70 years old (Goodpaster *et al.* 2006). These age-related declines in muscle strength in the lower limb indicate that the multiple fallers will demonstrate less stability at heel strike than the young adults, despite having similar measures of COM-COP separation. The greater strength in the younger adults would facilitate the decrease of the forward acceleration of the COM required from heel strike to foot flat to maintain stability, whereas the lower strength in the older adults presents a greater challenge in maintaining upright balance at this phase of the gait cycle.

The most hazardous phase for a slip during level walking is the period shortly after heel strike of the swing leg (Gatts and Woollacott, 2007). Forward slips occurring at heel strike are the most challenging type of slip for both young and older adults (Tang and Woollacott, 1998). Therefore, postural control is especially important at this phase of the gait cycle to control the forward momentum of the COM and to assist in balance recovery if walking is perturbed. The tibialis anterior, rectus femoris and biceps femoris are the predominant muscles used to regain balance when a slip occurs at heel strike, and older adults displayed longer onset latencies and smaller burst magnitudes in response to a slip than young adults (Tang and Woollacott, 1998). The implications of this delayed and reduced response in the event of a slip, and the reduced muscular strength and power in the lower limbs associated with ageing (McNeil *et al.* 2007; Perry *et al.* 2007) may place the multiple fallers at an increased chance of experiencing a fall.

The use of walking speed as a covariate is justified as local dynamic stability has been demonstrated to be influenced by walking velocity (England and Granata, 2007). Differences in self-selected walking speed have been suggested to influence the COM-COP distance (Hass *et al.* 2005). By using walking speed as a covariate, this present study has accounted for any differences in walking speed that may be present. The self-selection of walking speed, cadence and step length are proposed to be optimal for the stability of an individual’s head and pelvis accelerations in the vertical and AP directions (Latt *et al.* 2008). Therefore, analysing gait at the preferred speed in this sample population allows an assessment of stability that is optimal during locomotion, rather than as an artefact of controlling speed.

There were no differences between any of the groups in the frontal plane, although there was a trend towards lower COM-COP separation in the older adults. Sideways imbalance is harder to control than forward imbalance, where a compensatory step can be taken to regain stability (Heasley *et al.* 2005). As falls to the side are more likely to results in serious injuries such as hip fracture, it is perhaps unsurprising that older people adopt a more conservative approach to balance control in the frontal plane. The older adults utilised a narrower step width than the younger adults, although this was not significant, and this coupled with the trend towards decreased COM-COP separation at foot off may be a strategy to reduce the gravitational moment of the COM in the ML direction to try to minimise lateral instability (Woollacott and Tang, 1997) in these older adults. The hip abductors are thought to play a significant role in maintaining ML stability as the COM shifts rapidly between each foot (Hahn *et al.* 2005). A greater percentage of the capacity of the gluteus medius was required during walking for elderly compared to young participants, however their maximal strength was also significantly weaker (Hahn *et al.* 2005). As there were no differences between faller groups for COM-COP separation in the mediolateral direction, this indicated that the older adult groups have similar abilities to maintain balance in the frontal plane.

This is the first time that COM and COP relationships have been analysed during walking in groups of community-dwelling older adults with histories of no falls, a single fall or multiple falls. The significant differences observed in COM-COP separation and COM acceleration at heel strike in the sagittal plane between non-fallers and multiple fallers supported the second hypothesis of this study, and demonstrate that these posturographical measures are useful measurement tools to use in studies of this nature. The COM-COP variable has been shown to be modifiable after a 3-week physical activity intervention (Gatts and Woollacott, 2007), so this variable would appear to represent a valid outcome measure in physical activity intervention trials for reducing fall risk.

Age-related differences in dynamic stability have been detected in more complex situations such as obstacle crossing (Hahn and Chou, 2004), in gait temporo-spatial changes during dual-task walking (Hollman *et al.* 2007), and larger increases in trunk motion have been detected in older compared to young adults when negotiating a multi-surface terrain (Marigold and Patla, 2008). Differences in the magnitude of the COM-COP moment arm during gait initiation between healthy older people and in older people with vestibular dysfunction have also been reported (Chang and Krebs, 1999).To follow this research, therefore, it would be interesting to further investigate more complex situations such as gait transitions, dual-task walking, obstacle crossing, walking on an uneven surface or turning to gain further information about postural control using COM and COP measures in this population, and to determine whether further differences can be identified between groups of community-dwelling older adults with and without a history of falling (see Chapter 8).

7.3 Turning 360°

The biomechanical assessment of turning is of particular importance as falls when turning have a higher likelihood of resulting in a sideways fall than a forward or backward fall (Cumming and Klineberg, 1994). A fall to the side is more likely to result in a hip fracture than a fall forward or backward (Hayes *et al.* 1993; Greenspan *et al.* 1998), and falls when turning account for ~18% of hip fractures (Nevitt and Cummings, 1993). The ability to turn has been identified as an important task of daily living, and the evaluation of turning has been included in many clinical assessments to determine those at risk of falling (Tinetti, 1986; Berg *et al.* 1989; Reubens and Siu, 1990; Podsiadlo and Richardson, 1991; Bloem *et al.* 2001; Dite and Temple, 2002). This is the first study of its kind to investigate a standing 360º turn using objective, biomechanical methods. This study also investigated the effects of ageing on the ability to turn 360º, and further investigated whether there were any fall status related differences when turning 360º.

The main significant findings of this study are:

1. the multiple fallers took longer to turn than the young adults
2. multiple fallers utilised more steps to turn than the young adults
3. young adults and multiple fallers had higher peak anterior COM velocity than the non fallers
4. young adults had higher peak posterior COM velocity than the non fallers and the multiple fallers
5. non-fallers had lower COM velocity towards the outside of the turn than the young adults
6. head yaw preceded other reorientation of body segments in all participants when the 360º turn was initiated
7. the latency of reorientation of the pelvis with respect to the thorax was much shorter in multiple fallers than all other groups.

7.3.1 Time to turn

The multiple fallers took the longest time of the 4 groups to complete the 360º turn, and this was significantly longer than for the young adults, thus supporting the first research hypothesis. A longer turn time has been identified as an indicator of difficulty when turning (Thigpen *et al.* 2000), and multiple fallers have previously been shown to take a longer time to turn when executing a 180º turn in walking than non-multiple fallers (Dite and Temple, 2002). Normal turning movement has been rated as being able to complete a 360º turn in under 4 seconds (Berg *et al.* 1989), which the young adult group accomplished but the older adults did not. However, the participants in this current study were not requested to turn as quickly as they could but in their own speed which might partly account for this. The participants were requested to turn at their own speed so that they were exhibiting a typical movement pattern that would relate to their movement when conducting an activity of daily living. In another study a turn time of greater than 9.1 seconds was associated with falling (Lipsitz *et al.* 1991), although the participants were classified as frail and were not community-dwelling. This longer turn time reported by Lipsitz *et al.* may be a stronger indicator of frailty and frailty-related falls rather than a strong independent indictor of fall risk, particularly in an independent-living population of older adults.

7.3.2 Number of steps

The multiple fallers took more steps to turn than the other groups in this study, and this was significantly more than the young adults, also supporting the first hypothesis. The use of more steps when turning is thought to indicate instability and the loss of coordination (Fuller *et al.* 2007). The multiple fallers displayed a more en-bloc turning pattern during turn initiation (see section 7.4.3) compared to the other participant groups, however the multiple fallers did not use significantly more steps than either the non-faller or single faller groups in this study. Therefore, the number of steps used to turn is not a sensitive enough measure to detect differences in stability between fallers and non-fallers in community-dwelling older adults. The use of more than 12 steps to complete a 360º turn was previously associated with falling although all the participants were classified as frail and were not community-dwelling (Lipsitz *et al.* 1991). This is considerably more steps than the multiple faller group used in this current study (7.89 ± 1.44 steps), which may reflect the study population being less frail than the population employed by Lipsitz *et al*.

Multiple fallers have also been found to take more steps to turn in other turning studies, such as during a 180º turn taken during gait (Dite and Temple, 2002). The participants who had experienced multiple falls in the previous 6 months took on average an extra two steps to complete the turn compared to those who had only experienced one fall. As with the time to turn mentioned above, the number of steps to turn may be more an indicator of frailty in older adults and was not a sensitive enough measure to differentiate between those who have and have not experienced falls in otherwise healthy, community-dwelling older adults.

7.3.3 Onset of segmental reorientation

All of the participant groups demonstrated head yaw as the first movement in the initiation of a 360º turn. Head yaw has been shown as the first movement in studies involving different forms of turning such as walking a circular path (Grasso *et al.* 1996; Courtine and Schieppati, 2003), turning 30º, 60º (Hollands *et al.* 2001; Hollands *et al.* 2002), 40º (Fuller *et al.* 2007) or 90º (Grasso *et al.* 1998; Imai *et al.* 2001; Lamontagne *et al.* 2007) when walking, and turning 45, 90 and 135º from a stationary start (Hollands *et al.* 2004). Although eye movement was not measured in this current study, it is appropriate to suggest that as movement started at the head this was a strategy adopted by the participants to look where they were going. This gazecentric control strategy has been demonstrated previously when turning, and suggests that aligning the head with the new travel direction prior to reorientation of the rest of the body is an important component of the steering strategy (Hollands *et al.* 2002). The results of this current study demonstrate that this initial head yaw to initiate a 360º turn is present in both young and older adults, regardless of their faller status.

The majority of studies reporting segment reorientation have reported only the trunk, rather than the thorax and the pelvis. When the pelvis has been identified as a separate segment, in healthy participants, turning 60º (Huxham *et al.* 2008), 90º (Lamontagne *et al.* 2007) and 120º (Huxham *et al.* 2008) when walking was achieved by an onset of segment reorientation initiated by the head and followed by the thorax and then the pelvis.

The multiple fallers in the present study demonstrated a significantly shorter latency between reorientation onset of the thorax and the pelvis at the initiation of the turn. This was significantly shorter for both absolute time and for percentage of turn time. The multiple fallers are therefore demonstrating a more en-bloc strategy of turning their thorax and pelvis compared to the other groups, supporting the second hypothesis of the study. This more en-bloc strategy has also been demonstrated in stroke patients (Lamontagne *et al.* 2007) and Parkinson's disease patients (Huxham *et al.* 2008), both of which are patient groups prone to falls. In a comparison of older and young adults conducting rapid head movements during walking, older adults showed more synchronous movement between their trunk and pelvis than young adults, who were able to demonstrate the stabilisation of one body segment relative to another (Paquette *et al.* 2006).

The implications of a more rigid trunk position during turning are unclear. This could be a strategy adopted to compensate for a decreased ability to stabilise the thorax and the pelvis independently possibly due to a deficiency in postural control and therefore simplifying the control process whilst turning, or it could demonstrate increased rigidity in the axial skeleton. As this en-bloc turning strategy of the thorax and pelvis has been observed in stroke and Parkinson disease patients previously, and now in community-dwelling older adults who have experienced multiple falls, this is worthy of further investigation to establish whether this can be used as a strong indicator of those at increased risk of falling and to gain a better understanding of the mechanisms involved that lead to this segment reorientation strategy.

7.3.4 COM and COP measures

The two biomechanical requirements for successful gait initiation are the generation of momentum and the maintenance of balance (Polcyn *et al.* 1998). These requirements will also be valid for the initiation of a turn, such as the 360º turn from a stationary position. The initiation of a turn from a stationary position, like the initiation of gait, requires a transition from being relatively stationary to moving. As in gait initiation, turn initiation affects stability by moving from the relatively wide and stable base of double-limb support to the narrower and less stable single-limb support.

The COM was positioned significantly posteriorly in the older adults compared to the young adults when plotted with respect to the COP at the initiation of the turn. This was unsurprising based on the results of the standing balance study (section 7.1), where the COM was located in a relatively posterior position in the older adults in quiet standing, as the turn in this study was initiated from a quiet standing starting point.

Gait initiation can only begin if the COM and COP separate. This theory can also be applied to the initiation of a turn from a stationary start. The COM was shifted anteriorly with respect to the COP between the initiation of the turn and the foot off event in this current study. The COM-COP separation measured at toe off in the sagittal plane for the young adults was similar to that reported previously for gait initiation (Martin *et al.* 2002). This is despite the fact that in gait initiation the intended progression of the body is forward, whereas in the 360º turn the intended progression of the body is rotation. The uncoupling of the COM and the COP during gait initiation is believed to generate forward momentum (Hass *et al.* 2005), however as this uncoupling is also present in this turning study the uncoupling of the COM and the COP must also facilitate the rotational momentum required for turn initiation. The young adults had greater COM-COP separation than the older adults throughout this turn initiation process up to the first foot strike in the sagittal plane, although this was only significantly different from the non-fallers. These age-related reductions in COM-COP separation have been previously reported for gait initiation (Martin *et al.* 2002), and are proposed to be a conservative balance control strategy to compensate for decreased stability in older adults.

In a study of gait initiation in patients with Parkinson's disease, it was suggested that these individuals placed greater emphasis on ML weight transfer so that the forces are enhanced which subsequently move the COM closer to the stance leg prior to taking a step (Hass *et al.* 2008). As a result of the stance limb being fully loaded, the patients were able to simply pick up and step with their swing limb. There were no significant differences between groups in this present turning study for COM-COP separation in the ML direction at the beginning of the turn. However, the older adults did display less separation than the young adults in this direction for all measures. This may demonstrate a more conservative balance control for the older adults in this ML direction, and also may assist their turn initiation to compensate for any potential age-related strength differences.

COP data in this present study was only analysed as far as the first foot strike after turn initiation. This was because the relatively small size of the force plates (combined area of 800 x 600 mm) resulted in many of the participants stepping off one or both of the force plates during the turn so COP could not be calculated throughout the turn. It would be interesting to conduct further testing on the 360º turn using additional or larger force plates that allow data to be collected throughout the turn. This could provide more information about the mechanisms of stability throughout the turning process rather than just the initial part of the turn (see Chapter 8).

The multiple fallers had the fastest peak COM velocities in all directions of the older adults groups during the turn and the highest peak COM accelerations in the sagittal plane, despite having the slowest turn time. Although this was not significant, there is still an indication that the control of the COM might be reduced during turning in those individuals who have suffered multiple falls. These variables are worthy of further research in less active and independent older adults to establish whether the control of the COM during turning is diminished with decreasing levels of function.

Further research could also be conducted to establish whether this increased COM velocity and acceleration in the multiple fallers compared to the other older adults groups is related to segmental reorientation strategies. It is possible that the en-bloc thorax with respect to pelvis turning strategy at the initiation of the turn in the multiple fallers may have implications for the control of the COM during the turn, and therefore the control of dynamic stability throughout the turning movement. This could have further implications as an abnormal turn score in clinical testing was associated with falls when turning caused by a perturbation of the COM (Topper *et al.* 1993).

Standing turn performance is used in clinical tests to delineate elderly fallers from non-fallers. The 360º standing turn is utilised in two clinical assessments (Tinetti, 1986; Berg *et al.* 1989), although other assessments have used a 180º turn during walking (Podsiadlo and Richardson, 1991; Bloem *et al.* 2001). An advantage of using a standing turn as opposed to a turn during walking is that this separates differences in turning from the differences that may be present during walking. However, the measurements taken in the clinical assessments of the 360º turn, e.g. time to turn, are not sensitive enough to discriminate between fallers and non-fallers in community dwelling older adults. The use of the 360º standing turn does show differences between fallers and non-fallers, but only if sensitive variables such as the onset of segment reorientation are measured. Further research could determine whether these differences in segmental reorientation onset during turn initiation are also present between faller groups in turns of shorter rotational duration, e.g. 90º, or whether the added complexity of greater rotation presented by a 360º turn is necessary to elicit the presence of these observed differences between multiple fallers and non-fallers.

This is the first time that a biomechanical assessment has been conducted on the 360º standing turn, despite this movement being an item on clinical assessments related to balance and fall risk. There are clear trends towards lower stability from the young adults to the older adults shown in many of the analysed measures. There is also an apparent difference in segment reorientation onset at the beginning of the turn in the multiple fallers compared to all other groups resulting in a more en-bloc strategy of thorax and pelvis movement.

Chapter 8: Conclusions, implications and recommendations for further research

The following chapter restates the first five aims of the thesis and against each identifies the key findings from the research and their practical implications. Based on these findings, recommendations for further research are made for continued academic investigation into physical activity guideline evidence, biomechanical assessment of dynamic stability and falls in older adults. In doing so, the achievement of the sixth and final aim of the thesis stated as 'to propose recommendations based on this work for future research and to make suggestions for physical activity guidelines specifically with the aim to reduce the risk of falling' is implicit throughout.

8.1 Assessment and attainment of recommended levels of physical activity over the life-course and falls in older adults

8.1.1 Achievement of aims and implications

The first aim of this thesis was to design a new tool to retrospectively measure the lifetime adherence to recommended levels of physical activity based on attainment of the physical activity guidelines stated at the start of the research programme (i.e. for adults, attainment of 30 minutes of at least moderate intensity physical activity on at least five days per week). This aim was accomplished through the development of the Lifetime Physical Activity & Falls History (LPAFH) questionnaire that was designed to be an easily administered and time-economical recall tool specifically for the assessment of attainment of recommended levels of physical activity over the lifetime and falls history (including falls as outcomes, injury received from falling and fear of falling). The requirement to assess guideline specific physical activity level and intensity information over the participant's lifetime necessitated that the instrument was clearly focussed to permit it to be acceptable to participants and to gather reliable data. The development and piloting undertaken led to the reduction of the number of items due to participant time concerns and specificity of the information desired, reduction in the response options available to the participants (e.g. the FES from a 10 to 5 point response scale) and the combination of item responses in order to maximise test-retest reliability assessed using Kappa and both absolute and relative percentage level of agreement. Based on these findings, the practical implication is that the LPAFH can be used as a reliable measure of physical activity recall (in relation to attainment of the Department of Health's 2004 physical activity guidelines for health over the life-course) and therefore used to further investigate lifetime physical activity recommendation attainment and fall history in similar samples of community-dwelling older adults.

The second aim of the thesis was to assess whether lifetime adherence to the physical activity recommendations evident at the initiation of the research programme has a preventative effect on fall occurrence in community-dwelling older persons. Through completion of the new LPAFH questionnaire, the 314 respondents in this study demonstrated higher than anticipated physical activity levels throughout their lifetime, with the percentage of individuals adhering to current physical activity recommendations only dropping below 50% in the 60s for the men and the 70s for the women. This confirms that the volunteer sample used in the research represents a very active subset of the population, and as such, the implications of the findings to other different populations may be limited.

It should be emphasised however, that the data generated from the LPAFH questionnaire are novel in that the distinction between occupational and leisure activity was intentionally not made. The data are therefore, more aligned with the recommendations that specify time and intensity without concern for 'when' during the day such activity is performed. Therefore this would permit the sample to include consideration of physical activities that in previous surveys would have been intentionally compartmentalised or even excluded as non-health promoting physical activities e.g. household activities that 30 years ago would have required moderately intense levels of physical activity, as opposed to similar more automated activities in today's technologically advanced world. As such, the nature of the sample, the reliance on recall and the holistic focus of the LPAFH tool could potentially explain the higher levels of physical activity reported in this thesis, particularly in the females. The fact that there appeared to be a decline in compliance with the physical activity guidelines with increased age does, however, mirror the trend for reduced levels of physical activity as age progresses into old adulthood. As such, this study can also conclude that this decrease in activity is a process that occurs with age rather than purely a difference in behaviour across generations.

Despite the high activity levels of this study sample, with the majority classed as 'active enough' over their lifetime, 72% had experienced a fall, with proportionately more women than men reporting falling and with the majority of falls occurring outside the home. These findings alone demonstrate that despite their independent living, and relatively high level of physical activity (which may of course lead them to encounter more challenging situations) the sample are an important “at risk” group for experiencing a fall. They are therefore considered noteworthy as a study population for falls research in their own right and in addition to research undertaken with more frail populations. The effect of experiencing a fall in this group is also of concern as those who had experienced a fall were significantly more fearful of a subsequent fall than those who had not yet experienced a fall. This was mirrored by a lower confidence in the ability to carry out many different everyday tasks being evident in fallers compared to non-fallers. The implication, therefore, is that preventing the first fall is a key priority if in addition to reducing the physical ramifications from a fall, reducing fear of falling and thus enhancing quality of life is a healthcare goal.

Individuals who attain the Department of Health 2004 recommendations of 30 minutes of at least moderate intensity physical activity on five days a week during their lifetime do not experience significant reduction in fall occurrence than those who do not achieve these recommendations. Achievement of the guidelines also did not offer benefits when investigating the occurrence of multiple falls compared to single falls or no falls. From these data, it can therefore be concluded that achievement of the 2004 physical activity guidelines over the adult life-course offers insufficient protection against subsequent falls in males or females who at the time of participation were community dwelling and cognitively intact. There was, however, a tendency in the data toward decreased fall occurrence in those who had been most active over the life-course. Although not empirically supported by the current conclusion, promotion of increased levels of habitual physical activity should be encouraged as other health benefits such as decreased cancer risk (Friedenreich and

Cust, 2008), decreased risk of coronary heart disease (Batty, 2002) increased bone quality and strength (Daly and Bass, 2006), and increased bone mineral density (Kolbe-Alexander *et al.* 2004) have been identified. Further research is required to identify how much and what type of activity is needed over the life course to confer benefits for falls prevention.

The findings of this study and the conclusions drawn from them lead to practical recommendations that messages for the promotion of the attainment of fall-preventing levels of physical activity (whatever these levels may eventually be determined to be) should be both gender and age specific as well as directly relevant to the 'nature' of the sample towards which the messages are aimed. It is also recommended that such advice be related to 'how' and 'where' falls are most likely to occur, and in doing so suggest strategies to either minimise the external causes of such falls, or to develop 'situation-specific' interventions for both active and less active older adults.

8.1.2 Further research

The achievement of the first two aims of the thesis successfully created a new assessment tool and subsequently questioned the efficacy of the then 'current' physical activity guidelines for reducing falls. It also identified the following areas for future research.

Since the LPAFH questionnaire was developed and employed in this thesis, the physical activity guidelines for older adults in the USA have been revised to incorporate additional specific types and quantities of physical activity. These guidelines offered by the ACSM and the American Heart Association (2007) have specifically targeted older adults as opposed to just ‘adults’. As well as advocating the previously recommended levels and duration of aerobic physical activity (as assessed by the LPAFH), these revised recommendations include advice on activity to improve and/or maintain balance and flexibility as well as muscle strengthening exercises (Nelson *et al.* 2007). These guidelines are not limited only to weight training programmes, but also include activities like weight-bearing callisthenics and stair climbing. This gives flexibility to the recommendations, which allows individuals to engage in other activities for muscle strengthening benefits rather than purely weight training. The inclusion of balance activity has been recommended for older adults previously (American Geriatrics Society *et al.* 2001), however in both sets of recommendations there is no recommendation of the preferred types, frequency or duration of balance activity. The efficacy of such revised and more focussed guidelines aimed specifically at an older population will therefore be important to establish in future retrospective lifetime recall and intervention research.

Further research is recommended with the LPAFH instrument first to establish its suitability in another similar sample in England, before investigating its applicability for use in more ethnically diverse samples, in different countries and in different age groups. Whilst clearly designed for the sample target group, it may also be possible to adapt the LPAFH to incorporate more ‘situation specific’ items that would enable it to be used in different settings such as care or residential homes.

Additionally, and already as a reliable recall tool for lifetime attainment of aerobic physical activity recommendations, the LPAFH instrument could be extended to incorporate an existing 7-day recall instrument such as the Physical Activity Scale for the Elderly (Washburn *et al.* 1993). A more focussed 12-month recall instrument could also be appended as the conclusions drawn from the current thesis may suggest that investigation of more recent levels of physical activity might be more informative in relation to reducing immediate fall risk.

Adaptation and revision of the LPAFH tool could also permit the inclusion of additional items that would gather data relating to the revised recommendations covering such features as physical activities performed that may improve balance, co-ordination and strength and in particular in those regions of the body most associated with falls. Even in its current form, the LPAFH questionnaire could be used as a template to which additional items may be added to enable the efficacy of such revised guidelines for the prevention of falls to be investigated in similar samples of older adults. Caution is afforded to the generalisability of the LPAFH tool, however, which has currently only been developed and its test-retest reliability established in a community dwelling, cognitively intact sample of older adults in England.

It must be emphasised that unless a programme of study is able to be longitudinal over several decades, recall questionnaires are a necessary method to evaluate the aetiological effects of physical activity on the development of subsequent chronic disease or conditions, in this case falls. Therefore, the limitations of such instruments need to be accepted and accommodated, as they have been with the LPAFH questionnaire, with successive versions of questionnaires designed to limit recall error as much as possible and to gather focussed information against which the efficacy of condition-specific physical activity recommendation can be judged. One concern with all recall instruments, however, is their validation. Whilst responses to all questionnaires are liable to participant subjective response, the use of objective measurements concurrently to an instrument designed to recall distant lifetime physical activity is implausible.

The development of the LPAFH questionnaire and the original findings and conclusions from its use in this thesis have therefore furthered knowledge and understanding regarding lifetime physical activity guideline attainment and fall occurrence in community-dwelling older adults. This research should therefore stimulate novel academic research that may have the potential to influence future applied physical activity recommendations throughout the life-course that are designed to reduce falls in older adults.

8.2 Stability of Balance, Gait and Turning in Older Adults

8.2.1 Achievement of aims and implications

The third aim of the thesis was to assess whether there are differences in stability measures in standing associated with age and with fall status. In order to achieve this, COM and COP motion were measured in a group of young controls, and groups of older adults classified based on their falls history from the LPAFH questionnaire (non fallers, single fallers, multiple fallers). Few studies have compared the COM-COP separation variable between young adults and healthy older adults (Berger *et al.* 2005a; Masani *et al.* 2007), and only one to date (Berger *et al.* 2005b) has compared faller groups amongst higher functioning older persons using this variable.

Group differences were detected with reference to age rather than fall status. The young adults predominantly placed their COM anterior to their COP throughout the standing trials, whereas the older adults primarily placed their COM posterior to their COP throughout the trials. This indicates that the older adults were employing more of a hip strategy or combined hip and ankle strategy for balance control in the sagittal plane than the young adults (Winter, 1995a). This strategy adopted by the older adults reduces the forward bending force and loading of the plantarflexors (Gatev *et al.* 1999) and is indicative of a compensatory strategy employed by the older adults to account for the age-related decrease in muscle strength in the ankle musculature (Pääsuke *et al.* 2000; McNeil *et al.* 2007; Perry *et al.* 2007). The older adults also demonstrated an increased range of motion of their COM-COP separation in the sagittal plane than the young adults, due possibly to the reduced level of proprioception associated with ageing (Skinner *et al.* 1984) allowing the COM to drift further away from the COP before detection and subsequent correction. The separation of COM-COP, however, did not demonstrate any significant differences between community-dwelling older adults based on their fall history.

The significant differences found in these measures between young and old groups support that such measures are able to detect differences resultant from approximately 45 years of ageing. However, the conclusion drawn from the lack of differentiation between faller groups is that the 30-second standing test used in this thesis is not an effective measure for differentiating between different faller groups of older adults. The implication of this is that the use of simple test protocols that are static in nature are not suitable for use with community dwelling, cognitively intact older adults in clinical settings for screening for fall relevant parameters or as outcome measures in intervention trials.

The fourth aim of thesis was to assess whether there are differences in the dynamic stability of walking associated with age and with fall status. This is the first study that has investigated dynamic stability measures such as COM-COP separation during straight-line walking in groups of community-dwelling, older non-fallers, single fallers and multiple fallers as well as young adult controls. Such research is vitally important as walking has been reported as the activity when the highest number of falls occur (Berg *et al.* 1997), 40% of hip fractures result from falls during walking (Nevitt and Cummings, 1993) and walking has also been reported as the most popular form of physical activity for all adults (Taylor *et al.* 2004). If walking is a common activity associated with falling, and also the most common form of physical activity, it is essential to increase understanding of the mechanisms of stability during walking to reduce the risk of falling and also to encourage this form of activity in a safe and controlled way.

The conclusions drawn from the study identify that the older adults walked slower than the young adults and utilised a shorter stride length. The multiple fallers also spent significantly longer in stance as a percentage of their stride time than the young adults, but there were no differences in the commonly measured temporo-spatial characteristics of gait (e.g. walking speed, cadence, stride time, stride length, step width) between the older adult faller groups. These summary measures of gait only provide an indirect measure of the stability of walking, however, and are not sensitive enough to detect any difference in stability in walking between groups of community-dwelling older adults. Although these measures provide useful summary information about walking, they do not provide enough information by themselves to discriminate between faller groups in studies of this nature, or as measures of the effectiveness of a physical-activity based falls intervention programme in community-dwelling older adults. It should be concluded therefore, from the current research, that these measures are not suitable for use in such populations as an independent indicator of fall risk or as an outcome measure for falls prevention interventions. Whilst the goal of any intervention may be to increase walking speed, and in doing so enhance quality of life through increased functional mobility, the increase in walking speed *per se* should not be presumed to be a successful outcome for reduced fall risk.

The young adults and the older multiple fallers displayed greater COM-COP separation than the non-fallers and single fallers, and greater COM acceleration than the non-fallers at heel strike in the sagittal plane. To initiate a step during walking, the COM is accelerated in a forward direction to effectively initiate the start of fall forward to take the COM ahead of the base of support, with the fall then averted by the safe placement of the swing foot (Winter, 1995a). Consequently a fall is effectively initiated and averted repeatedly throughout gait. The multiple fallers were, therefore, effectively falling forwards faster than the non-fallers and single fallers at heel strike. As slips occurring at heel strike are the most difficult types of slip to recover from (Tang and Woollacott, 1998) and a greater distance between the COM and COP results in larger moment arms for the body weight about joints of the supporting limb (Hahn and Chou, 2004), coupled with the age-related decreases in muscle strength and power observed in the lower limbs (Lindle *et al.* 1997; Hurley *et al.* 1998; Pääsuke *et al.* 2000; Goodpaster *et al.* 2006; McNeil *et al.* 2007; Perry *et al.* 2007), these findings indicate less ability to control upright posture in the multiple fallers compared to the non-fallers if a perturbation occurred at this phase of the gait cycle. Therefore, the significant difference observed between multiple fallers and non-fallers for COM-COP separation and COM acceleration in the sagittal plane at heel strike in this study demonstrates that posturographical measures such as these are of value in studies investigating fall-related as well as age-related differences during locomotion. The implications that can be drawn from this are that these direct measures of stability during walking are able to discriminate between non-fallers and multiple fallers in otherwise functionally similar older adults. These measures, therefore, should be used wherever feasible in preference to simple measurement of temporo-spatial parameters such as walking speed, stride length and stride width.

The fifth aim of the thesis was to assess whether there are any differences in dynamic stability of a 360º standing turn, and the turning strategy adopted, associated with age and fall status. Whilst the test employed has been used previously as an item within the Berg Balance Scale (Berg *et al.* 1989) and the Performance Orientated Mobility Assessment (Tinetti, 1986), previous work has merely focussed on the monitoring of basic characteristics of test completion in relation to the number of steps taken and the time taken to complete the turn. The findings and conclusions from this study are therefore original and further knowledge through the measurement and consideration of the COM and COP and the examination of body segment orientations during the completion of the turn.

The older multiple fallers took significantly longer to turn 360º, and utilised more steps to complete the turn than the young adults. However, these differences were not significant between multiple faller and non-faller status in the older adults. It should therefore be concluded that these measures should not be used in attempts to distinguish between those at lower and higher risk of falling in screening procedures or as outcome measures in interventions with similar participant samples to those used in the current thesis. This does not suggest that such basic measures should not be recorded, but that in populations such as this, they should be used more as descriptions of movement as opposed to indicators of fall likelihood.

The COM was located in a significantly more posterior position when plotted with respect to the COP in the older adults compared to the young adults at the initiation of the turn. These age-related reductions in COM-COP separation have been previously reported for gait initiation (Martin *et al.* 2002), and are proposed to be a conservative balance control strategy to compensate for decreased stability in older adults. The conclusion therefore, is that ageing rather than faller status is the most discriminating factor in COM-COP separation at turn initiation, mirroring the conclusion from the standing balance study.

The multiple fallers had the fastest peak COM velocities in all directions of the older adults groups during the turn and the highest peak COM accelerations in the sagittal plane, despite having the slowest turn time. Although these differences were not found to be significant, there is a strong indication that the control of the COM is reduced during turning in those individuals who have suffered multiple falls.

Examination of segmental movement of the body identified that all of the participants demonstrated head yaw as the first movement in the initiation of a 360º turn. The multiple fallers demonstrated a significantly shorter latency between reorientation onset of the thorax and the pelvis at the initiation of the turn compared to all the other groups. Therefore, the conclusion is that multiple fallers exhibit a more en-bloc strategy of turning their thorax and pelvis compared to the other groups, which has also been found in samples of other adults with conditions known to be associated with heightened fall risk e.g. stroke (Lamontagne *et al.* 2007) and Parkinson's disease patients (Huxham *et al.* 2008). It should also be concluded that the investigation of reorientation of body segments during turning may be an important addition to current practise for the assessment of fall risk in a variety of both healthy participants and specific patient groups.

8.2.2 Further research

From the conclusions of this biomechanical study, the following suggestions for further research are made.

The 30-second standing test with eyes either open or closed was not challenging enough to discriminate between faller groups in this sample. Further research in this important participant group should therefore investigate means to make such simple tasks more challenging. This could be achieved through lengthening the duration of the test; adding a secondary or tertiary distraction task e.g. completing the Stroop colour-word test; making the task itself more challenging through changing the nature of the floor surface e.g. standing on foam (although consideration should be given to standardisation of the thickness and density of any such material and the impact this would have upon the measured body movements (Patel *et al.* 2008)). Of course, the development of any such variation should undergo rigorous validation and reliability assessment in the population in which it is intended to be used.

Conclusions from the walking and turning studies also highlight areas for further research using the COM, COP and COM-COP separation variables for both the assessment of physical activity intervention efficacy and methodological advancement. Whilst the measures used in this thesis are precise, valid, and reliable, they are also expensive and therefore relatively inaccessible. Although such expense may limit their use in clinical settings, they should wherever feasible and practical be employed as outcome measures for intervention studies (e.g. habitual physical activity or structured 'exercise' interventions). Further research is warranted using these measures as the criterion against which to validate less expensive field measures that could be more commonly employed in clinical settings e.g. assessment of the validity of less-expensive and more mobile equipment techniques such as accelerometers to estimate COM and pressure mats to estimate COP to determine whether these measures are sensitive enough to detect fall-related differences in COM-COP separation during walking.

The COM-COP separation variable is of interest to investigate in other walking studies, which may provide useful information about the ability to deal with the challenges of locomotion in everyday life. This variable has already been utilised in obstacle crossing (Hahn and Chou, 2004; Lee and Chou, 2006), but could also be investigated in studies using variable terrain or during dual-tasking.

The 360º turn showed clear differences in body segment reorientation onset between multiple fallers and all other groups at turn initiation. Further research could investigate different amounts of turn rotation, e.g. 90º, 180º as well as 360º to identify whether a specific amount of rotation is most sensitive to the detection of these differences. This could lead to further recommendations about future turning protocols. The mechanism(s) accounting for the “en-bloc” strategy of turning also need to be identified.

Some of the technical limitations in the data collection processes for the turning study also identifies some areas for future research and methodological development. The force plates available for use in the turning study were not of sufficient size that the participants could remain on them throughout the turn. Further research using larger force plates to assess COM-COP separation throughout the turn may provide additional information about dynamic stability during a 360º standing turn, as this was beyond the scope of this study.

Finally, in relation to future research proposed from the biomechanics-related conclusions, retrospective studies, such as conducted in this thesis, are weaker than prospective studies in predicting future falls as differences detected between falls groups were not detected prior to a fall (Moe-Nilssen *et al.* 2008). However, the differences observed here between the groups in the walking and turning studies could be investigated in future prospective studies to identify if differentiation in these variables is present prior to a fall event having taken place.

The conclusions from the physical activity and biomechanical studies also offers direction for future research in relation to the future potential identification of appropriate fall-prevention physical activity guidelines for stages of and the entire life-course and for the assessment of efficacy of physical activity interventions, e.g.

activities that preserve or increase strength in the hip and knee extensors and ankle dorsiflexors may help maintain stability during walking.

8.3 Concluding statement

The aetiology of the majority of falls is multifactorial (Tinetti, 2003), however activity-orientated assessments of activities such as walking and turning are still of value to evaluate individuals who are more likely to fall during these activities and to gain a greater understanding of the mechanisms that may contribute to decreased stability during these activities. Therefore, the posturographic variables utilised in this thesis are of benefit for future studies investigating dynamic stability and falls in older people, and as outcome measures for the assessment of the benefits of long-term adherence to physical activity or as measures of the efficacy of intervention programmes for reducing fall risk.

In addition to the generation of original findings and furtherance of academic knowledge, the rationale made, the research undertaken, the findings generated and the conclusions drawn from this programme of research training have some key practical considerations and evidence to inform the National Service Framework for Older People Standard 6 – Falls (Department of Health, 2008). The recommendations that are fed into a national service framework are based on evidence in four main areas: primary prevention; tools for early systematic detection of increased risk; measures when increased risk is identified; and best practice in clinical management and rehabilitation after falls and fractures (Swift, 2001). In relation to primary prevention, the thesis has identified that lifetime adherence to the 2004 physical activity guidelines, offers no increased primary prevention for falls in community dwelling, cognitively intact older adults and in doing so supports the revision of the guidelines to include recommendation to undertake activities reported to enhance balance, strength and flexibility . The thesis has also provided research evidence for the efficacy of biomechanical tools that could either themselves be used for, or which could be used to validate cheaper more practical alternatives, for early systematic detection of increased fall risk. The thesis has also identified fall related biomechanical variables that are able to discriminate between different faller groups, thus being sensitive enough to identify increased fall risk. Finally, it has also made recommendation for the use of these identified measures as more valid and reliable outcome measures for fall prevention interventions.

Reference List

Abu-Omar,K., Rutten,A. & Robine,J.M. (2004). Self-rated health and physical activity in the European Union. *Sozial- und Präventivmedizin* **49**(4):235-242.

Allum,J.H. & Carpenter,M.G. (2005). A speedy solution for balance and gait analysis: angular velocity measured at the centre of body mass. *Current Opinion in Neurology* **18**(1):15-21.

American College of Sports Medicine (1993). Position Stand. Physical activity, physical fitness, and hypertension. *Medicine and Science in Sports and Exercise* **25**(10):i-x.

American College of Sports Medicine (1978). Position statement on the recommended quantity and quality of exercise for developing and maintaining fitness in healthy adults. *Medicine and Science in Sports* **10**(3):vii-x.

American College of Sports Medicine (2000). *ACSM's Guidelines for Exercise Testing and Presciption.* Sixth edn. Lippincott Williams & Wilkins: Philadelphia.

American Geriatrics Society, British Geriatrics Society & American Academy of Orthopaedic Surgeons Panel on Falls Prevention (2001). Guideline for the prevention of falls in older persons. *Journal of the American Geriatrics Society* **49**(5):664-672.

Amiridis,I.G., Hatzitaki,V. & Arabatzi,F. (2003). Age-induced modifications of static postural control in humans. *Neuroscience Letters* **350**(3):137-140.

Auvinet,B., Berrut,G., Touzard,C., Moutel,L., Collet,N., Chaleil,D. & Barrey,E. (2003). Gait abnormalities in elderly fallers. *Journal of Aging and Physical Activity* **11**(1):40-52.

Batty,G.D. (2002). Physical activity and coronary heard disease in older adults: A systematic review of epidemiological studies. *European Journal of Public Health* **12**:171-176.

Bauman,A., Armstrong,T., Davies,J., Owen,N., Brown,W., Bellew,B. & Vita,P. (2003). Trends in physical activity participation and the impact of integrated campaigns among Australian adults, 1997-99. *Australian and New Zealand Journal of Public Health* **27**(1):76-79.

Benda,B.J., Riley,P.O. & Krebs,D.E. (1994). Biomechanical relationship between center of gravity and center of pressure during standing. *IEEE Transactions on Rehabilitation Engineering* **2**(1):3-10.

Bendall,M.J., Bassey,E.J. & Pearson,M.B. (1989). Factors affecting walking speed of elderly people. *Age and Ageing* **18**:327-332.

Benjuya,N., Melzer,I. & Kaplanski,J. (2004). Aging-Induced Shifts From a Reliance on Sensory Input to Muscle Cocontraction During Balanced Standing. *Journals of Gerontology Series A: Biological Sciences and Medical Sciences* **59**(2):M166-M171.

Berg,K., Wood-Dauphinée,S., Williams,J.I. & Gayton,D. (1989). Measuring balance in the elderly: preliminary development of an instrument. *Physiotherapy Canada* **41**(6):304-311.

Berg,W.P., Alessio,H.M., Mills,E.M. & Tong,C. (1997). Circumstances and consequences of falls in independent community-dwelling older adults. *Age and Ageing* **26**:261-268.

Berger,L., Buisson,G., Chuzel,M. & Rougier,P. (2005a). Undisturbed upright stance control in the elderly: Part 1. Age-related changes in undisturbed upright stance control. *Journal of Motor Behaviour* **37**(5):348-358.

Berger,L., Buisson,G., Chuzel,M. & Rougier,P. (2005b). Undisturbed upright stance control in the elderly: Part 2. Postural-control impairments in elderly fallers. *Journal of Motor Behaviour* **37**(5):359-366.

Bhatt,T., Wening,J.D. & Pai,Y.C. (2005). Influence of gait speed on stability: recovery from anterior slips and compensatory stepping. *Gait and Posture* **21**(2):146-156.

Bischoff,H.A., Conzelmann,M., Lindemann,D., Singer-Lindpaintner,L., Stucki,G., Vonthein,R., Dick,W., Theiler,R. & Stähelin,H.B. (2001). Self-reported exercise before age 40: Influence on quantitative skeletal ultrasound and fall risk in the elderly. *Archives of Physical Medicine and Rehabilitation* **82**(6):801-806.

Blair,S.N. & Connelly,J.C. (1996). How much physical activity should we do? The case for moderate amounts and intensities of physical activity. *Research Quarterly for Exercise and Sport* **67**(2):193-205.

Blair,S.N., LaMonte,M.J. & Nichaman,M.Z. (2004). The evolution of physical activity recommendations: how much is enough? *American Journal of Clinical Nutrition* **79**(5):913S-920S.

Blanc,Y., Balmer,C., Landis,T. & Vingerhoets,F. (1999). Temporal parameters and patterns of the foot roll over during walking: normative data for healthy adults. *Gait and Posture* **10**:97-108.

Bloem,B.R., Valkenburg,V.V., Slabbekoorn,M. & Willemsen,M.D. (2001). The multiple tasks test. Development and normal strategies. *Gait and Posture* **14**(3):191-202.

Bohannon,R.W. (1997). Comfortable and maximum walking speed of adults aged 20-79 years: reference values and determinants. *Age and Ageing* **26**(1):15-19.

Boulgarides,L.K., McGinty,S.M., WIllett,J.A. & Barnes,C.W. (2003). Use of clinical and impairment-based tests to predict falls by community-dwelling older adults. *Physical Therapy* **83**(4):328-339.

Brach,J.S., Berlin,J.E., Van Swearingen,J.M., Newman,A.B. & Studenski,S.A. (2005). Too much or too little step width variability is associated with a fall history in older persons who walk at or near normal gait speed. *Journal of Neuroengineering and Rehabilitation* **2**:21.

Brauer,S.G., Burns,Y.R. & Galley,P. (2000). A prospective study of laboratory and clinical measures of postural stability to predict community-dwelling fallers. *Journal of Gerontology Series A: Biological Sciences and Medical Sciences* **55A**(8):M469-M476.

Brooke-Wavell,K. & Cooling,V.C. (2009). Fall risk factors in older female lawn bowls players and controls. *Journal of Aging & Physical Activity* **17**(1):123-130.

Bryant,E.C., Trew,M.E., Bruce,A.M., Kuisma,R.M.E. & Smith,A.W. (2005). Gender differences in balance performance at the time of retirement. *Clinical Biomechanics* **20**:330-335.

Buzzi,U.H., Stergiou,N., Kurz,M.J., Hageman,P.A. & Heidel,J. (2003). Nonlinear dynamics indicates aging affects variability during gait. *Clinical Biomechanics* **18**:435-443.

Campbell,A.J., Borrie,M.J., Spears,G.F., Jackson,S.L., Brown,J.S. & Fitzgerald,J.L. (1990). Circumstances and consequences of falls experienced by a community population 70 years and over during a prospective study. *Age and Ageing* **19**(2):136-141.

Campbell,A.J., Robertson,M.C., Gardner,M.M., Norton,R.N. & Buchner,D.M. (1999). Falls prevention over 2 years: a randomised controlled trial in women 80 years and older. *Age and Ageing* **28**(6):513-518.

Carter,N.D., Kannus,P. & Khan,K.M. (2001). Exercise in the prevention of falls in older people. *Sports Medicine* **31**(6):427-438.

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

Caspersen,C.J., Powell,K.E. & Christenson,G.M. (1985). Physical activity, exercise, and physical fitness: definitions and distinctions for health-related research. *Public Health Reports* **100**(2):126-131.

Chad,K.E., Reeder,B.A., Harrison,E.L., Ashworth,N.L., Sheppard,S.M., Schultz,S.L., Bruner,B.G., Fisher,K.L. & Lawson,J.A. (2005). Profile of physical activity levels in community-dwelling older adults. *Medicine and Science in Sports and Exercise* **37**(10):1774-1784.

Chamberlin,M.E., Fulwider,B.D., Sanders,S.L. & Medeiros,J.M. (2005). Does fear of falling influence spatial and temporal gait parameters in elderly persons beyond changes associated with normal aging? *Journal of Gerontology Series A: Biological Sciences and Medical Sciences* **60**(9):1163-1167.

Chang,H.A. & Krebs,D.E. (1999). Dynamic balance control in elders: Gait initiation assessment as a screening tool. *Archives of Physical Medicine and Rehabilitation* **80**(5):490-494.

Chasan-Taber,L., Erickson,J.B., McBride,J.W., Nasca,P.C., Chasan-Taber,S. & Freedson,P.S. (2002). Reproducibility of a self-administered lifetime physical activity questionnaire among female college alumnae. *American Journal of Epidemiology* **155**(3):282-289.

Chou,L.S., Kaufman,K.R., Brey,R.H. & Draganich,L.F. (2001). Motion of the whole body's center of mass when stepping over obstacles of different heights. *Gait and Posture* **13**(1):17-26.

Chou,L.S., Kaufman,K.R., Hahn,M.E. & Brey,R.H. (2003). Medio-lateral motion of the center of mass during obstacle crossing distinguishes elderly individuals with imbalance. *Gait and Posture* **18**(3):125-133.

Christou,E.A., Yang,Y. & Rosengren,K.S. (2003). Taiji training improves knee extensor strength and force control in older adults. *Journal of Gerontology Series A: Biological Sciences and Medical Sciences* **58A**(8):763-766.

Close,J., Ellis,M., Hooper,R., Glucksman,E., Jackson,S. & Swift,C. (1999). Prevention of falls in the elderly trial (PROFET): a randomised controlled trial. *Lancet* **353**(9147):93-97.

Cohen,J. (1960). A coefficient of agreement for nominal scales. *Educational and Psychological Measurement* **20**(1):37-46.

Collins,J.J., De Luca,C.J., Burrows,A. & Lipsitz,L.A. (1995). Age-related changes in open-loop and closed-loop postural control mechanisms. *Experimental Brain Research* **104**:480-492.

Cornilleau-Pérès,V., Shabana,N., Droulez,J., Goh,J.C.H., Lee,G.S.M. & Chew,P.T.K. (2005). Measurement of the visual contribution to postural steadiness from the COP movement: methodology and reliability. *Gait and Posture* **22**(2):96-106.

Corriveau,H., Hebert,R., Prince,F. & Raiche,M. (2000). Intrasession reliability of the "center of pressure minus center of mass" variable of postural control in the healthy elderly. *Archives of Physical Medicine and Rehabilitation* **81**(1):45-48.

Corriveau,H., Hébert,R., Prince,F. & Raîche,M. (2001). Postural control in the elderly: An analysis of test-retest and interrater reliability of the COP-COM variable. *Archives of Physical Medicine and Rehabilitation* **82**:80-85.

Courtine,G. & Schieppati,M. (2003). Human walking along a curved path. I. Body trajectory, segment orientation and the effect of vision. *European Journal of Neuroscience* **18**(1):177-190.

Crespo,C.J., Keteyian,S.J., Heath,G.W. & Sempos,C.T. (1996). Leisure-time physical activity among US adults. Results from the Third National Health and Nutrition Examination Survey. *Archives of Internal Medicine* **156**(1):93-98.

Cristarella,M.C. (1977). Visual Functions of Elderly. *American Journal of Occupational Therapy* **31**(7):432-440.

Cromwell,R.L. & Newton,R.A. (2004). Relationship between balance and gait stability in healthy older adults. *Journal of Aging and Physical Activity* **12**(1):90-100.

Cumming,R.G. & Klineberg,R.J. (1994). Fall frequency and characteristics and the risk of hip fractures. *Journal of the American Geriatrics Society* **42**(7):774-778.

Cummings,S.R., Nevitt,M.C. & Kidd,S. (1988). Forgetting falls: The limited accuracy of recall of falls in the elderly. *Journal of the American Geriatrics Society* **36**(7):613-616.

Daly,R.M. & Bass,S.L. (2006). Lifetime sport and leisure activity participation is associated with greater bone size, quality and strength in older men. *Osteoporosis International* **17**(8):1258-1267.

Dawson,J., Juszczak,E., Thorogood,M., Foster,C., Marks,S.A., Dodd,C. & Fitzpatrick,R. (2003). Distant past exercise in women: Measures may be reliable, but are they valid? *Medicine and Science in Sports and Exercise* **35**(5):862-866.

de Hoon,E.W., Allum,J.H., Carpenter,M.G., Salis,C., Bloem,B.R., Conzelmann,M. & Bischoff,H.A. (2003). Quantitative assessment of the stops walking while talking test in the elderly. *Archives of Physical Medicine and Rehabilitation* **84**:838-842.

de Rekeneire,N., Visser,M., Peila,R., Nevitt,M.C., Cauley,J.A., Tylavsky,F.A., Simonsick,E.M. & Harris,T.B. (2003). Is a fall just a fall: Correlates of falling in healthy older persons. The health, aging and body composition study. *Journal of the American Geriatrics Society* **51**(6):841-846.

DeBusk,R.F., Stenestrand,U., Sheehan,M. & Haskell,W.L. (1990). Training effects of long versus short bouts of exercise in healthy subjects. *American Journal of Cardiology* **65**(15):1010-1013.

Delbaere,K., Bourgois,J., van den Noortgate,N., Vanderstraeten,G., Willems,T. & Cambier,D. (2006a). A home-based multidimensional exercise program reduced physical impairment and fear of falling. *Acta Clinica Belgica* **61**(6):340-350.

Delbaere,K., Crombez,G., Van den Noortgate,N., Willems,T. & Cambier,D. (2006b). The risk of being fearful or fearless of falls in older people: An empirical validation. *Disability and Rehabilitation* **28**(12):751-756.

Dempster,W.T. (1955) Space requirements of the seated operator. pp.55-159. Wright-Patterson Air Force Base:

Department of Health . Older People's NSF Standard Six - Falls. http://www.dh.gov.uk/en/SocialCare/Deliveringadultsocialcare/Olderpeople/OlderpeoplesNSFstandards/DH_4002294 . 2008. 29-9-2008. (GENERIC) Ref Type: Electronic Citation

Department of Health (1999) Health survey for England 1998: Cardiovascular disease. London: The Stationary Office.

Department of Health (2004a) Risk factors for cardiovascular disease. 2, London: The Stationary Office.

Department of Health (2007) Chronic Diseases: The health of older people. 2, London: The Stationary Office.

Department of Health (1996) Strategy statement on physical activity. London: The Stationary Office.

Department of Health (2004b) At least five a week: Evidence on the impact of physical activity and its relationship to health. London: Department of Health.

Department of Health and Ageing (1999) National physical activity guidelines for Australians. Canberra:

Deshpande,N., Metter,E.J., Lauretani,F., Bandinelli,S., Guralnik,J. & Ferrucci,L. (2008). Activity restriction induced by fear of falling and objective and subjective measures of physical function: a prospective cohort study. *Journal of the American Geriatrics Society* **56**(4):615-620.

DeVita,P. & Hortobagyi,T. (2000). Age causes a redistribution of joint torques and powers during gait. *Journal of Applied Physiology* **88**(5):1804-1811.

Dinger,M.K., Oman,F., Tyalor,E.L., Vesely,S.K. & Able,J. (2004). Stability and convergent validity of the Physical Activity Scale for the Elderly (PASE). *Journal of Sports Medicine and Physical Fitness* **44**(2):186-192.

Dite,W. & Temple,V.A. (2002). Development of a clinical measure of turning for older adults. *American Journal of Physical Medicine and Rehabilitation* **81**(11):857-866.

Doyle,T.L.A., Dugan,E.L., Humphries,B. & Newton,R.U. (2004). Discriminating between elderly and young using a fractal dimension analysis of centre of pressure. *International Journal of Medical Sciences* **1**(1):11-20.

Ebrahim,S., Thompson,P.W., Baskaran,V. & Evans,K. (1997). Randomized placebo-controlled trial of brisk walking in the prevention of postmenopausal osteoporosis. *Age and Ageing* **26**(4):253-260.

England,S.A. & Granata,K.P. (2007). The influence of gait speed on local dynamic stability of walking. *Gait and Posture* **25**(2):172-178.

Falkner,K.L., Trevisan,M. & McCann,S.E. (1999). Reliability of recall of physical activity in the distant past. *American Journal of Epidemiology* **150**(2):195-205.

Feskanich,D., Willett,W. & Colditz,G. (2002). Walking and leisure-time activity and risk of hip fracture in postmenopausal women. *Journal of the American Medical Association* **288**(18):2300-2306.

Florindo,A.A., Latorre,M.D.O., Jaime,P.C., Tanaka,T., Pippa,M.G.B. & Zerbini,C.A.F. (2004). Past and present habitual physical activity and its relationship with bone mineral denisty in men aged 50 years and older in Brazil. *Journal of Gerontology Series A: Biological Sciences and Medical Sciences* **57A**(10):M654-M657.

Friedenreich,C.M., Courneya,K.S. & Bryant,H.E. (1998). The lifetime total physical activity questionnaire: Development and reliability. *Medicine and Science in Sports and Exercise* **30**(2):266-274.

Friedenreich,C.M. & Cust,A.E. (2008). Physical activity and breast cancer risk; impact of timing, type and dose of activity and populations subgroup effects. *British Journal of Sports Medicine* **42**(8):636-647.

Friedman,S.M., Munoz,B., West,S.K., Rubin,G.S. & Fried,L.P. (2002). Falls and fear of falling: Which comes first? A longitudinal prediction model suggests strategies for primary and secondary prevention. *Journal of the American Geriatrics Society* **50**(8):1329-1335.

Fuller,J.R., Adkin,A.L. & Vallis,L.A. (2007). Strategies used by older adults to change travel direction. *Gait and Posture* **25**(3):393-400.

Gage,W.H., Winter,D.A., Frank,J.S. & Adkin,A.L. (2004). Kinematic and kinetic validity of the inverted pendulum model in quiet standing. *Gait and Posture* **19**(2):124-132.

Gatev,P., Thomas,S., Kepple,T. & Hallett,M. (1999). Feedforward ankle strategy of balance during quiet stance in adults. *Journal of Physiology-London* **514**(3):915-928.

Gatts,S.K. & Woollacott,M.H. (2007). How Tai Chi improves balance: Biomechanics of recovery to a walking slip in impaired seniors. *Gait and Posture* **25**(2):205-214.

Gérin-Lajoie,M., Richards,C.L. & McFadyen,B.J. (2006). The circumvention of obstacles during walking in different environmental contexts: A comparison between older and younger adults. *Gait and Posture* **24**(3):364-369.

Giakas,G. (2004). Power spectrum analysis and filtering. In *Innovative Analyses of Human Movement*, (ed. N. Stergiou), pp. 223-258. Human Kinetics: Champaign.

Gilsing,M.G., van den Bosch,C.G., Lee,S.G., Ashton-Miller,J.A., Alexander,N.B., Schultz,A.B. & Ericson,W.A. (1995). Association of age with the threshold for detecting ankle inversion and eversion in upright stance. *Age and Ageing* **24**:58-66.

Glaister,B.C., Bernatz,G.C., Klute,G.K. & Orendurff,M.S. (2007). Video task analysis of turning during activities of daily living. *Gait and Posture* **25**(2):289-294.

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

Granata,K.P. & Lockhart,T.E. (2008). Dynamic stability differences in fall-prone and healthy adults. *Journal of Electromyography and Kinesiology* **18**(2):172-178.

Grasso,R., Glasauer,S., Takei,Y. & Berthoz,A. (1996). The predictive brain: anticipatory control of head direction for the steering of locomotion. *Neuroreport* **7**(6):1170-1174.

Grasso,R., Prevost,P., Ivanenko,Y.P. & Berthoz,A. (1998). Eye-head coordination for the steering of locomotion in humans: an anticipatory synergy. *Neuroscience Letters* **253**(2):115-118.

Greenspan,S.L., Myers,E.R., Kiel,D.P., Parker,R.A., Hayes,W.C. & Resnick,N.M. (1998). Fall direction, bone mineral density, and function: risk factors for hip fracture in frail nursing home elderly. *American Journal of Medicine* **104**:539-545.

Gregg,E.W., Pereira,M.A. & Caspersen,C.J. (2000). Physical activity, falls, and fractures among older adults: a review of the epidemiologic evidence. *Journal of the American Geriatrics Society* **48**(8):883-893.

Grisso,J.A., Kelsey,J.L., Strom,B.L., Chiu,G.Y., Maislin,G., O'Brien,L.A., Hoffman,S. & Kaplan,F. (1991). Risk factors for falls as a cause of hip fracture in women. The Northeast Hip Fracture Study Group. *The New England Journal of Medicine* **324**(19):1326-1331.

Gutierrez-Farewik,E.M., Bartonek,A. & Saraste,H. (2006). Comparison and evaluation of two common methods to measure center of mass displacement in three dimensions during gait. *Human Movement Science* **25**(2):238-256.

Hadjistavropoulos,T., Martin,R.R., Sharpe,D., Lints,A.C., McCreary,D.R. & Asmundson,G.J. (2007). A longitudinal investigation of fear of falling, fear of pain, and activity avoidance in community-dwelling older adults. *Journal of Aging and Health* **19**(6):965-984.

Hahn,M.E. & Chou,L.S. (2004). Age-related reduction in sagittal plane center of mass motion during obstacle crossing. *Journal of Biomechanics* **37**(6):837-844.

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

Ham,S.A., Macera,C.A., Jones,D.A., Ainsworth,B.E. & Turczyn,K.M. (2004). Considerations for physical activity research: Variations on a theme. *Journal of Physical Activity and Health* **1**(2):98-113.

Hasan,S.S., Robin,D.W., Szurkus,D.C., Ashmead,D.H., Peterson,S.W. & Shiavi,R.G. (1996). Simultaneous measurement of body center of pressure and center of gravity during upright stance. Part II: Amplitude and frequency data. *Gait and Posture* **4**(1):11-20.

Hase,K. & Stein,R.B. (1999). Turning strategies during human walking. *Journal of Neurophysiology* **81**(6):2914-2922.

Haskell,W.L., Lee,I.M., Pate,R.R., Powell,K.E., Blair,S.N., Franklin,B.A., Macera,C.A., Heath,G.W., Thompson,P.D. & Bauman,A. (2007). Physical activity and public health: Updated recommendations for adults from the American College of Sports Medicine and the American Heart Association. *Medicine and Science in Sports and Exercise* **39**(8):1423-1434.

Hass,C.J., Waddell,D.E., Fleming,R.P., Juncos,J.L. & Gregor,R.J. (2005). Gait initiation and dynamic balance control in Parkinson's Disease. *Archives of Physical Medicine and Rehabilitation* **86**:2172-2176.

Hass,C.J., Waddell,D.E., Wolf,S.L., Juncos,J.L. & Gregor,R.J. (2008). Gait initiation in older adults with postural instability. *Clinical Biomechanics* **23**(6):743-753.

Hauer,K., Lamb,S.E., Jørstad,E.C., Todd,C. & Becker,C. (2006). Systematic review of definitions and methods of measuring falls in randomised controlled fall prevention trials. *Age and Ageing* **35**(1):5-10.

Hayes,W.C., Myers,E.R., Morris,J.N., Gerhart,T.N., Yett,H.S. & Lipsitz,L.A. (1993). Impact near hip dominates fracture risk in elderly nursing home residents who fall. *Calcified Tissue International* **52**:192-198.

Hayes,W.C., Myers,E.R., Robinovitch,S.N., van den Kroonenberg,A., Courtney,A. & McMahon,T.A. (1996). Etiology and prevention of age-related hip fractures. *Bone* **18**(1 Supplement):77S-86S.

Heasley,K., Buckley,J.G., Scally,A., Twigg,P. & Elliott,D.B. (2005). Falls in older people: Effects of age and blurring vision on the dynamics of stepping. *Investigative Ophthalmology and Visual Science* **46**(10):3584-3588.

Helbostad,J.L. & Moe-Nilssen,R. (2003). The effect of gait speed on lateral balance control during walking in healthy elderly. *Gait and Posture* **18**(2):27-36.

Hill,K.D., Schwarz,J.A., Kalogeropoulos,A.J. & Gibson,S.J. (1996). Fear of falling revisited. *Archives of Physical Medicine and Rehabilitation* **77**:1025-1029.

Hillsdon,M., Cavill,N., Nanchahal,K., Diamond,A. & White,I.R. (2001). National level promotion of physical activity: Results from England's ACTIVE for LIFE campaign. *Journal of Epidemiology and Community Health* **55**(10):755-761.

Hof,A.L., van Bockel,R.M., Schoppen,T. & Postema,K. (2007). Control of lateral balance in walking. Experimental findings in normal subjects and above-knee amputees. *Gait and Posture* **25**(2):250-258.

Hollands,M.A., Patla,A.E. & Vickers,J.N. (2002). "Look where you're going!": gaze behaviour associated with maintaining and changing the direction of locomotion. *Experimental Brain Research* **143**(2):221-230.

Hollands,M.A., Sorensen,K.L. & Patla,A.E. (2001). Effects of head immobilization on the coordination and control of head and body reorientation and translation during steering. *Experimental Brain Research* **140**(2):223-233.

Hollands,M., Ziavra,N. & Bronstein,A. (2004). A new paradigm to investigate the roles of head and eye movements in the coordination of whole-body movements. *Experimental Brain Research* **154**(2):261-266.

Hollman,J.H., Kovash,F.M., Kubik,J.J. & Linbo,R.A. (2007). Age-related differences in spatiotemporal markers of gait stability during dual task walking. *Gait and Posture* **26**(1):113-119.

Holloszy,J.O. (1983). Exercise, health, and aging: A need for more information. *Medicine and Science in Sports and Exercise* **15**(1):1-5.

Hong Kong Sports Development Board (2002) Sports Participation Survey 2000. Hong Kong: Sports Development Board.

Hong,Y., Li,J.X. & Robinson,P.D. (2000). Balance control, flexibility, and cardiorespiratory fitness among older Tai Chi practitioners. *British Journal of Sports Medicine* **34**(1):29-34.

Hourigan,S., Nitz,J., Brauer,S., O'Neill,S., Wong,J. & Richardson,C. (2008). Positive effects of exercise on falls and fracture risk in osteopenic women. *Osteoporosis International* **19**(7):1077-1086.

Hue,O.A., Seynnes,O., Ledrole,D., Colson,S.S. & Bernard,P.L. (2004). Effects of a physical activity program on postural stability in older people. *Aging Clinical and Experimental Research* **16**(5):356-362.

Hurley,M.V., Rees,J. & Newham,D.J. (1998). Quadriceps function, proprioceptive acuity and functional performance in healthy young, middle-aged and elderly subjects. *Age and Ageing* **27**:55-62.

Huxham,F., Baker,R., Morris,M.E. & Iansek,R. (2008). Head and trunk rotation during walking turns in Parkinson Disease. *Movement Disorders* **23**(10):1391-1397.

Imai,T., Moore,S.T. & Raphan,T. (2001). Interaction of the body, head, and eyes during walking and turning. *Experimental Brain Research* **136**(1):1-18.

Jensen,J., Lundin-Olsson,L., Nyberg,L. & Gustafson,Y. (2002). Fall and injury prevention in older people living in residential care facilities. A cluster randomized trial. *Annals of Internal Medicine* **136**(10):733-741.

Jian,Y., Winter,D.A., Ishac,M.G. & Gilchrist,L. (1993). Trajectory of the body COG and COP during initiation and termination of gait. *Gait and Posture* **1**(1):9-22.

Jones,D.A., Ainsworth,B.E., Croft,J.B., Macera,C.A., Lloyd,E.E. & Yusuf,H.R. (1998). Moderate leisure-time physical activity: who is meeting the public health recommendations? A national cross-sectional study. *Archives of Family Medicine* **7**(3):285-289.

Judge,J.O., Ounpuu,S. & Davis,R.B. (1996). Effects of age on the biomechanics and physiology of gait. *Clinics in Geriatric Medicine* **12**(4):659-&.

Kannus,P. (1999). Preventing osteoporosis, falls, and fractures among elderly people: Promotion of lifelong physical activity is essential. *British Medical Journal* **318**(7178):205-206.

Karlsson,M. (2004). Has exercise an antifracture efficacy in women? *Scandanavian Journal of Medicine and Science in Sports* **14**(1):2-15.

Karvonen,M.J. (1996). Physical activity for a healthy life. *Research Quarterly for Exercise and Sport* **67**(2):213-215.

Kaya,B.K., Krebs,D.E. & Riley,P.O. (1998). Dynamic stability in elders: Momentum control in locomotor ADL. *Journals of Gerontology Series A-Biological Sciences and Medical Sciences* **53**(2):M126-M134.

Keegan,T.H.M., Kelsey,J.L., King,A.C., Quesenberry Jr,C.P. & Sidney,S. (2004). Characteristics of fallers who fracture at the foot, distal forearm, proximal humerus, pelvis, and shaft of the tibia/fibula compared with fallers who do not fracture. *American Journal of Epidemiology* **159**(2):192-203.

King,M.B., Judge,J.O. & Wolfson,L. (1994). Functional base of support decreases with age. *Journal of Gerontology Series A: Biological Sciences and Medical Sciences* **49**(6):M258-M263.

Ko,S.U., Gunter,K.B., Costello,M., Aum,H., MacDonald,S., White,K.N., Snow,C.M. & Hayes,W.C. (2007). Stride width discriminates gait of side-fallers compared to other-directed fallers during overground walking. *Journal of Aging and Health* **19**(2):200-212.

Kolbe-Alexander,T.L., Charlton,K.E. & Lambert,E.V. (2004). Lifetime physical activity and determinants of estimated bone mineral density using calcaneal ultrasound in older South African adults. *Journal of Nutrition, Health and Aging* **8**(6):521-530.

Kressig,R.W., Gregor,R.J., Oliver,A., Waddell,D., Smith,W., O'Grady,M., Curns,A.T., Kutner,M. & Wolf,S.L. (2004). Temporal and spatial features of gait in older adults transitioning to frailty. *Gait and Posture* **20**:30-35.

Kriska,A.M., Knowler,W.C., LaPorte,R.E., Drash,A.L., Wing,R.R., Blair,S.N., Bennett,P.H. & Kuller,L.H. (1990). Development of questionnaire to examine relationship of physical activity and diabetes in Pima Indians. *Diabetes Care* **13**(4):401-411.

Kriska,A.M., Sandler,R.B., Cauley,J.A., LaPorte,R.E., Hom,D.L. & Pambianco,G. (1988). The assessment of historical physical activity and its relation to adult bone parameters. *American Journal of Epidemiology* **127**(5):1053-1063.

Kuo,A.D. (1995). An Optimal-Control Model for Analyzing Human Postural Balance. *IEEE Transactions on Biomedical Engineering* **42**(1):87-101.

Kurozawa,Y., Hosoda,T., Iwai,N., Nose,T., Yoshimura,T. & Tamakoshi,A. (2005). Levels of physical activity among participants in the JACC study. *Journal of Epidemiology* **15**(Supplement 1):S43-S47.

Lacquaniti,F., Grasso,R. & Zago,M. (1999). Motor patterns in walking. *News in Physiological Sciences* **14**:168-174.

Lajoie,Y. & Gallagher,S.P. (2004). Predicting falls within the elderly community: comparison of postural sway, reaction time, the Berg balance scale and the Activities-specific Balance Confidence (ABC) scale for comparing fallers and non-fallers. *Archives of Gerontology and Geriatrics* **38**(1):11-26.

Lamb,S.E., Jørstad-Stein,E.C., Hauer,K. & Becker,C. (2005). 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.

Lamontagne,A., Paquette,C. & Fung,J. (2007). Stroke affects the coordination of gaze and posture during preplanned turns while walking. *Neurorehabilitation and Neural Repair* **21**(1):62-67.

Lan,C., Lai,J.S., Chen,S.Y. & Wong,M.K. (2000). Tai Chi Chaun to improve muscular strength and endurance in elderly individuals: a pilot study. *Archives of Physical Medicine and Rehabilitation* **81**:604-607.

Lan,C., Lai,J.S. & Wong,M.K. (1998). 12-month Tai Chi training in the elderly: Its effect on health fitness. *Medicine and Science in Sports and Exercise* **30**(3):345-351.

Landis,J.R. & Koch,G.G. (1977). The measurement of observer agreement for categorical data. *Biometrics* **33**(1):159-174.

Latt,M.D., Menz,H.B., Fung,V.S. & Lord,S.R. (2008). Walking speed, cadence and step length are selected to optimize the stability of head and pelvis accelerations. *Experimental Brain Research* **184**(2):201-209.

Laughton,C.A., Slavin,M., Katdare,K., Nolan,L., Bean,J.F., Kerrigan,D.C., Phillips,E., Lipsitz,L.A. & Collins,J.J. (2003). Aging, muscle activity, and balance control: Physiologic changes associated with balance impairment. *Gait and Posture* **18**(2):101-108.

Lee,H.J. & Chou,L.S. (2006). Detection of gait instability using the center of mass and center of pressure inclination angles. *Archives of Physical Medicine and Rehabilitation* **87**(4):569-575.

Lee,L.W. & Kerrigan,D.C. (1999). Identification of kinetic differences between fallers and nonfallers in the elderly. *American Journal of Physical Medicine and Rehabilitation* **78**:242-246.

Li,F., Fisher,K.J., Harmer,P., McAuley,E. & Wilson,N.L. (2003). Fear of falling in elderly persons: Association with falls, functional ability, and quality of life. *Journal of Gerontology Series B: Psychological Sciences* **58B**(5):P283-P290.

Li,F., Harmer,P., Fisher,K.J. & McAuley,E. (2004). Tai Chi: Improving functional balance and predicting subsequent falls in older persons. *Medicine and Science in Sports and Exercise* **36**(12):2046-2052.

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

Lin,M.R., Hwang,H.F., Wang,Y.W., Chang,S.H. & Wolf,S.L. (2006). Community-Based Tai Chi and Its Effect on Injurious Falls, Balance, Gait, and Fear of Falling in Older People. *Physical Therapy* **86**(9):1189-1201.

Lin,S.I. & Woollacott,M.H. (2002). Postural muscle reponses following changing balance threats in young, stable older, and unstable older adults. *Journal of Motor Behaviour* **34**(1):37-44.

Lin,Y.C., Wong,A.M.K., Chou,S.W., Tang,F.T. & Wong,P.Y. (2000). The effects of Tai Chi Chuan on postural stability in the elderly: Preliminary report. *Changgeng Yi Xue Za Zhi* **23**(4):197-204.

Lindle,R.S., Metter,E.J., Lynch,N.A., Fleg,J.L., Fozard,J.L., Tobin,J., Roy,T.A. & Hurley,B.F. (1997). Age and gender comparisons of muscle strength in 654 women and men aged 20-93 yr. *Journal of Applied Physiology* **83**(5):1581-1587.

Lipsitz,L.A., Jonsson,P.V., Kelley,M.M. & Koestner,J.S. (1991). Causes and correlates of recurrent falls in ambulatory frail elderly. *Journal of Gerontology Series A: Biological Sciences and Medical Sciences* **46**(4):M114-M122.

Lissner,L., Potischman,N., Troiano,R. & Bengtsson,C. (2004). Recall of physical activity in the distant past: the 32-year follow-up of the Prospective Population Study of Women in Goteborg, Sweden. *American Journal of Epidemiology* **159**(3):304-307.

Littman,A.J., White,E., Kristal,A.R., Patterson,R.E., Satia-Abouta,J. & Potter,J.D. (2004). Assessment of a one-page questionnaire on long-term recreational physical activity. *Epidemiology* **15**(1):105-113.

Liu,M.Q., Anderson,F.C., Pandy,M.G. & Delp,S.L. (2006). Muscles that support the body also modulate forward progression during walking. *Journal of Biomechanics* **39**(14):2623-2630.

Liu-Ambrose,T., Khan,K.M., Eng,J.J., Lord,S.R. & McKay,H.A. (2004). Balance confidence improves with resistance or agility training. *Gerontology* **50**:373-382.

Livingstone,M.B., Robson,P.J., McCarthy,S., Kiely,M., Harrington,K., Browne,P., Galvin,M., Wareham,N.J. & Rennie,K.L. (2001). Physical activity patterns in a nationally representative sample of adults in Ireland. *Public Health Nutrition* **4**(5A):1107-1116.

Lord,S.R. & Clark,R.D. (1996). Simple physiological and clinical tests for the accurate prediction of falling in older people. *Gerontology* **42**:199-203.

Lord,S.R., Lloyd,D.G. & Li,S.K. (1996). Sensori-motor function, gait patterns and falls in community-dwelling women. *Age and Ageing* **25**:292-299.

Lord,S.R., Sherrington,C. & Menz,H.B. (2001). *Falls in older people: Risk factors and strategies for prevention.* Cambridge University Press: Cambridge.

Lord,S.R. & Ward,J.A. (1994). Age-Associated Differences in Sensorimotor Function and Balance in Community-Dwelling Women. *Age and Ageing* **23**(6):452-460.

Lord,S.R., Ward,J.A., Williams,P. & Strudwick,M. (1995). The effect of a 12-month exercise trial on balance, strength, and falls in older women: A randomised controlled trial. *Journal of the American Geriatrics Society* **43**(1198):1206.

Lundin-Olsson,L., Nyberg,L. & Gustafson,Y. (1997). "Stops walking when talking" as a predictor of falls in elderly people. *Lancet* **349**(9052):617.

Lyon,I.N. & Day,B.L. (1997). Control of frontal plane body motion in human stepping. *Experimental Brain Research* **115**(2):345-356.

Mackey,D.C. & Robinovitch,S.N. (2005). Postural steadiness during quiet stance does not associate with ability to recover balance in older women. *Clinical Biomechanics* **20**:776-783.

Mackey,D.C. & Robinovitch,S.N. (2006). Mechanisms underlying age-related differences in ability to recover balance with the ankle strategy. *Gait and Posture* **23**(1):59-68.

MacKinnon,C.D. & Winter,D.A. (1993). Control of whole body balance in the frontal plane during human walking. *Journal of Biomechanics* **26**(6):633-644.

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

Maki,B.E., Holliday,P.J. & Topper,A.K. (1994). A prospective study of postural balance and risk of falling in an ambulatory and independent elderly population. *Journal of Gerontology Series A: Biological Sciences and Medical Sciences* **49**(2):M72-M84.

Marigold,D.S. (2008). Role of peripheral visual cues in online visual guidance of locomotion. *Exercise and Sport Sciences Reviews* **36**(3):145-151.

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

Martin,M., Shinberg,M., Kuchibhatla,M., Ray,L., Carollo,J.J. & Schenkman,M.L. (2002). Gait initiation in community-dwelling adults with Parkinson disease: Comparison with older and younger adults without the disease. *Physical Therapy* **82**(6):566-577.

Masani,K., Popovic,M.R., Nakazawa,K., Kouzaki,M. & Nozaki,D. (2003). Importance of body sway velocity information in controlling ankle extensor activities during quiet stance. *Journal of Neurophysiology* **90**(6):3774-3782.

Masani,K., Vette,A.H., Kouzaki,M., Kanehisa,H., Fukunaga,T. & Popovic,M.R. (2007). Larger center of pressure minus center of gravity in the elderly induces larger body acceleration during quiet standing. *Neuroscience Letters* **422**(3):202-206.

Masani,K., Vette,A.H. & Popovic,M.R. (2006). Controlling balance during quiet standing: Proportional and derivative controller generates preceding motor command to body sway position observed in experiments. *Gait and Posture* **23**(2):164-172.

Mazzeo,R.S., Cavanagh,P., Evans,W.J., Fiatarone,M., Hagberg,J., McAuley,E. & Startzell,J. (1998). ACSM Position Stand: Exercise and Physical Activity for Older Adults. *Medicine and Science in Sports and Exercise* **30**(6):992-1008.

McKinley,P., Jacobson,A., Leroux,A., Bednarczyk,V., Rossignol,M. & Fung,J. (2008). Effect of a Community-Based Argentine Tango Dance Program on Functional Balance and Confidence in Older Adults. *Journal of Aging and Physical Activity* **16**(4):435-453.

McNeil,C.J., Vandervoort,A.A. & Rice,C.L. (2007). Peripheral impairments cause a progressive age-related loss of strength and velocity-dependent power in the dorsiflexors. *Journal of Applied Physiology* **102**(5):1962-1968.

Meinhart-Shibata,P., Kramer,M., Ashton-Miller,J.A. & Persad,C. (2005). Kinematic analyses of the 180° standing turn: effects of age on strategies adopted by healthy young and older women. *Gait and Posture* **22**(2):119-125.

Meng,Q., Li,B. & Holstein,H. (2006). Recognition of human periodic movements from unstructured information using a motion-based frequency domain approach. *Image and Vision Computing* **24**(8):795-809.

Menz,H.B., Lord,S.R. & Fitzpatrick,R.C. (2003). Age-related differences in walking stability. *Age and Ageing* **32**(2):137-142.

Meyer,K., Rezny,L., Breuer,C., Lamprecht,M. & Stamm,H.P. (2005). Physical activity of adults aged 50 years and older in Switzerland. *Sozial- und Präventivmedizin* **50**(4):218-229.

Mills,P.M. & Barrett,R.S. (2001). Swing phase mechanics of healthy young and elderly men. *Human Movement Science* **20**(4-5):427-446.

Moe-Nilssen,R., Nordin,E. & Lundin-Olsson,L. (2008). Criteria for evaluation of measurement properties of clinical balance measures for use in fall prevention studies. *Journal of Evaluation in Clinical Practice* **14**(2):236-240.

Montero-Odasso,M., Schapira,M., Varela,C., Pitteri,C., Soriano,E.R., Kaplan,R., Camera,L.A. & Mayorga,L.M. (2004). Gait velocity in senior people. An easy test for detecting mobility impairment in community elderly. *Journal of Nutrition, Health and Aging* **8**(5):340-343.

Montero-Odasso,M., Schapira,M., Soriano,E.R., Varela,M., Kaplan,R., Camera,L.A. & Mayorga,L.M. (2005). Gait Velocity as a Single Predictor of Adverse Events in Healthy Seniors Aged 75 Years and Older. *Journals of Gerontology Series A: Biological Sciences and Medical Sciences* **60**(10):1304-1309.

Montoye,H.J. & Taylor,H.L. (1984). Measurement of physical activity in population studies: A review. *Human Biology* **56**(2):195-216.

Morasso,P.G. & Schieppati,M. (1999). Can Muscle Stiffness Alone Stabilize Upright Standing? *Journal of Neurophysiology* **82**(3):1622-1626.

Morris,J.N., HEADY,J.A., RAFFLE,P.A., ROBERTS,C.G. & PARKS,J.W. (1953). Coronary heart-disease and physical activity of work. *Lancet* **265**(6795):1053-1057.

Moxley Scarborough,D., Krebs,D.E. & Harris,B.A. (1999). Quadriceps muscle strength and dynamic stability in elderly persons. *Gait and Posture* **10**(1):10-20.

Muntner,P., Gu,D., Wildman,R.P., Chen,J., Qan,W., Whelton,P.K. & He,J. (2005). Prevalence of physical activity among Chinese adults: results from the International Collaborative Study of Cardiovascular Disease in Asia. *American Journal of Public Health* **95**(9):1631-1636.

Nashner,L.M. & Mccollum,G. (1985). The Organization of Human Postural Movements - A Formal Basis and Experimental Synthesis. *Behavioral and Brain Sciences* **8**(1):135-150.

Nelson,M.E., Rejeski,W.J., Blair,S.N., Duncan,P.W., Judge,J.O., King,A.C., Macera,C.A. & Castaneda-Sceppa,C. (2007). Physical activity and public health in older adults: Recommendations from the American College of Sports Medicine and the American Heart Association. *Medicine and Science in Sports and Exercise* **39**(8):1435-1445.

Neptune,R.R., Zajac,F.E. & Kautz,S.A. (2004). Muscle force redistributes segmental power for body progression during walking. *Gait and Posture* **19**(2):194-205.

Nevitt,M.C. & Cummings,S.R. (1993). Type of fall and risk of hip and wrist fractures: the study of osteoporotic fractures. The Study of Osteoporotic Fractures Research Group. *Journal of the American Geriatrics Society* **41**(11):1226-1234.

Nicholl,J.P., Coleman,P. & Brazier,J.E. (1994). Health and healthcare costs and benefits of exercise. *Pharmacoeconomics* **5**(2):109-122.

Nordell,E., Jarnlo,G.B., Jetsén,C., Nordström,L. & Thorngren,K.G. (2000). Accidental falls and related fractures in 65-74 year olds: A retrospective study of 332 patients. *Acta Orthopaedica Scandinavica* **71**(2):175-179.

Nowalk,M.P., Prendergast,J.M., Bayles,C.M., D'Amico,F.J. & Colvin,G.C. (2001). A randomised trial of exercise programs among older individuals living in two long-term care facilities: The FallsFREE Program. *Journal of the American Geriatrics Society* **49**(7):859-865.

Oberg,T., Karsznia,A. & Oberg,K. (1993). Basic Gait Parameters - Reference Data for Normal Subjects, 10-79 Years of Age. *Journal of Rehabilitation Research and Development* **30**(2):210-223.

Office for National Statistics (2006) Population Trends. 126, Her Majesty's Stationary Office.

Onambele,G.L., Narici,M.V. & Maganaris,C.N. (2006). Calf muscle-tendon properties and postural balance in old age. *Journal of Applied Physiology* **100**(6):2048-2056.

Orendurff,M.S., Segal,A.D., Berge,J.S., Flick,K.C., Spanier,D. & Klute,G.K. (2006). The kinematics and kinetics of turning: limb asymmetries associated with walking a circular path. *Gait and Posture* **23**(1):106-111.

Orendurff,M.S., Segal,A.D., Klute,G.K., Berge,J.S., Rohr,E.S. & Kadel,N.J. (2004). The effect of walking speed on center of mass displacement. *Journal of Rehabilitation Research and Development* **41**(6):829-834.

Orsini,N., Bellocco,R., Bottai,M., Pagano,M. & Wolk,A. (2007). Reproducibility of the past year and historical self-administered total physical activity questionnaire among older women. *European Journal of Epidemiology* **22**(6):363-368.

Pääsuke,M., Ereline,J., Gapeyeva,H., Sirkel,S. & Sander,P. (2000). Age-related differences in twitch contractile properties of plantarflexor muscles in women. *Acta Physiologica Scandinavica* **170**(1):51-57.

Paffenbarger,R.S., Jr., Blair,S.N. & Lee,I.M. (2001). A history of physical activity, cardiovascular health and longevity: the scientific contributions of Jeremy N Morris, DSc, DPH, FRCP. *International Journal of Epidemiology* **30**(5):1184-1192.

Pai,Y.C. & Patton,J. (1997). Center of mass velocity-position predictions for balance control. *Journal of Biomechanics* **30**(4):347-354.

Pajala,S., Era,P., Koskenvuo,M., Kaprio,J., Tormakangas,T. & Rantanen,T. (2008). Force platform balance measures as predictors of indoor and outdoor falls in community-dwelling women aged 63-76 years. *Journal of Gerontology Series A: Biological Sciences and Medical Sciences* **63**(2):171-178.

Pande,I., Scott,D.L., O'Neill,T.W., Pritchard,C., Woolf,A.D. & Davis,M.J. (2006). Quality of life, morbidity, and mortality after low trauma hip fracture in men. *Annals of the Rheumatic Diseases* **65**(1):87-92.

Panzer,V.P., Bandinelli,S. & Hallett,M. (1995). Biomechanical Assessment of Quiet Standing and Changes Associated with Aging. *Archives of Physical Medicine and Rehabilitation* **76**(2):151-157.

Paquette,C., Paquet,N. & Fung,J. (2006). Aging affects coordination of rapid head motions with trunk and pelvis movements during standing and walking. *Gait and Posture* **24**(1):62-69.

Park,R.J. (1997). High-protein diets, "damaged hearts," and rowing men: antecedents of modern sports medicine and exercise science, 1867-1928. *Exercise and Sport Sciences Reviews* **25**:137-169.

Pate,R.R., Pratt,M., Blair,S.N., Haskell,W.L., Macera,C.A., Bouchard,C., Buchner,D., Ettinger,W., Heath,G.W. & King,A.C. (1995). Physical activity and public health. A recommendation from the Centers for Disease Control and Prevention and the American College of Sports Medicine. *Journal of the American Medical Association* **273**(5):402-407.

Patel,M., Fransson,P.A., Lush,D. & Gomez,S. (2008). The effect of foam surface properties on postural stability assessment while standing. *Gait and Posture* **28**(4):649-656.

Patla,A.E. (1997). Understanding the roles of vision in the control of human locomotion. *Gait and Posture* **5**(1):54-69.

Patla,A.E., Adkin,A. & Ballard,T. (1999). Online steering: coordination and control of body center of mass, head and body reorientation. *Experimental Brain Research* **129**(4):629-634.

Pavol,M.J., Owings,T.M., Foley,K.T. & Grabiner,M.D. (2002). Influence of lower extremity strength of healthy older adults on the outcome of an induced trip. *Journal of the American Geriatrics Society* **50**(2):256-262.

Pereira,M.A., Kriska,A.M., Day,R.D., Cauley,J.A., LaPorte,R.E. & Kuller,L.H. (1998). A randomized walking trial in postmenopausal women: effects on physical activity and health 10 years later. *Archives of Internal Medicine* **158**(15):1695-1701.

Perry,M., Carville,S., Smith,I., Rutherford,O. & Newham,D. (2007). Strength, power output and symmetry of leg muscles: effect of age and history of falling. *European Journal of Applied Physiology* **100**(5):553-561.

Piirtola,M. & Era,P. (2006). Force platform measurements as predictors of falls among older people - a review. *Gerontology* **52**(1):1-16.

Podsiadlo,D. & Richardson,S. (1991). The timed "up and go": A test of basic functional mobility for frail elderly persons. *Journal of the American Geriatrics Society* **39**(2):142-148.

Polcyn,A.F., Lipsitz,L.A., Kerrigan,D.C. & Collins,J.J. (1998). Age-related changes in the initiation of gait: Degradation of central mechanisms for momentum generation. *Archives of Physical Medicine and Rehabilitation* **79**:1582-1589.

Powell,L.E. & Myers,A.M. (1995). The activities-specific balance confidence (ABC) scale. *Journal of Gerontology Series A: Biological Sciences and Medical Sciences* **50A**(1):M28-M34.

Pozzo,T., Berthoz,A. & Lefort,L. (1990). Head Stabilization During Various Locomotor Tasks in Humans .1. Normal Subjects. *Experimental Brain Research* **82**(1):97-106.

Prieto,T.E., Myklebust,J.B., Hoffmann,R.G., Lovett,E.G. & Myklebust,B.M. (1996). Measures of postural steadiness: Differences between healthy young and elderly adults. *IEEE Transactions on Biomedical Engineering* **43**(9):956-966.

Prince,F., Corriveau,H., Hèbert,R. & Winter,D.A. (1997). Gait in the elderly. *Gait and Posture* **5**(2):128-135.

Rauch,S.D., Velazquez-Villasenor,L., Dimitri,P.S. & Merchant,S.N. (2001). Decreasing Hair Cell Counts in Aging Humans. *Annals of the New York Academy of Sciences* **942**(1):220-227.

Raymakers,J.A., Samson,M.M. & Verhaar,H.J.J. (2005). The assessment of body sway and the choice of the stability parameter(s). *Gait and Posture* **21**(1):48-58.

Reubens,D.B. & Siu,A.L. (1990). An objective measure of physical function of elderly outpatients. The physical performance test. *Journal of the American Geriatrics Society* **38**(10):1105-1112.

Richmond,R.L. (2008). The changing face of the Australian population: growth in centanarians. *The Medical Journal of Australia* **188**(12):720-723.

Ringsberg,K.A.M., Gärdsell,P., Josefsson,P.O. & Obrant,K.J. (2001). The impact of long-term moderate physical activity on functional performance, bone mineral density and fracture incidence in elderly women. *Gerontology* **47**(1):15-20.

Rogers,M.W. & Mille,M.L. (2003). Lateral stability and falls in older people. *Exercise and Sport Sciences Reviews* **31**(4):182-187.

Runge,C.F., Shupert,C.L., Horak,F.B. & Zajac,F.E. (1999). Ankle and hip postural strategies defined by joint torques. *Gait and Posture* **10**(2):161-170.

Salkeld,G., Cameron,I.D., Cumming,R.G., Easter,S., Seymour,J., Kurrle,S.E. & Quine,S. (2000). Quality of life related to fear of falling and hip fracture in older women: a time trade off study. *British Medical Journal* **320**(7231):341-345.

Scheffer,A.C., Schuurmans,M.J., van Dijk,N., van der Hooft,T. & de Rooij,S.E. (2008). Fear of falling: measurement strategy, prevalence, risk factors and consequences among older persons. *Age and Ageing* **37**(1):19-24.

Schuit,A.J., Schouten,E.G., Westerterp,K.R. & Saris,W.H.M. (1997). Validity of the physical activity scale for the elderly (PASE): According to energy expenditure assessed by the double labeled water method. *Journal of Clinical Epidemiology* **50**(5):541-546.

Schwartz,A.V., Kelsey,J.L., Sidney,S. & Grisso,J.A. (1998). Characteristics of falls and risk of hip fracture in elderly men. *Osteoporosis International* **8**(3):240-246.

Scuffham,P., Chaplin,S. & Legood,R. (2003). Incidence and costs of unintentional falls in older people in the United Kingdom. *Journal of Epidemiology and Community Health* **57**(9):740-744.

Shaffer,S.W. & Harrison,A.L. (2007). Aging of the Somatosensory System: A Translational Perspective. *Physical Therapy* **87**(2):193-207.

Sheldon,J.H. (1963). The effect of age on the control of sway. *Gerontologica Clinica* **5**:129-138.

Shephard,R.J. (2003). Limits to the measurement of habitual physical activity by questionnaires. *British Journal of Sports Medicine* **37**(3):197-206.

Sherrington,C., Whitney,J.C., Lord,S.R., Herbert,R.D., Cumming,R.G. & Close,J.C. (2008). Effective exercise for the prevention of falls: a systematic review and meta-analysis. *Journal of the American Geriatrics Society* **56**(12):2234-2243.

Shimba,T. (1984). An Estimation of Center of Gravity from Force Platform Data. *Journal of Biomechanics* **17**(1):53-60.

Shumway-Cook,A., Silver,I.F., LeMier,M., York,S., Cummings,P. & Koepsell,T.D. (2007). Effectiveness of a Community-Based Multifactorial Intervention on Falls and Fall Risk Factors in Community-Living Older Adults: A Randomized, Controlled Trial. *Journals of Gerontology Series A: Biological Sciences and Medical Sciences* **62**(12):1420-1427.

Sim,J. & Wright,C.C. (2005). The kappa statistic in reliability studies: use, interpretation, and sample size requirements. *Physical Therapy* **85**(3):257-268.

Skelton,D.A., Kennedy,J. & Rutherford,O.M. (2002). Explosive power and asymmetry in leg muscle function in frequent fallers and non-fallers aged over 65. *Age and Ageing* **31**(2):119-125.

Skelton,D.A., Young,A., Walker,A. & Hoinville,E. (1999) Physical activity in later life: Further analysis of the Allied Dunbar Fitness Survey and the Health Education Authority Survey of Activity and Health. London: Health Education Authority.

Skinner,H.B., Barrack,R.L. & Cook,S.D. (1984). Age-related decline in proprioception. *Clinical Orthopaedics and Related Research* **184**:208-211.

Slattery,M.L. (1996). How much physical activity do we need to maintain health and prevent disease? Different diseases--different mechanisms. *Research Quarterly for Exercise and Sport* **67**(2):209-212.

Smeesters,C., Hayes,W.C. & McMahon,T.A. (2001). Disturbance type and gait speed affect fall direction and impact location. *Journal of Biomechanics* **34**(3):309-317.

Smith,L.K., Lelas,J.L. & Kerrigan,D.C. (2002). Gender differences in pelvic motions and center of mass displacement during walking: Stereotypes quantified. *Journal of Womens Health and Gender-Based Medicine* **11**(5):453-458.

Sports Council & Health Education Authority (1992) Allied Dunbar National Fitness Survey. London: Sports Council/ HEA.

Steinberg,M., Cartwright,C., Peel,N. & Williams,G. (2000). A sustainable programme to prevent falls and near falls in community dwelling older people: results of a randomised trial. *Journal of Epidemiology and Community Health* **54**(3):227-232.

Stevens,D.L. & Tomlinson,G.E. (1971). Measurement of human postural sway. *Proceedings of the Royal Society of Medicine* **64**(6):653-655.

Swift,C.G. (2001). Falls in late life and their consequences - implementing effective services. *British Medical Journal* **322**:855-857.

Swiss Federal Office of Sports, Swiss Federal Office of Public Health, Swiss Federal Statistical Office & Network HEPA Switzerland (2000). Physical activity in the Swiss population: Prevalence data and associations with health.

Schweizerische Zeitschrift für Sportmedizin und Sporttraumatologie **48**(2):27-88.

Taggart,H.M. (2002). Effects of Tai Chi exercise on balance, functional mobility, and fear of falling among older women. *Applied Nursing Research* **15**(4):235-242.

Tanaka,T., Noriyasu,S., Ino,S., Ifukube,T. & Nakata,M. (1996). Objective method to determine the contribution of the great toe to standing balance and preliminary observations of age-related effects. *IEEE Transactions on Rehabilitation Engineering* **4**(2):84-90.

Tang,P.F. & Woollacott,M.H. (1998). Inefficient postural responses to unexpected slips during walking in older adults. *Journal of Gerontology Series A: Biological Sciences and Medical Sciences* **53**(6):M471-M480.

Taylor,A.H., Cable,N.T., Faulkner,G., Hillsdon,M., Narici,M. & van der Bij,A.K. (2004). Physical activity and older adults: a review of health benefits and the effectiveness of interventions. *Journal of Sports Sciences* **22**:703-725.

Tencer,A.F., Koepsell,T.D., Wolf,M.E., Frankenfeld,C.L., Buchner,D.M., Kukull,W.A., LaCroix,A.Z., Larson,E.B. & Tautvydas,M. (2004). Biomechanical properties of shoes and risk of falls in older adults. *Journal of the American Geriatrics Society* **52**(11):1840-1846.

Thapa,P.B., Gideon,P., Fought,R.L., Kormicki,M. & Ray,W.A. (1994). Comparison of clinical and biomechanical measures of balance and mobility in elderly nursing home residents. *Journal of the American Geriatrics Society* **42**:493-500.

Thigpen,M.T., Light,K.E., Creel,G.L. & Flynn,S.M. (2000). Turning difficulty characteristics of adults aged 65 years or older. *Physical Therapy* **80**(12):1174-1187.

Thirunarayan,M.A., Kerrigan,D.C., Rabuffetti,M., Croce,U.D. & Saini,M. (1996). Comparison of three methods for estimating vertical displacement of center of mass during level walking in patients. *Gait and Posture* **4**(4):306-314.

Tinetti,M.E. (1986). Performance-orientated assessment of mobility problems in elderly patients. *Journal of the American Geriatrics Society* **34**:119-126.

Tinetti,M.E., Liu,W.L. & Claus,E.B. (1993). Predictors and prognosis of inability to get up after falls among elderly persons. *Journal of the American Medical Association* **269**(1):65-70.

Tinetti,M.E., Mendes de Leon,C.F., Doucette,J.T. & Baker,D.I. (1994). Fear of falling and fall-related efficacy in relationship to functioning among community-living elders. *Journal of Gerontology Series A: Biological Sciences and Medical Sciences* **49**(3):M140-M147.

Tinetti,M.E., Richman,D. & Powell,L. (1990). Falls efficacy as a measure of fear of falling. *Journal of Gerontology Series B: Psychological Sciences* **45**(6):P239-P243.

Tinetti,M.E., Speechley,M. & Ginter,S.F. (1988). Risk factors for falls among elderly persons living in the community. *The New England Journal of Medicine* **319**(26):1701-1707.

Tinetti,M.E. (2003). Preventing Falls in Elderly Persons. *The New England Journal of Medicine* **348**(1):42-49.

Tinetti,M.E., Franklin Williams,T. & Mayewski,R. (1986). Fall risk index for elderly patients based on number of chronic disabilities. *The American Journal of Medicine* **80**(3):429-434.

Tirosh,O. & Sparrow,W.A. (2004). Gait termination in young and older adults: Effects of stopping stimulus probability and stimulus delay. *Gait and Posture* **19**(3):243-251.

Topper,A.K., Maki,B.E. & Holliday,P.J. (1993). Are activity-based assessments of balance and gait in the elderly predictive of risk of falling and/ or type of fall? *Journal of the American Geriatrics Society* **41**:479-487.

Tsang,W.W.N. & Hui-Chan,C.W.Y. (2003). Effects of Tai Chi on joint proprioception and stability limits in elderly subjects. *Medicine and Science in Sports and Exercise* **35**(12):1962-1971.

Tsang,W.W.N. & Hui-Chan,C.W.Y. (2004). Effects of exercise on joint sense and balance in elderly men: Tai Chi versus golf. *Medicine and Science in Sports and Exercise* **36**(4):658-667.

Turano,K., Rubin,G.S., Herdman,S.J., Chee,E. & Fried,L.P. (1994). Visual Stabilization of Posture in the Elderly: Fallers vs. Nonfallers. *Optometry and Vision Science* **71**(12):761-769.

Washburn,R.A., Smith,K.W., Jette,A.M. & Janney,C.A. (1993). The Physical Activity Scale for the Elderly (PASE): development and evaluation. *Journal of Clinical Epidemiology* **46**(2):153-162.

Watelain,E., Barbier,F., Allard,P., Thevenon,A. & Angué,J.C. (2000). Gait pattern classification of healthy elderly men based on biomechanical data. *Archives of Physical Medicine and Rehabilitation* **81**(5):579-586.

Whitehead,M., Sayers,M. & Whent,H. (1995). *Health Update 5: Physical Activity.* Health Education Authority: London.

Whittle,M.W. (1997). Three-dimensional motion of the center of gravity of the body during walking. *Human Movement Science* **16**(2-3):347-355.

WHO Regional Office for Europe . Health for All database (HFA-DB). http://www.euro.who.int/hfadb . 2008. 18-11-2008. (GENERIC)
Ref Type: Electronic Citation

Winter,D.A. (1995a). *A.B.C. of balance during standing and walking.* Waterloo Biomechanics: Waterloo.

Winter,D.A. (1995b). Human balance and posture control during standing and walking. *Gait and Posture* **3**(4):193-214.

Winter,D.A. (1987). Sagittal Plane Balance and Posture in Human Walking. *Ieee Engineering in Medicine and Biology Magazine* **6**(3):8-11.

Winter,D.A., Patla,A.E., Frank,J.S. & Walt,S.E. (1990). Biomechanical Walking Pattern Changes in the Fit and Healthy Elderly. *Physical Therapy* **70**(6):340-347.

Winter,D.A., Patla,A.E., Prince,F., Ishac,M. & Gielo-Perczak,K. (1998). Stiffness control of balance in quiet standing. *Journal of Neurophysiology* **80**(3):1211-1221.

Winter,D.A., Prince,F., Frank,J.S., Powell,C. & Zabjek,K.F. (1996). Unified theory regarding A/P and M/L balance in quiet stance. *Journal of Neurophysiology* **75**(6):2334-2343.

Winter,D.A., Sidwall,H.G. & Hobson,D.A. (1974). Measurement and reduction of noise in kinematics of locomotion. *Journal of Biomechanics* **7**(2):157-159.

Wojciechowski,R., Trick,G.L. & Steinman,S.B. (1995). Topography of the age-related decline in motion sensitivity. *Optometry and Vision Science* **72**(2):67-74.

Wong,A.M., Lin,Y.C., Chou,S.W., Tang,F.T. & Wong,P.Y. (2001). Coordination exercise and postural stability in elderly people: Effect of Tai Chi Chuan. *Archives of Physical Medicine and Rehabilitation* **82**(5):608-612.

Woollacott,M.H. & Tang,P.F. (1997). Balance control during walking in the older adult: Research and its implications. *Physical Therapy* **77**(6):646-660.

World Health Organization, Noncommunicable Diseases and Mental Health & Noncomunicable Disease Prevention and Health Promotion (2003) Annual global move for health initiative: A concept paper. pp.1-10. Geneva, Switzerland: World Health Organization.

Wu,G. & Cavanagh,P.R. (1995). ISB recommendations for standardization in the reporting of kinematic data. *Journal of Biomechanics* **28**(10):1257-1261.

Xu,D., Canton,L.G. & Rosengren,K.S. (2004). Anticipatory postural adjustments for altering direction during walking. *Journal of Motor Behavior* **36**(3):316-326.

Xu,D., Chow,J.W. & Wang,Y.T. (2006). Effects of turn angle and pivot foot on lower extremity kinetics during walk and turn actions. *Journal of Applied Biomechanics* **22**(1):74-79.

Yaffe,K., Barnes,D., Nevitt,M., Lui,L.Y. & Covinsky,K. (2001). A prospective study of physical activity and cognitive decline in elderly women: Women who walk. *Archives of Internal Medicine* **161**:1703-1708.

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

Yardley,L. & Smith,H. (2002). A prospective study of the relationship between feared consequences of falling and avoidance of activity in community-living older people. *The Gerontologist* **42**(1):17-23.

Yu,E., Abe,M., Masani,K., Kawashima,N., Eto,F., Haga,N. & Nakazawa,K. (2008). Evaluation of postural control in quiet standing using center of mass acceleration: Comparison among the young, the elderly, and people with stroke. *Archives of Physical Medicine and Rehabilitation* **89**(6):1133-1139.

Zijlstra,G.A.R., van Haastregt,J.C.M., van Eijk,J.T.M., van Rossum,E., Stalenhoef,P.A. & Kempen,G.I.J.M. (2007). 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**:304-309.

Conference presentations

Wright, R.L., Peters, D.M., Robinson, P.D., Watt, T.N. & Hollands, M.A. (2009), Age and falls history-related differences in the biomechanics of 360º pivot turns, 19th Conference of the International Society for Posture & Gait Research, Bologna, Italy

Wright, R.L., Peters, D.M., Robinson, P.D. & Hollands, M.A. (2007). Dynamic stability of gait in elderly fallers and non-fallers, 18th Conference of the International Society for Posture & Gait Research, Burlington, USA

Wright, R. L., Robinson, P. D. & Peters, D. M. (2007), Does life-span achievement of current physical activity recommendations reduce the likelihood of falling? Journal of Sports Sciences, 25(3), 285

Wright, R. L., Robinson, P. D. & Peters, D. M. (2006), Does life-span achievement of current physical activity recommendations reduce the likelihood of falling? British Association of Sport & Exercise Sciences Annual Conference, Wolverhampton, UK

Wright, R. L., Peters, D. M. & Robinson, P. D. (2005), The impact of lifetime physical activity on fear of falling and fall occurrence, 18th Congress of the International Association of Gerontology, Rio de Janeiro, Brazil

Appendix II

Lifetime Physical Activity and Falls History Questionnaire

For the initial part of my PhD, I am designing a questionnaire to look at the amount of physical activity individuals have participated in throughout their lifetime, and to investigate whether this is related to falling. This is the pilot stage of the questionnaire, where I am testing the questionnaire to find out how easy it is to complete, how long it takes, and whether there are issues concerning any of the questions. I would be very grateful if you could complete the questionnaire and then complete the questions on this page about how you found the questionnaire.

How long approximately did the questionnaire take to complete?

……………………………………………………………………………………

Were there any issues or problems with any of the questions?

…………………………………………………………………………………………

…………………………………………………………………………………………

…………………………………………………………………………………………

…………………………………………………………………………………………

…………………………………………………………………………………………

…………………………………

Any other comments?

…………………………………………………………………………………………

…………………………………………………………………………………………

…………………………………………………………………………………………

…………………………………………………………………………………………

…………………………………………………………………………………………

…………………………………………………………………………………………

……………………

Thank you.

Lifetime Physical Activity and Falls History Questionnaire

Thank you for agreeing to complete this questionnaire. Your answers will be used as data in the first study of my Doctoral thesis and subsequent academic publications. We need as many people over the age of 50/60 to complete the questionnaire so if you are aware of any other people in the Worcestershire area who may be willing to participate in this section of the data collection it would be really helpful if you could put them in touch with us at r.wright@worc.ac.uk or (01905) 855531.

Many thanks again for your decision to complete this questionnaire.

Q1. Name: ………………………………………………………………………..

Q2. Age: …………….. years and……………….. months

Q3. Please circle your gender: **Male** / **Female**

Q4. How tall are you? …………. Metres or ………. Ft ……… ins

Q5. How heavy are you? …………. Kgs or ………. St ……… lbs

Q6. What is your current marital status?: ……………………………………...

Q7. Are you, or have you ever been, a smoker? Yes **[ ]** No **[ ]**

Q8. Have you ever experienced a loss of balance where you came to rest on the ground, against a wall or against a piece of furniture? Yes **[ ]** No **[ ]**

If yes: At what age did you first fall? …… years & …… months

Did this first fall cause a fracture? Yes **[ ]** No **[ ]**

Have you continued to fall regularly since then? Yes **[ ]** No **[ ]**

Q9. Have you ever been diagnosed as having osteoporosis? Yes **[ ]** No **[ ]**

If yes: At what age was this diagnosed? …… years & …… months

If you would be willing to discuss your answers to the questionnaire in more detail, or if you might be interested in the next stage of the research please include your contact details below:

Telephone number: ……………………………………………………………...
House no. & road: ………………………………………………………………..
Town & postcode: ……………………………………………………………….
Email address here: ……………………..@……………………………………..

Fear of Falling Questionnaire:

Q10. Are you afraid of falling (please tick)?…………… Yes **[ ]** No **[ ]**

Q11. Please rate on a scale from 1 to 10 how confident you feel about doing each of the following activities **without falling**, where 1 = not at all confident and 10 = completely confident:

Cleaning the house	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
Getting dressed and undressed	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
Preparing simple meals	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
Taking a bath or shower	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
Simple shopping	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
Getting in and out of a chair	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
Going up and down stairs	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
Walking around the neighbourhood	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
Reaching into cabinets or closets	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
Hurrying to answer the phone	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**

Physical Activity Intensity examples

Please use the following definitions when answering the following questions in order to help you decide the **INTENSITY** of physical activity you are relating to:

Moderate intensity includes:

- walking at a brisk or fast pace;
- heavy housework;
- working as a labourer, roofer, or refuse collector;
- sports and exercises such as football, tennis, swimming, aerobics and cycling at a level of effort which would not make an average person sweaty or out of breath;
- heavy DIY;
- heavy gardening.

Vigorous intensity includes:

- Sports and exercises such as squash, running, football, swimming, tennis, aerobics and cycling at a level that would make the average person sweaty and out of breath;
- working as miner or forestry worker or any other occupation that involves frequent climbing, lifting or carrying of heavy loads.

Important definitions

Please use the following definitions when you are recalling your fall/stumble history:

A FALL is:

- a loss of balance resulting in the body, or part of the body, **coming to rest on the ground**.

A STUMBLE is:

- a loss of balance resulting in the body, or part of the body, **coming to rest against a wall, a piece of furniture or another object** which may have prevented a fall.

During an average week when you were in your 20's………

Q12. How many days per week did you **accumulate at least 30 minutes** of **Moderate or Vigorous** intensity physical activity in your **LEISURE TIME** (please circle)?

0 days	1 day	2 days	3 days	4 days	5 days	6 days	7 days

Q13. Please list all occupations you were involved in for 4 years or more during your **20s**…………………………………………………………………………..
…………………………………………………………………………………….

Q14. How many days per week did you **accumulate 30 minutes** of **Moderate or Vigorous** intensity physical activity in your **OCCUPATION** (please circle)?

0 days	1 day	2 days	3 days	4 days	5 days	6 days	7 days

Q15. How many days per week did you **NOT manage to accumulate 30** minutes of **Moderate or Vigorous intensity** physical activity in your **combined occupational and leisure-time**.(please circle)?

0 days	1 day	2 days	3 days	4 days	5 days	6 days	7 days

Q16. Were you advised by medical staff, e.g. doctor, physiotherapist, to participate in more physical activity during your 20's (please tick)?
Yes **[ ]** No **[ ]**

Q17. Did you suffer any injuries to your back, pelvis, hips or legs that limited the amount of physical activity you could do for longer than one year (please tick)? Yes **[ ]** No **[ ]**

During an average week when you were in your 30's………

Q18. How many days per week did you **accumulate at least 30 minutes** of **Moderate or Vigorous** intensity physical activity in your **LEISURE TIME** (please circle)?

0 days	1 day	2 days	3 days	4 days	5 days	6 days	7 days

Q19. Please list all occupations you were involved in for 4 years or more during your **30s**…………………………………………………………………………...
……………………………………………………………………………...

Q20. How many days per week did you **accumulate 30 minutes** of **Moderate or Vigorous** intensity physical activity in your **OCCUPATION** (please circle)?

0 days	1 day	2 days	3 days	4 days	5 days	6 days	7 days

Q21. How many days per week did you **<u>NOT</u> manage to accumulate 30** minutes of **Moderate or Vigorous intensity** physical activity in your **combined occupational and leisure-time**.(please circle)?

0 days	1 day	2 days	3 days	4 days	5 days	6 days	7 days

Q22. Were you advised by medical staff, e.g. doctor, physiotherapist, to participate in more physical activity during your 50's (please tick)?
Yes **[ ]** No **[ ]**

Q23. Did you suffer any injuries to your back, pelvis, hips or legs that limited the amount of physical activity you could do for longer than one year (please tick)? Yes **[ ]** No **[ ]**

During an average week when you were in your 40's………

Q24. How many days per week did you **accumulate at least 30 minutes** of **Moderate or Vigorous** intensity physical activity in your **LEISURE TIME** (please circle)?

0 days	**1 day**	**2 days**	**3 days**	**4 days**	**5 days**	**6 days**	**7 days**

Q25. Please list all occupations you were involved in for 4 years or more during your **40s**……………………………………………………………………………..
……………………………………………………………………………………..

Q26. How many days per week did you **accumulate 30 minutes** of **Moderate or Vigorous** intensity physical activity in your **OCCUPATION** (please circle)?

0 days	**1 day**	**2 days**	**3 days**	**4 days**	**5 days**	**6 days**	**7 days**

Q27. How many days per week did you **NOT manage to accumulate 30** minutes of **Moderate or Vigorous intensity** physical activity in your **combined occupational and leisure-time**.(please circle)?

0 days	**1 day**	**2 days**	**3 days**	**4 days**	**5 days**	**6 days**	**7 days**

Q28. Were you advised by medical staff, e.g. doctor, physiotherapist, to participate in more physical activity during your 50's (please tick)?
Yes **[ ]** No **[ ]**

Q29. Did you suffer any injuries to your back, pelvis, hips or legs that limited the amount of physical activity you could do for longer than one year (please tick)? Yes **[ ]** No **[ ]**

During an average week when you were in your 50's………

Q30. How many days per week did you **accumulate at least 30 minutes** of **Moderate or Vigorous** intensity physical activity in your **LEISURE TIME** (please circle)?

0 days	**1 day**	**2 days**	**3 days**	**4 days**	**5 days**	**6 days**	**7 days**

Q31. Please list all occupations you were involved in for 4 years or more during your **50s**……………………………………………………………………………..
……………………………………………………………………………………..

Q32. How many days per week did you **accumulate 30 minutes** of **Moderate or Vigorous** intensity physical activity in your **OCCUPATION** (please circle)?

0 days	**1 day**	**2 days**	**3 days**	**4 days**	**5 days**	**6 days**	**7 days**

Q33. How many days per week did you **<u>NOT</u> manage to accumulate 30** minutes of **Moderate or Vigorous intensity** physical activity in your **combined occupational and leisure-time**.(please circle)?

0 days	**1 day**	**2 days**	**3 days**	**4 days**	**5 days**	**6 days**	**7 days**

Q34. Were you advised by medical staff, e.g. doctor, physiotherapist, to participate in more physical activity during your 50's (please tick)?
Yes **[ ]** No **[ ]**

Q35. Did you suffer any injuries to your back, pelvis, hips or legs that limited the amount of physical activity you could do for longer than one year (please tick)? Yes **[ ]** No **[ ]**

Q36. Did you experience any loss of balance where you came to rest on the ground, a wall or piece of furniture in your 50's? Yes **[ ]** No **[ ]**
If **<u>yes</u>**, please complete the following falls history questionnaire before proceeding to the next decade section on page ??

Falls history questionnaire:

Q37. Did you experience a fall where you came to rest **on the ground**?

Yes **[ ]** No **[ ]**

If yes, on how many occasions did this occur? **………………** times

Q38. Did you experience a stumble, which caused you to come to rest **against a wall or piece of furniture**? Yes **[ ]** No **[ ]**

If yes, on how many occasions did this occur? **………………** times

Q39. Where did you fall (please tick)?

			How many times?
Walking indoors	yes **[ ]**	no **[ ]**	**[ ]**
Getting out of bed	yes **[ ]**	no **[ ]**	**[ ]**
Getting out of a chair	yes **[ ]**	no **[ ]**	**[ ]**
Using the shower/bath	yes **[ ]**	no **[ ]**	**[ ]**
Using the toilet	yes **[ ]**	no **[ ]**	**[ ]**
Walking up or down stairs	yes **[ ]**	no **[ ]**	**[ ]**
Walking outdoors	yes **[ ]**	no **[ ]**	**[ ]**
In the garden	yes **[ ]**	no **[ ]**	**[ ]**
Getting out of a vehicle	yes **[ ]**	no **[ ]**	**[ ]**
On a kerb/ gutter	yes **[ ]**	no **[ ]**	**[ ]**
In a public building	yes **[ ]**	no **[ ]**	**[ ]**
In another person's home	yes **[ ]**	no **[ ]**	**[ ]**

Falls or stumbles not described above (please specify)

……………………………………..…….

Q40. How did you fall or stumble (tick more than one if necessary)?

		How many times?
I tripped	**[ ]**	**[ ]**
I slipped	**[ ]**	**[ ]**
I lost my balance	**[ ]**	**[ ]**
My legs gave way	**[ ]**	**[ ]**
I felt faint	**[ ]**	**[ ]**
I felt giddy/ dizzy	**[ ]**	**[ ]**
I am not sure	**[ ]**	**[ ]**

Q41. What type of injuries did you suffer as a result of these fall/s (tick more than one if necessary)?

None	**[ ]**	Broken Wrist	**[ ]**	Back Pain	**[ ]**
Bruises	**[ ]**	Broken Hip	**[ ]**	Any other injury:	
Cuts/ grazes	**[ ]**	Broken Ribs	**[ ]**	**…………………………..**	

During an average week when you were in your 60's………

Q42. How many days per week did you **accumulate at least 30 minutes** of **Moderate or Vigorous** intensity physical activity in your **LEISURE TIME** (please circle)?

0 days	1 day	2 days	3 days	4 days	5 days	6 days	7 days

Q43. Please list all occupations you were involved in for 4 years or more during your **60s**……………………………………………………………………………..
……………………………………………………………………………………..

Q44. How many days per week did you **accumulate 30 minutes** of **Moderate or Vigorous** intensity physical activity in your **OCCUPATION** (please circle)?

0 days	1 day	2 days	3 days	4 days	5 days	6 days	7 days

Q45. How many days per week did you **NOT manage to accumulate 30** minutes of **Moderate or Vigorous intensity** physical activity in your **combined occupational and leisure-time**.(please circle)?

0 days	1 day	2 days	3 days	4 days	5 days	6 days	7 days

Q46. Were you advised by medical staff, e.g. doctor, physiotherapist, to take more physical activity during your 60's (please tick)?Yes **[ ]** No **[ ]**

Q47. Did you suffer any injuries to your back, pelvis, hips or legs that limited the amount of physical activity you could do for longer than one year (please tick)? Yes **[ ]** No **[ ]**

Q48. Did you experience any loss of balance where you came to rest on the ground, a wall or piece of furniture in your 60's? Yes **[ ]** No **[ ]**
If **yes**, please complete the following falls history questionnaire before proceeding to the next decade section on page ??

Falls history questionnaire:

Q49. Did you experience a fall where you came to rest **on the ground**?
Yes **[ ]** No **[ ]**

If yes, on how many occasions did this occur? **……………….** times

Q50. Did you experience a stumble, which caused you to come to rest **against a wall or piece of furniture**? Yes **[ ]** No **[ ]**

If yes, on how many occasions did this occur? **……………….** times

Q51. Where did you fall or stumble (please tick)?

			How many times?
Walking indoors	yes **[ ]**	no **[ ]**	**[ ]**
Getting out of bed	yes **[ ]**	no **[ ]**	**[ ]**
Getting out of a chair	yes **[ ]**	no **[ ]**	**[ ]**
Using the shower/bath	yes **[ ]**	no **[ ]**	**[ ]**
Using the toilet	yes **[ ]**	no **[ ]**	**[ ]**
Walking up or down stairs	yes **[ ]**	no **[ ]**	**[ ]**
Walking outdoors	yes **[ ]**	no **[ ]**	**[ ]**
In the garden	yes **[ ]**	no **[ ]**	**[ ]**
Getting out of a vehicle	yes **[ ]**	no **[ ]**	**[ ]**
On a kerb/ gutter	yes **[ ]**	no **[ ]**	**[ ]**
In a public building	yes **[ ]**	no **[ ]**	**[ ]**
In another person's home	yes **[ ]**	no **[ ]**	**[ ]**

Falls or stumbles not described above (please specify)
……………………………………..…….

Q52. How did you fall or stumble (tick more than one if necessary)?

		How many times?
I tripped	**[ ]**	**[ ]**
I slipped	**[ ]**	**[ ]**
I lost my balance	**[ ]**	**[ ]**
My legs gave way	**[ ]**	**[ ]**
I felt faint	**[ ]**	**[ ]**
I felt giddy/ dizzy	**[ ]**	**[ ]**
I am not sure	**[ ]**	**[ ]**

Q53. What type of injuries did you suffer as a result of these fall/s (tick more than one if necessary)?

None	**[ ]**	Broken Wrist	**[ ]**	Back Pain	**[ ]**
Bruises	**[ ]**	Broken Hip	**[ ]**	Any other injury:	
Cuts/ grazes	**[ ]**	Broken Ribs	**[ ]**	**…………………………..**	

During an average week when you were in your 70's………

Q54. How many days per week did you **accumulate at least 30 minutes** of **Moderate or Vigorous** intensity physical activity in your **LEISURE TIME** (please circle)?

0 days	**1 day**	**2 days**	**3 days**	**4 days**	**5 days**	**6 days**	**7 days**

Q55. Please list all occupations you were involved in for 4 years or more during your **70s**……………………………………………………………………………..
……………………………………………………………………………………..

Q56. How many days per week did you **accumulate 30 minutes** of **Moderate or Vigorous** intensity physical activity in your **OCCUPATION** (please circle)?

0 days	**1 day**	**2 days**	**3 days**	**4 days**	**5 days**	**6 days**	**7 days**

Q57. How many days per week did you **NOT manage to accumulate 30** minutes of **Moderate or Vigorous intensity** physical activity in your **combined occupational and leisure-time**.(please circle)?

0 days	**1 day**	**2 days**	**3 days**	**4 days**	**5 days**	**6 days**	**7 days**

Q58. Were you advised by medical staff, e.g. doctor, physiotherapist, to take more physical activity during your 70's (please tick)?Yes **[ ]** No **[ ]**

Q59. Did you suffer any injuries to your back, pelvis, hips or legs that limited the amount of physical activity you could do for longer than one year (please tick)? Yes **[ ]** No **[ ]**Did you experience a fall where you came to rest on the ground, a wall or piece of furniture in your 70's (please tick)? Yes **[ ]** No **[ ]**

Q60. Did you experience any loss of balance where you came to rest on the ground, a wall or piece of furniture in your 70's? Yes **[ ]** No **[**
If **yes**, please complete the following falls history questionnaire before proceeding to the next decade section on page ??

Falls history questionnaire:

Q61. Did you experience a fall where you came to rest **on the ground**?
Yes **[ ]** No **[ ]**

If yes, on how many occasions did this occur? **………………** times

Q62. Did you experience a stumble, which caused you to come to rest **against a wall or piece of furniture**? Yes **[ ]** No **[ ]**

If yes, on how many occasions did this occur? **………………** times

Q63. Where did you fall or stumble (please tick)?

			How many times?
Walking indoors	yes **[ ]**	no **[ ]**	**[ ]**
Getting out of bed	yes **[ ]**	no **[ ]**	**[ ]**
Getting out of a chair	yes **[ ]**	no **[ ]**	**[ ]**
Using the shower/bath	yes **[ ]**	no **[ ]**	**[ ]**
Using the toilet	yes **[ ]**	no **[ ]**	**[ ]**
Walking up or down stairs	yes **[ ]**	no **[ ]**	**[ ]**
Walking outdoors	yes **[ ]**	no **[ ]**	**[ ]**
In the garden	yes **[ ]**	no **[ ]**	**[ ]**
Getting out of a vehicle	yes **[ ]**	no **[ ]**	**[ ]**
On a kerb/ gutter	yes **[ ]**	no **[ ]**	**[ ]**
In a public building	yes **[ ]**	no **[ ]**	**[ ]**
In another person's home	yes **[ ]**	no **[ ]**	**[ ]**

Falls not described above (please specify) ………………………………………….………

Q64. How did you fall or stumble (tick more than one if necessary)?

		How many times?
I tripped	**[ ]**	**[ ]**
I slipped	**[ ]**	**[ ]**
I lost my balance	**[ ]**	**[ ]**
My legs gave way	**[ ]**	**[ ]**
I felt faint	**[ ]**	**[ ]**
I felt giddy/ dizzy	**[ ]**	**[ ]**
I am not sure	**[ ]**	**[ ]**

Q65. What type of injuries did you suffer as a result of these fall/s (tick more than one if necessary)?

None	**[ ]**	Broken Wrist	**[ ]**	Back Pain	**[ ]**
Bruises	**[ ]**	Broken Hip	**[ ]**	Any other injury:	
Cuts/ grazes	**[ ]**	Broken Ribs	**[ ]**	**…………………………..**	

Appendix III

Lifetime Physical Activity and Falls History Questionnaire

Thank you for agreeing to complete this questionnaire. Your answers will be used as data in the first study of my Doctoral thesis and subsequent academic publications. We need as many people over the age of 50/60 to complete the questionnaire so if you are aware of any other people in the Worcestershire area who may be willing to participate in this section of the data collection it would be really helpful if you could put them in touch with us at r.wright@worc.ac.uk or (01905) 855513.

Many thanks again for your decision to complete this questionnaire.

Q1. Name: ……………………………………………………………………..

Q2. Age: …………….. years and……………….. months

Q3. Please circle your gender: **Male** / **Female**

Q4. How tall are you? …………. Metres or ………. Ft ……… ins

Q5. How heavy are you? …………. Kgs or ………. St ……… lbs

Q6. What is your current marital status?: ………………………………………..

Q7. What was the highest level of education you attended (please tick)?
Secondary **[ ]** Further education **[ ]** University **[ ]**

Q8. Are you, or have you ever been, a smoker? Yes **[ ]** No **[ ]**

Q8. Do you use a walking aid, e.g. cane, zimmer frame? Yes **[ ]** No **[ ]**

Q9. Have you ever been diagnosed as having osteoporosis? Yes **[ ]** No **[ ]**

If yes: At what age was this diagnosed? …… years & …… months

If you would be willing to discuss your answers to the questionnaire in more detail, or if you might be interested in the next stage of the research please include your contact details below: (This is not a definite commitment on your behalf)

Telephone number: ………………………………………………………………….
House no. & road: ………………………………………………………………...
…………………………………………………………………
Town & postcode: …………………………………………………………………
…………………………………………………………………
Email address here: ……………………..@……………………………………...

Fear of Falling Questionnaire:

Q10. Are you currently afraid of falling (please tick)?…… Yes **[ ]** No **[ ]**

Q11. Please rate on a scale from 1 to 10 (please circle) how confident you feel about doing each of the following activities **without falling**, where 1 = not at all confident, 5 = fairly confident and 10 = completely confident:

Cleaning the house	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
Getting dressed and undressed	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
Preparing simple meals	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
Taking a bath or shower	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
Simple shopping	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
Getting in and out of a chair	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
Going up and down stairs	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
Walking around the neighbourhood	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
Reaching into cabinets or closets	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
Hurrying to answer the door or phone	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
Walking in icy conditions	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
Getting in/ out of car	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
Using public transport	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
Crossing roads	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
Using front or rear steps at home	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
Picking up an item e.g. a slipper from the floor	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**

Physical Activity Intensity examples

Please use the following definition when answering the following questions in order to help you decide the **INTENSITY** of physical activity you are relating to:

MODERATE intensity includes:

- walking at a brisk or fast pace;
- heavy housework;
- working as a labourer, roofer, farmer, domestic cleaner or refuse collector;
- sports and exercises such as football, tennis, swimming, aerobics and cycling at a level of effort which would not make an average person sweaty or out of breath;
- heavy DIY;
- heavy gardening.

During an average week when you were in your 20's………

Q12. How many days per week did you **accumulate at least 30 minutes** of **Moderate or higher** intensity physical activity (during both your **LEISURE TIME** and **OCCUPATION**) (please circle)?

0 days	**1 day**	**2 days**	**3 days**	**4 days**	**5 days**	**6 days**	**7 days**

Q13. Please state your main occupation(s) during your **20s** ……………………….
…………………………………………………………………………………….
……………………………………………………………………………………..

Q16. Were you advised by medical staff, e.g. doctor, physiotherapist, to participate in more physical activity during your 20's (please tick)?
Yes **[ ]** No **[ ]**

Q17. Did you suffer any injuries to your back, pelvis, hips or legs that limited the amount of physical activity you could do for longer than one year in your 20s (please tick)? Yes **[ ]** No **[ ]**

During an average week when you were in your 30's………

Q18. How many days per week did you **accumulate at least 30 minutes** of **Moderate or higher** intensity physical activity (during both your **LEISURE TIME** and **OCCUPATION**) (please circle)?

0 days	1 day	2 days	3 days	4 days	5 days	6 days	7 days

Q19. Please state your main occupation(s) during your **30s** ………………………
……………………………………………………………………………………..
……………………………………………………………………………………..

Q20. Were you advised by medical staff, e.g. doctor, physiotherapist, to participate in more physical activity during your 30's (please tick)?
Yes **[ ]** No **[ ]**

Q21. Did you suffer any injuries to your back, pelvis, hips or legs that limited the amount of physical activity you could do for longer than one year in your 30s (please tick)? Yes **[ ]** No **[ ]**

During an average week when you were in your 40's………

Q22. How many days per week did you **accumulate at least 30 minutes** of **Moderate or higher** intensity physical activity (during both your **LEISURE TIME** and **OCCUPATION**) (please circle)?

0 days	1 day	2 days	3 days	4 days	5 days	6 days	7 days

Q23. Please state your main occupation(s) during your **40s** ………………………
……………………………………………………………………………………..
……………………………………………………………………………………..

Q24. Were you advised by medical staff, e.g. doctor, physiotherapist, to participate in more physical activity during your 40's (please tick)?
Yes **[ ]** No **[ ]**

Q25. Did you suffer any injuries to your back, pelvis, hips or legs that limited the amount of physical activity you could do for longer than one year in your 40s (please tick)? Yes **[ ]** No **[ ]**

During an average week when you were in your 50's………

Q26. How many days per week did you **accumulate at least 30 minutes** of **Moderate or higher** intensity physical activity (during both your **LEISURE TIME** and **OCCUPATION**) (please circle)?

0 days	1 day	2 days	3 days	4 days	5 days	6 days	7 days

Q27. Please state your main occupation(s) during your **50s** ………………………
………………………………………………………………………………….
…………………………………………………………………………………..

Q28. Were you advised by medical staff, e.g. doctor, physiotherapist, to participate in more physical activity during your 50's (please tick)?
Yes **[ ]** No **[ ]**

Q29. Did you suffer any injuries to your back, pelvis, hips or legs that limited the amount of physical activity you could do for longer than one year in your 50s (please tick)? Yes **[ ]** No **[ ]**

During an average week when you were in your 60's………

Q30. How many days per week did you **accumulate at least 30 minutes** of **Moderate or higher** intensity physical activity (during both your **LEISURE TIME** and **OCCUPATION**) (please circle)?

0 days	1 day	2 days	3 days	4 days	5 days	6 days	7 days

Q31. Please state your main occupation(s) during your **60s** ………………………
………………………………………………………………………………….
…………………………………………………………………………………..

Q32. Were you advised by medical staff, e.g. doctor, physiotherapist, to participate in more physical activity during your 60's (please tick)?
Yes **[ ]** No **[ ]**

Q33. Did you suffer any injuries to your back, pelvis, hips or legs that limited the amount of physical activity you could do for longer than one year in your 60s (please tick)? Yes **[ ]** No **[ ]**

During an average week when you were in your 70's………

Q34. How many days per week did you **accumulate at least 30 minutes** of **Moderate or higher** intensity physical activity (during both your **LEISURE TIME** and **OCCUPATION**) (please circle)?

0 days	**1 day**	**2 days**	**3 days**	**4 days**	**5 days**	**6 days**	**7 days**

Q35. Please state your main occupation(s) during your **70s** ………………………
……………………………………………………………………………………..
……………………………………………………………………………………..

Q36. Were you advised by medical staff, e.g. doctor, physiotherapist, to participate in more physical activity during your 70's (please tick)?
Yes **[ ]** No **[ ]**

Q37. Did you suffer any injuries to your back, pelvis, hips or legs that limited the amount of physical activity you could do for longer than one year in your 70s (please tick)? Yes **[ ]** No **[ ]**

During an average week when you were in your 80's………

Q38. How many days per week did you **accumulate at least 30 minutes** of **Moderate or higher** intensity physical activity (during both your **LEISURE TIME** and **OCCUPATION**) (please circle)?

0 days	**1 day**	**2 days**	**3 days**	**4 days**	**5 days**	**6 days**	**7 days**

Q39. Please state your main occupation(s) during your **80s** ………………………
……………………………………………………………………………………..
……………………………………………………………………………………..

Q40. Were you advised by medical staff, e.g. doctor, physiotherapist, to participate in more physical activity during your 80's (please tick)?
Yes **[ ]** No **[ ]**

Q41. Did you suffer any injuries to your back, pelvis, hips or legs that limited the amount of physical activity you could do for longer than one year in your 80s (please tick)? Yes **[ ]** No **[ ]**

Falls history questionnaire:

Q42. Have you experienced a fall where you came to rest **on the ground**?
Yes **[ ]** No **[ ]**

If yes, on how many occasions did this occur? 1 **[ ]** 2-3 **[ ]** 4-5 **[ ]** More than 5 **[ ]**

At approximately what age did this first occur? …………………………….

Q43. Have you experienced a stumble, which caused you to come to rest **against a wall or piece of furniture**? Yes **[ ]** No **[ ]**

If yes, on how many occasions did this occur? 1 **[ ]** 2-3 **[ ]** 4-5 **[ ]** More than 5 **[ ]**

Q44. Where did you fall or stumble (please tick)?

			How many times?
Walking indoors	yes **[ ]**	no **[ ]**	**[ ]**
Getting out of bed	yes **[ ]**	no **[ ]**	**[ ]**
Getting out of a chair	yes **[ ]**	no **[ ]**	**[ ]**
Using the shower/bath	yes **[ ]**	no **[ ]**	**[ ]**
Using the toilet	yes **[ ]**	no **[ ]**	**[ ]**
Walking up or down stairs	yes **[ ]**	no **[ ]**	**[ ]**
Walking outdoors	yes **[ ]**	no **[ ]**	**[ ]**
In the garden	yes **[ ]**	no **[ ]**	**[ ]**
Getting out of a vehicle	yes **[ ]**	no **[ ]**	**[ ]**
On a kerb/ gutter	yes **[ ]**	no **[ ]**	**[ ]**
In a public building	yes **[ ]**	no **[ ]**	**[ ]**
In another person's home	yes **[ ]**	no **[ ]**	**[ ]**
In icy conditions	yes **[ ]**	no **[ ]**	**[ ]**

Falls or stumbles not described above (please specify)
……………………………..…………………………………………………….
………………………………………………………………………………………
………………………………………………………………………………………
………………………………………………………………………………………

Q45. How did you fall or stumble (tick more than one if necessary)?

		How many times?
I tripped	**[ ]**	**[ ]**
I slipped	**[ ]**	**[ ]**
I lost my balance	**[ ]**	**[ ]**
My legs gave way	**[ ]**	**[ ]**

I felt faint	**[ ]**	**[ ]**
I felt giddy/ dizzy	**[ ]**	**[ ]**
I am not sure	**[ ]**	**[ ]**

Q46. What type of injuries did you suffer as a result of these fall/s (tick more than one if necessary)?

None	**[ ]**	Broken Wrist	**[ ]**	Back Pain	**[ ]**
Bruises	**[ ]**	Broken Hip	**[ ]**	Any other injury:	
Cuts/ grazes	**[ ]**	Broken Ribs	**[ ]**	**…………………………..**	

Appendix IV

Lifetime Physical Activity and Falls History Questionnaire

Thank you for agreeing to complete this questionnaire. Your answers will be used as data in the first study of my Doctoral thesis and subsequent academic publications. We need as many people over the age of 50/60 to complete the questionnaire so if you are aware of any other people in the Worcestershire area who may be willing to participate in this section of the data collection it would be really helpful if you could put them in touch with us at r.wright@worc.ac.uk or (01905) 855513.

Many thanks again for your decision to complete this questionnaire.

Q1. Name: ……………………………………………………………………………..

Q2. Age: …………….. years and……………….. months

Q3. Please circle your gender: **Male** / **Female**

Q4. How tall are you? **…………..** Metres or **……….** Ft **………** ins

Q5. How heavy are you? **…………..** Kgs or **……….** St **………** lbs

Q6. What is your current marital status?: ……………………………………...

Q7. What was the highest level of education you attended (please tick)?
Secondary **[ ]** Further education **[ ]** University **[ ]**

Q8. Are you, or have you ever been, a smoker? Yes **[ ]** No **[ ]**

Q8. Do you use a walking aid, e.g. cane, zimmer frame? Yes **[ ]** No **[ ]**

Q9. Have you ever been diagnosed as having osteoporosis? Yes **[ ]** No **[ ]**

If yes: At what age was this diagnosed? **……** years & **……** months

If you would be willing to discuss your answers to the questionnaire in more detail, or if you might be interested in the next stage of the research please include your contact details below: (This is not a definite commitment on your behalf)

Telephone number: ……………………………………………………………….

House no. & road: ……………………………………………………………...
……………………………………………………………………

Town & postcode: ……………………………………………………………….
……………………………………………………………………

Email address here: ………………………@………………………………………...

Fear of Falling Questionnaire:

Q10. Are you currently afraid of falling (please tick)?…… Yes **[ ]** No **[ ]**

Q11. Please rate on a scale from 1 to 5 (please circle) how confident you feel about doing each of the following activities **without falling**, where 1 = not at all confident, 3 = fairly confident and 5 = completely confident:

Cleaning the house	**1**	**2**	**3**	**4**	**5**
Getting dressed and undressed	**1**	**2**	**3**	**4**	**5**
Preparing simple meals	**1**	**2**	**3**	**4**	**5**
Taking a bath or shower	**1**	**2**	**3**	**4**	**5**
Simple shopping	**1**	**2**	**3**	**4**	**5**
Getting in and out of a chair	**1**	**2**	**3**	**4**	**5**
Going up and down stairs	**1**	**2**	**3**	**4**	**5**
Walking around the neighbourhood	**1**	**2**	**3**	**4**	**5**
Reaching into cabinets or closets	**1**	**2**	**3**	**4**	**5**
Hurrying to answer the door or phone	**1**	**2**	**3**	**4**	**5**
Walking in icy conditions	**1**	**2**	**3**	**4**	**5**
Getting in/ out of car	**1**	**2**	**3**	**4**	**5**
Using public transport	**1**	**2**	**3**	**4**	**5**
Crossing roads	**1**	**2**	**3**	**4**	**5**
Using front or rear steps at home	**1**	**2**	**3**	**4**	**5**
Picking up an item e.g. a slipper from the floor	**1**	**2**	**3**	**4**	**5**
Other (please specify)……………... ………………………………………...	**1**	**2**	**3**	**4**	**5**

Physical Activity Intensity examples

Please use the following definition when answering the following questions in order to help you decide the **INTENSITY** of physical activity you are relating to:

MODERATE intensity includes:

- walking at a brisk or fast pace;
- heavy housework;
- working as a labourer, roofer, farmer, domestic cleaner or refuse collector;
- sports and exercises such as football, tennis, swimming, aerobics and cycling at a level of effort which would not make an average person sweaty or out of breath;
- heavy DIY;
- heavy gardening.

During an average week when you were in your 20's………

Q12. How many days per week did you **accumulate at least 30 minutes** of **Moderate or higher** intensity physical activity (during both your **LEISURE TIME** and **OCCUPATION**) (please circle)?

0 days	**1 day**	**2 days**	**3 days**	**4 days**	**5 days**	**6 days**	**7 days**

Q13. Please state your main **occupation(s)** during your **20s** ……………………….
……………………………………………………………………………………….
………………………………………………………………………………………..

Q16. Were you advised by medical staff, e.g. doctor, physiotherapist, to participate in more physical activity during your 20's (please tick)?
Yes **[ ]** No **[ ]**

Q17. Did you suffer any injuries to your back, pelvis, hips or legs or any disease that limited the amount of physical activity you could do for longer than one year in your 20s (please tick)? Yes **[ ]** No **[ ]**

During an average week when you were in your 30's………

Q18. How many days per week did you **accumulate at least 30 minutes** of **Moderate or higher** intensity physical activity (during both your **LEISURE TIME** and **OCCUPATION**) (please circle)?

0 days	**1 day**	**2 days**	**3 days**	**4 days**	**5 days**	**6 days**	**7 days**

Q19. Please state your main **occupation(s)** during your **30s** ………………………
……………………………………………………………………………………..
……………………………………………………………………………………..

Q20. Were you advised by medical staff, e.g. doctor, physiotherapist, to participate in more physical activity during your 30's (please tick)?
Yes **[ ]** No **[ ]**

Q21. Did you suffer any injuries to your back, pelvis, hips or legs or any disease that limited the amount of physical activity you could do for longer than one year in your 30s (please tick)? Yes **[ ]** No **[ ]**

During an average week when you were in your 40's………

Q22. How many days per week did you **accumulate at least 30 minutes** of **Moderate or higher** intensity physical activity (during both your **LEISURE TIME** and **OCCUPATION**) (please circle)?

0 days	**1 day**	**2 days**	**3 days**	**4 days**	**5 days**	**6 days**	**7 days**

Q23. Please state your main **occupation(s)** during your **40s** ………………………
……………………………………………………………………………………..
……………………………………………………………………………………..

Q24. Were you advised by medical staff, e.g. doctor, physiotherapist, to participate in more physical activity during your 40's (please tick)?
Yes **[ ]** No **[ ]**

Q25. Did you suffer any injuries to your back, pelvis, hips or legs or any disease that limited the amount of physical activity you could do for longer than one year in your 40s (please tick)? Yes **[ ]** No **[ ]**

During an average week when you were in your 50's………

Q26. How many days per week did you **accumulate at least 30 minutes** of **Moderate or higher** intensity physical activity (during both your **LEISURE TIME** and **OCCUPATION**) (please circle)?

0 days	**1 day**	**2 days**	**3 days**	**4 days**	**5 days**	**6 days**	**7 days**

Q27. Please state your main **occupation(s)** during your **50s** ………………………
………………………………………………………………………………………..
………………………………………………………………………………………..

Q28. Were you advised by medical staff, e.g. doctor, physiotherapist, to participate in more physical activity during your 50's (please tick)?
Yes **[ ]** No **[ ]**

Q29. Did you suffer any injuries to your back, pelvis, hips or legs or any disease that limited the amount of physical activity you could do for longer than one year in your 50s (please tick)? Yes **[ ]** No **[ ]**

During an average week when you were in your 60's………

Q30. How many days per week did you **accumulate at least 30 minutes** of **Moderate or higher** intensity physical activity (during both your **LEISURE TIME** and **OCCUPATION**) (please circle)?

0 days	**1 day**	**2 days**	**3 days**	**4 days**	**5 days**	**6 days**	**7 days**

Q31. Please state your main **occupation(s)** during your **60s** ………………………
………………………………………………………………………………………..
………………………………………………………………………………………..

Q32. Were you advised by medical staff, e.g. doctor, physiotherapist, to participate in more physical activity during your 60's (please tick)?
Yes **[ ]** No **[ ]**

Q33. Did you suffer any injuries to your back, pelvis, hips or legs or any disease that limited the amount of physical activity you could do for longer than one year in your 60s (please tick)? Yes **[ ]** No **[ ]**

During an average week when you were in your 70's………

Q34. How many days per week did you **accumulate at least 30 minutes** of **Moderate or higher** intensity physical activity (during both your **LEISURE TIME** and **OCCUPATION**) (please circle)?

0 days	**1 day**	**2 days**	**3 days**	**4 days**	**5 days**	**6 days**	**7 days**

Q35. Please state your main **occupation(s)** during your **70s** ……………………….
…………………………………………………………………………………..
…………………………………………………………………………………..

Q36. Were you advised by medical staff, e.g. doctor, physiotherapist, to participate in more physical activity during your 70's (please tick)?
Yes **[ ]** No **[ ]**

Q37. Did you suffer any injuries to your back, pelvis, hips or legs or any disease that limited the amount of physical activity you could do for longer than one year in your 70s (please tick)? Yes **[ ]** No **[ ]**

During an average week when you were in your 80's………

Q38. How many days per week did you **accumulate at least 30 minutes** of **Moderate or higher** intensity physical activity (during both your **LEISURE TIME** and **OCCUPATION**) (please circle)?

0 days	**1 day**	**2 days**	**3 days**	**4 days**	**5 days**	**6 days**	**7 days**

Q39. Please state your main **occupation(s)** during your **80s** ……………………….
…………………………………………………………………………………..
…………………………………………………………………………………..

Q40. Were you advised by medical staff, e.g. doctor, physiotherapist, to participate in more physical activity during your 80's (please tick)?
Yes **[ ]** No **[ ]**

Q41. Did you suffer any injuries to your back, pelvis, hips or legs or any disease that limited the amount of physical activity you could do for longer than one year in your 80s (please tick)? Yes **[ ]** No **[ ]**

Falls history questionnaire:

Please use the following definitions when you are recalling your falls/stumble history:

A FALL is:

- a loss of balance resulting in the body, or part of the body, **coming to rest on the ground**.

A STUMBLE is:

- a loss of balance resulting in the body, or part of the body**,** coming to rest against a wall, a piece of furniture or another object **which may have prevented a fall.**

Q42. Have you experienced a fall where you came to rest **on the ground**?
Yes **[ ]** No **[ ]**

If yes, on how many occasions did this occur? 1 **[ ]** 2-3 **[ ]** 4-5 **[ ]** More than 5 **[ ]**

At approximately what age did this first occur? …………………………….

Q43.Have you experienced a stumble, which caused you to come to rest **against a wall or piece of furniture**? Yes **[ ]** No **[ ]**

If yes, on how many occasions did this occur? 1 **[ ]** 2-3 **[ ]** 4-5 **[ ]** More than 5 **[ ]**

Q44. Where did you fall or stumble (please tick)?

			How many times?
Walking indoors	yes **[ ]**	no **[ ]**	[ ]
Getting out of bed	yes **[ ]**	no **[ ]**	[ ]
Getting out of a chair	yes **[ ]**	no **[ ]**	[ ]
Using the shower/bath	yes **[ ]**	no **[ ]**	[ ]
Using the toilet	yes **[ ]**	no **[ ]**	[ ]
Walking up or down stairs	yes **[ ]**	no **[ ]**	[ ]
Walking outdoors	yes **[ ]**	no **[ ]**	[ ]
In the garden	yes **[ ]**	no **[ ]**	[ ]
Getting out of a vehicle	yes **[ ]**	no **[ ]**	[ ]
On a kerb/ gutter	yes **[ ]**	no **[ ]**	[ ]
In a public building	yes **[ ]**	no **[ ]**	[ ]
In another person's home	yes **[ ]**	no **[ ]**	[ ]
In icy conditions	yes **[ ]**	no **[ ]**	[ ]

Falls or stumbles not described above (please specify)
……………………………..……………………………………………………….
…………………………………………………………………………………………
…………………………………………………………………………………………
…………………………………………………………………………………………

Q45. How did you fall or stumble (tick more than one if necessary)?

		How many times?
I tripped	[ ]	[ ]
I slipped	[ ]	[ ]
I lost my balance	[ ]	[ ]
My legs gave way	[ ]	[ ]
I felt faint	[ ]	[ ]
I felt giddy/ dizzy	[ ]	[ ]
I am not sure	[ ]	[ ]

Q46. What type of injuries did you suffer as a result of these fall/s (tick more than one if necessary)?

None	[ ]	Broken Wrist	[ ]	Broken Ankle	[ ]
Bruises	[ ]	Broken Hip	[ ]	Back Pain	[ ]
Cuts/ grazes	[ ]	Broken Ribs	[ ]		

Any other injury: **………………………………………………………………………….**
……………………………………………………………………………………..

Appendix V

Physical activity questionnaire data

Participants achieving the physical activity recommendations in each decade

Decade	Yes	No
20s	67.5	32.5
30s	71.7	28.3
40s	66.5	33.5
50s	60.0	40.0
60s	50.0	50.0
70s	43.7	56.3
80s	38.2	61.8
Lifetime	29.9	70.1

Males and females achieving the physical activity recommendations

Decade	Males	Females
20s	62.8	69.1
30s	57.7	76.4
40s	59	69
50s	57.1	60.9
60s	43.8	51.6
70s	35	46.5
80s	37.5	38.5
Lifetime	30.8	29.7

Percentage of non-fallers and fallers achieving the recommended amount of physical activity for each decade and across the lifetime

Decade	Non-Fallers	Fallers
20s	67	68
30s	67	73.4
40s	69.3	65.2
50s	66.3	57.8
60s	53.2	48.5
70s	42.5	44.1
80s	60	34.5
Lifetime	38.6	26.7

Health Questionnaire

Note: The purpose of this questionnaire is to find out about your health before you take part in laboratory testing. It is important that you answer all questions truthfully, and as completely as possible. All information given will be treated in confidence. Please tick the appropriate box for each question, adding written comments as requested.

Name: …………………………………………………. Age ………………..

		Yes	No
1.	Have you ever suffered from any form of heart complaint?	☐	☐

		Yes	No
2.	In the past month, have you had chest pain without doing physical activity?	☐	☐

3. Have you ever suffered from:

	Yes	No
Asthma	☐	☐
Diabetes	☐	☐
Bronchitis	☐	☐
Epilepsy	☐	☐
High blood pressure	☐	☐
Low blood pressure	☐	☐
Any other condition I may need to know about	☐	☐

If yes, give brief details:

		Yes	No
4.	Are you taking any form of medication?	☐	☐

If yes, give brief details:

		Yes	No
5.	Do you have a muscle or joint injury?	☐	☐

If yes, give brief details:

		Yes	No
6.	Do you experience dizziness or have you ever lost consciousness during everyday tasks?	☐	☐

		Yes	No
7.	Are you fitted with a pacemaker?	☐	☐

		Yes	No
8.	Do you suffer from any allergies or skin complaints?	☐	☐

If yes, give brief details:

Informed Consent Form

1. The purpose of this study is to analyse movement and balance during tasks of everyday living, and to investigate whether this is related to the risk of falling. For this study, you will be required to attend one laboratory testing session, and to complete regular questions on any fall occurrence for a further 12 months. During the laboratory session, you will be required to have small markers attached to your skin or clothing using sticky tape. It is important for you to realise that you may stop when you wish because of feelings of unbalance, dizziness or any other discomfort.

2. Any discomfort and risks attendant to the procedures are to the best of my knowledge short-term and minimal. There is a slight risk of reddening of the skin occurring in reaction to the sticky tape. Trained first aid personnel are available to deal with unusual situations that may arise.

3. Any questions about the procedures used in the laboratory or the results of your test are encouraged. If you have any concerns or questions, please ask us for further explanations.

4. The information that is obtained during testing will be treated as privileged and confidential. It is not to be released or revealed to any person without your written consent. The information obtained, however, may be used for statistical analysis or scientific purposes with your right to privacy retained.

5. I hereby consent to voluntarily engage in motion analysis and balance testing. My permission to perform these tests is given voluntarily. I understand that I am free to withdraw from this study at any time, if I desire.

I have read this form, and I understand the test procedures that I will perform and the attendant risks and discomforts. Knowing these risks and discomforts, and having had an opportunity to ask questions that have been answered to my satisfaction, I consent to participate in this study.

Name: ....

Signed: ....… Date: ....………

Exercise Scientist: ....………………

Signed: ....….. Date: ....……

Laboratory set-up

Figure showing the camera positions (orange), the capture volume used (purple square) and the two force plates (yellow). (NB. The numbers reflect the identity of the cameras within the Vicon system, not the number of cameras).

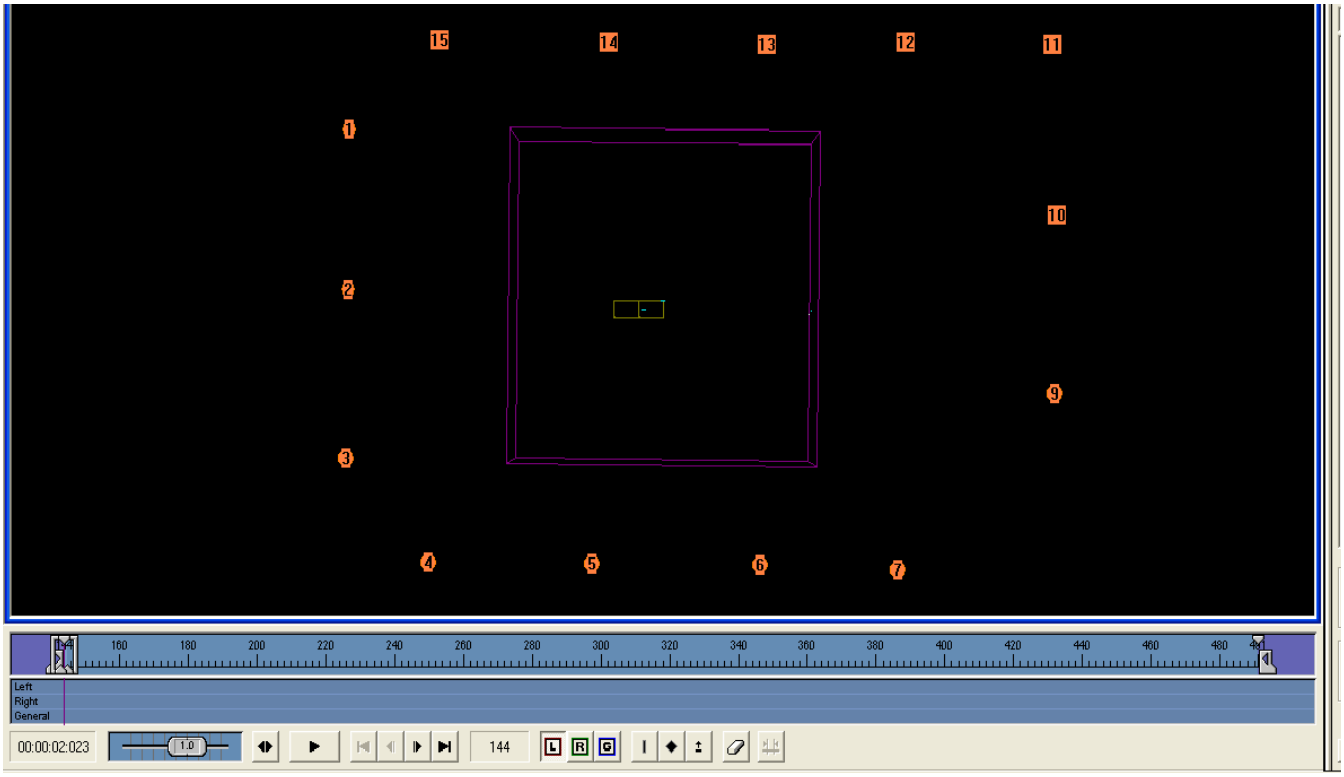


Photo of the laboratory

Marker placement

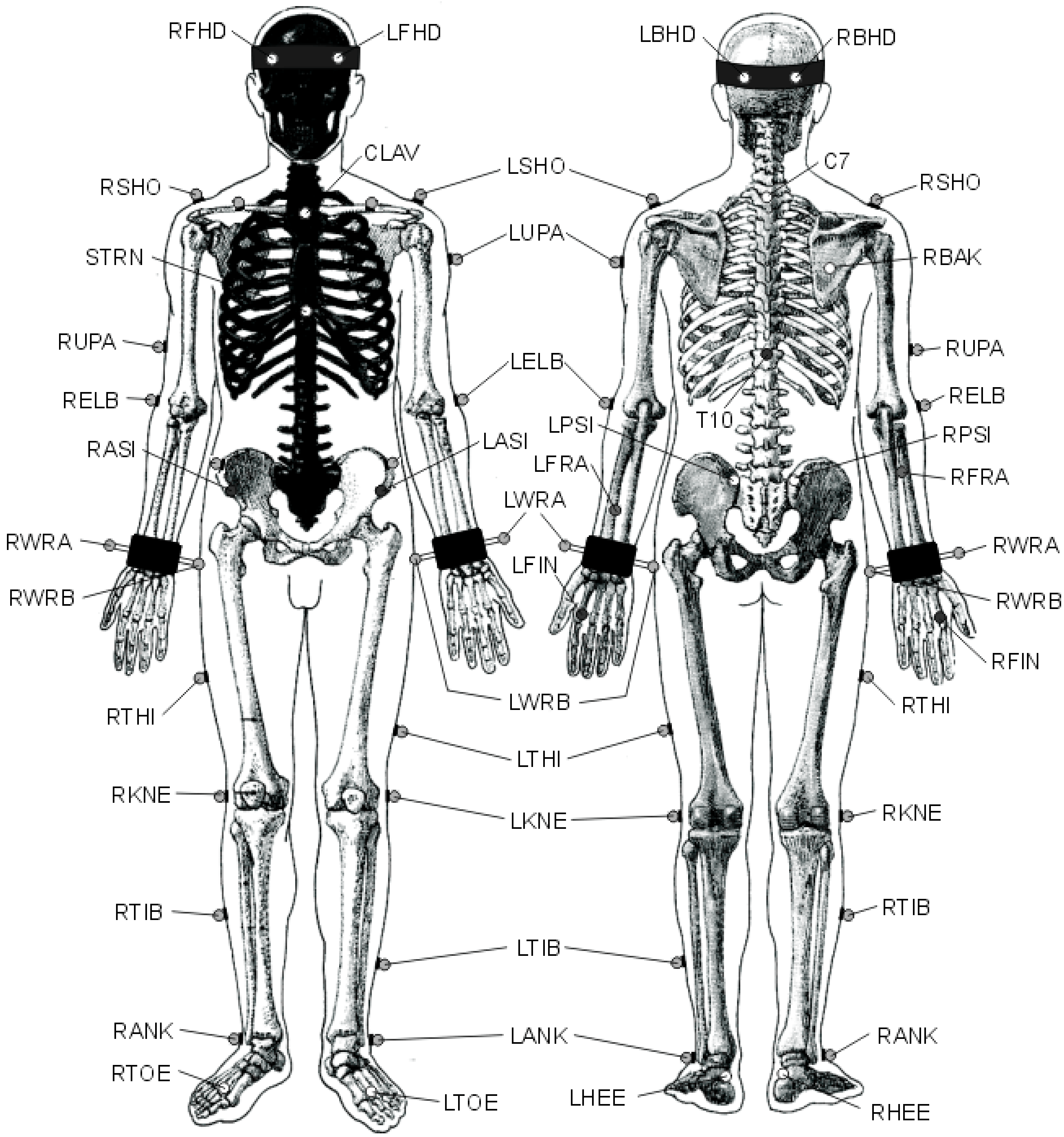
Retro-reflective spheres were attached using double sided tape or prefabricated head and wrist bands on the following anatomical landmarks:

- LFHD Left Front Head
- RFHD Right Front Head
- LBHD Left Back Head
- RBHD Right Back Head
- LSHO Left Shoulder
- RSHO Right Shoulder
- CLAV Clavicle
- STRN Sternum
- C7 7^{th} Cervical Vertebrate
- T10 10^{th} Thoracic Vertebrate
- RBAK Right Back
- LUPA Left Upper Arm
- RUPA Right Upper Arm
- LELB Left Elbow
- RELB Right Elbow
- LFRA Left Forearm
- RFRA Right Forearm
- LWRA Left Wrist A
- LWRB Left Wrist B
- RWRA Right Wrist A
- RWRB Right Wrist B
- LFIN Left Finger
- RFIN Right Finger
- LASI Left Anterior Suprailiac
- RASI Right Anterior Suprailiac
- LPSI Left Posterior Suprailiac
- RPSI Right Posterior Suprailiac
- RHIP Right Hip (additional to PiG – purely to help with asymmetry)
- LTHI Left Thigh (attached on wand)
- RTHI Right Thigh (attached on wand)
- LKNE Left Knee
- RKNE Right Knee
- LTIB Left Tibia (attached on wand)
- RTIB Right Tibia (attached on wand)
- LANK Left Ankle
- RANK Right Ankle
- LHEE Left Heel
- RHEE Right Heel
- LTOE Left Toe
- RTOE Right Toe
- LMT5 Left 5^{th} Metatarsal (additional to PiG)
- RMT5 Right 5^{th} Metatarsal (additional to PiG)

Appendix IX

And for the static trial the following markers were also required to assist with calculations of subject measurements:

- LKNEI Left Internal Knee
- RKNEI Right Internal Knee
- LANKI Left Internal Ankle
- RANKI Right Internal Ankle



The generation of surrogate data prior to filtering the data

Due to the nature of the data collection, there were points in the trial where markers could be obscured, e.g. a thigh marker could be obscured by arm swing during walking. Within the Vicon software, it is accepted practice to fill in gaps up to 1/10th of a second (6 frames at 60 Hz) using a spline fitting algorithm. However, gaps of greater than 6 frames were not filled, leading to gaps in the COM data when COM was determined based on the positions of these markers.

Gaps in the data can create issues when a digital filter is applied: the filter takes in information across a large window of data points, and this can generate artefacts in the data that spread beyond the original gap as the filter attempts to deal with the sudden discontinuity in the data. Depending on the characteristics of the filter, the data artefacts can be simple deflections in the data values (see figure IX.1), or as extreme as large oscillations, or 'ringing', that extends out to either side of the data gap (green area).

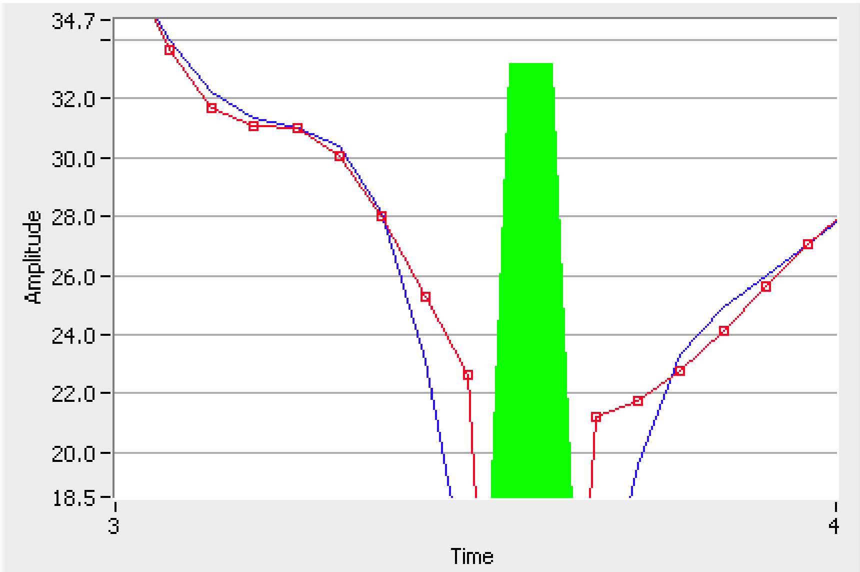


Figure IX.1. Raw (red) and filtered (blue) data around a data gap (green area)

To minimise the likelihood of filter artefacts contaminating the measured data values, surrogate data was created using a spline interpolant in the data gaps prior to filtering. This reduced the ringing effect in the filtered data (figure IX.2). This filtered data could subsequently be exported into Excel along side a data file identifying which was the recorded data and which was the surrogate data. This allowed the surrogate data to be removed prior to data analysis so that only actual data went into this process. The use of a spline interpolate to bridge the data gap allows the data points either side of the gap to be useable and not distorted by the filtering process.

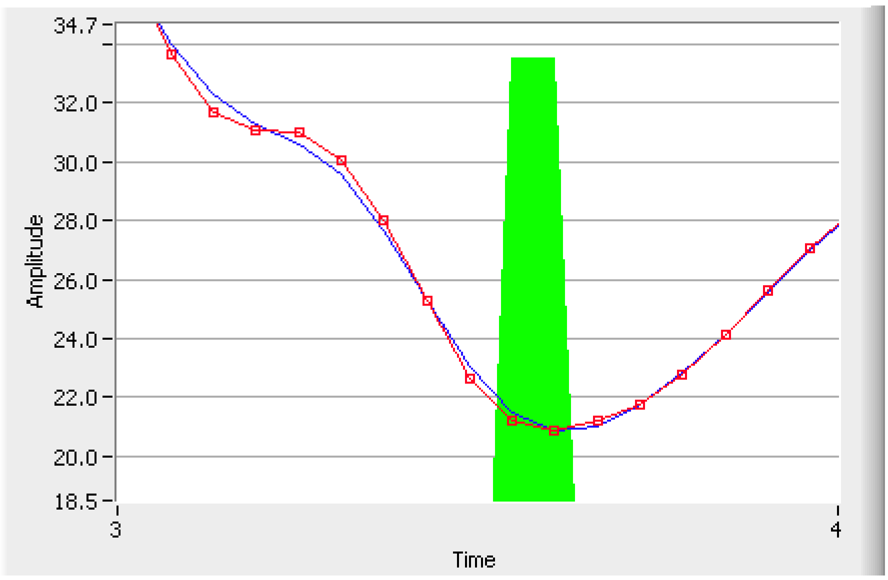


Figure IX.2. Raw (red) and filtered (blue) data using surrogate data through the data gap (green area)

Establishing the start and end of a turn from quiet standing

Participants were asked to initiate a turn from a quiet standing position. This introduces a problem in analysing the data of correctly identifying the initiation point of the turn manoeuvre. This is particularly difficult from a quiet standing position as the participant will naturally oscillate around a fixed position.

The simplest approach to isolating only the turn data is to set a threshold, either in position or rotational speed and only analyse data outside this threshold. However, optimum thresholds will be different for different participants and in all cases it will discard data that is part of the actual turn event.

To overcome these difficulties, the approach used was to identify the turn as consisting of a single continuous, rotational movement in one direction. This approach lends itself well to entirely objective isolation of the “turn” segment of the data by relatively simple mathematical analysis.

The starting data is a trace of body segment (e.g. head yaw) angle against time (figure X.1).

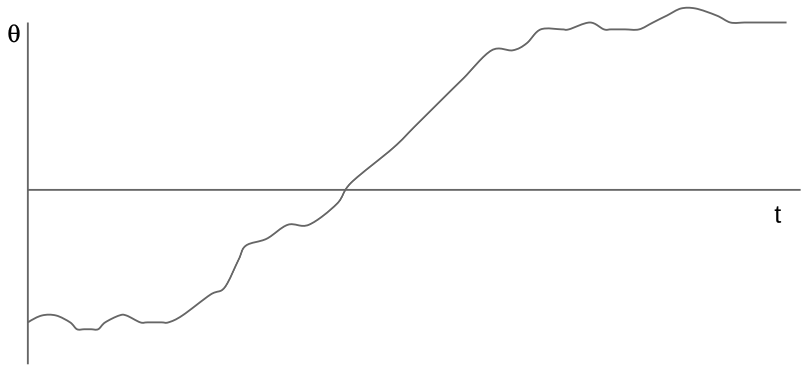


Figure X.1. Example head yaw data against time

From this the instantaneous rotation rate of the body segment is calculated, as shown in figure X.2. Continuous sections of data above or below zero correspond to continuous movement in one direction, with the zero crossings representing stationary points in the body segment movement.

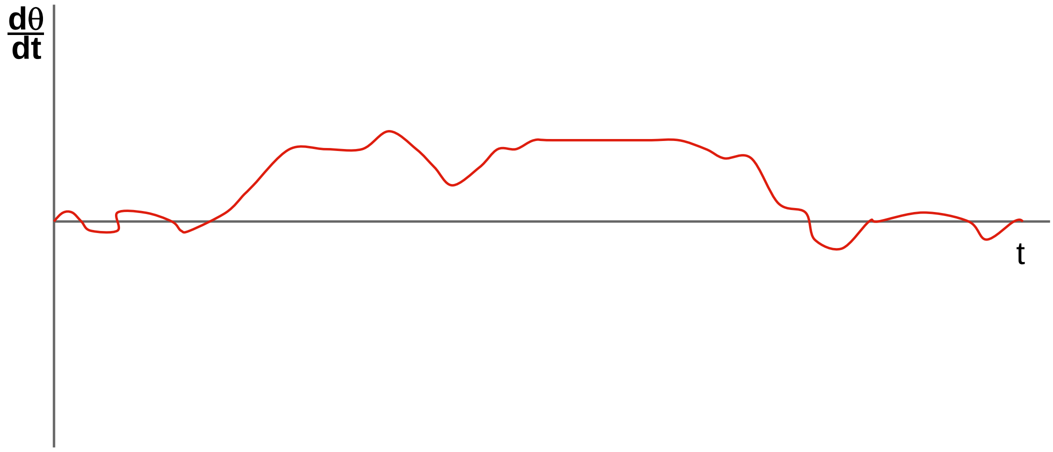


Figure X.2. Angular velocity of a segment

Given the nature of the measurement, an assumption can be made, that the greatest rotational velocity should be reached during the actual turn event. This is easily located as shown in figure X.3.

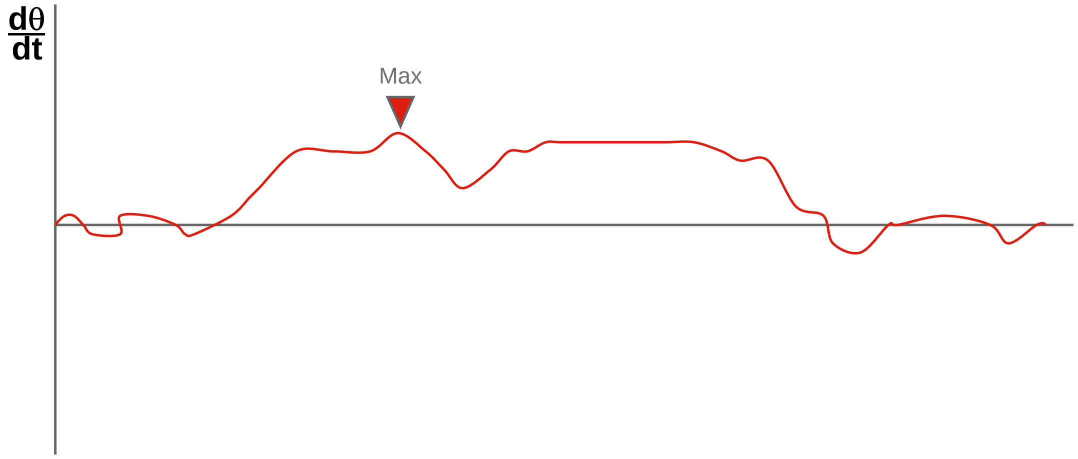


Figure X.3. Angular velocity of a segment, with the point of maximal velocity indicated

Once the maximum point is located, the area of interest in the data can be expanded to identify the start and end of the turn (the transition to and from continuous rotation in single direction; zero crossings; figure X.4).

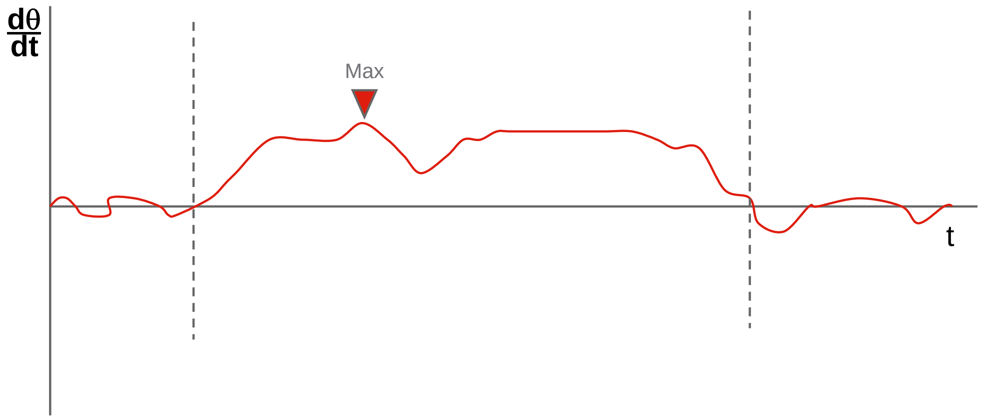


Figure X.4. Angular velocity of a segment, with the zero crossings pre and post the position of maximal velocity.

Once the bounding points are located the data that corresponds only to the turn event can be isolated for analysis (figure X.5).

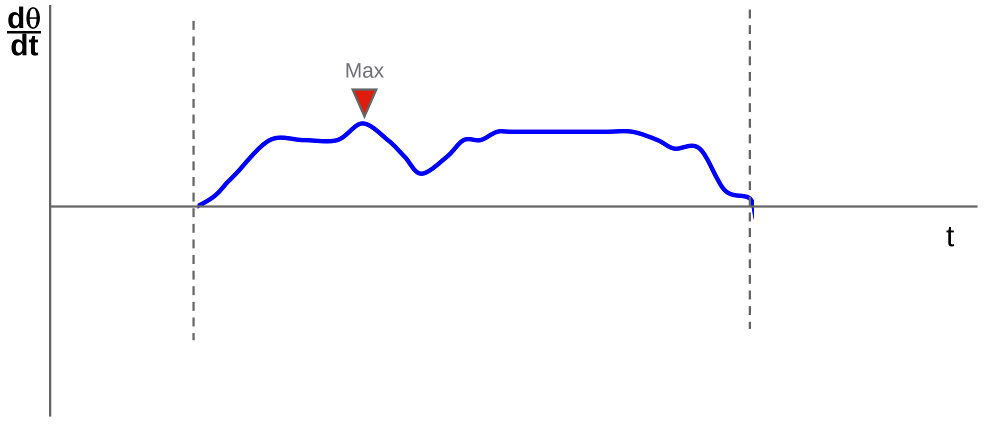


Figure X.5. The isolated area of rotational velocity of a segment that corresponds to the turn event

This allowed turn time to be determined, and the onset of reorientation and the sequencing of the body segments to be identified.

Body segment turn onset data

Body segment turn onset latencies at turn initiation expressed as time and percentage of turn time for the participant groups *indicates a significant difference from the multiple fallers

	Young Adults	Non-fallers	Single fallers	Multiple fallers
Thorax latency with respect to head (s)	0.10 ± 0.08	0.14 ± 0.08	0.13 ± 0.07	0.13 ± 0.14
Thorax latency with respect to head(% of turn time)	2.16 ± 1.35	2.81 ± 1.29	2.81 ± 1.59	2.62 ± 2.51
Pelvis latency with respect to head (s)	0.14 ± 0.09	0.19 ± 0.09	0.17 ± 0.08	0.15 ± 0.13
Pelvis latency with respect to head (% of turn time)	3.15 ± 1.57	3.69 ± 1.41	3.69 ± 1.83	2.91 ± 2.37
Pelvis latency with respect to thorax (s)	0.04 ± 0.02*	0.05 ± 0.02*	0.04 ± 0.03*	0.02 ± 0.01
Pelvis latency with respect to thorax (% of turn time)	0.98 ± 0.35*	0.93 ± 0.35*	0.90 ± 0.61*	0.36 ± 0.28
Foot off latency with respect to head (s)	0.37 ± 0.13	0.39 ± 0.15	0.43 ± 0.09	0.49 ± 0.20
Foot off latency with respect to head (% of turn time)	9.53 ± 2.95	7.97 ± 2.88	9.81 ± 1.55	9.63 ± 3.41
Foot off latency with respect to thorax (s)	0.27 ± 0.08	0.26 ± 0.12	0.32 ± 0.08	0.34 ± 0.14
Foot off latency with respect to thorax (% of turn time)	6.90 ± 2.03	5.19 ± 2.38	7.48 ± 2.07	6.91 ± 2.61
Foot off latency with respect to pelvis (s)	0.23 ± 0.08	0.21 ± 0.11*	0.29 ± 0.09	0.31 ± 0.11
Foot off latency with respect to pelvis (% of turn time)	5.97 ± 2.00	4.26 ± 2.37	6.68 ± 2.32	6.40 ± 2.45