Preventing falls in older adults: Understanding postural instability to improve fall assessment and prevention

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Abstract

Falls in older adults are a serious and increasing problem for the NHS. Due to their multifactorial causes falls are difficult to prevent but research suggests that assessment and early interventions of those at risk of falling can help reduce fall frequency and consequently alleviate the health service burden and improve quality of life for older adults.

The overall objective of this work was to investigate postural stability in persons over the age of 65 years to understand why this age group are susceptible to falls. Three main research aims were pursued (i) establish the scale of the issue of falls in older adults; (ii) develop an assessment system to measure postural stability; (iii) determine the conditions that compromise postural stability and assess awareness of this compromised stability.

Firstly the existing literature was reviewed and a large scale analysis of accident reports from a sample of UK care homes was carried out. The results showed that falls are a serious issue for older adults residing in care homes, but also that accident reports are not necessarily reliable and some institutions may underreport falls. Pilot work in the early stages of the research process developed an accurate and reliable system to measure levels of postural stability. A Wii balance board was interfaced with a computer based kinematic assessment tool to measure postural stability whilst carrying out a variety of computerised secondary tasks. This assessment system was then used to fulfil the final research aim of investigating postural stability in older adults when loaded with various secondary tasks. Older adults' postural stability was found to be compromised when undertaking a concurrent visuomotor task, but critically the results showed that this group were unaware of this compromise. The implications of these findings are discussed and further research directions are suggested.

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1 Introduction to the research area and thesis overview

1.1 Thesis overview

The main aim of this thesis is to investigate postural instability in people over the age of 65 years with a view to improving risk assessment and fall prevention. This research will strive to reach a fuller understanding of the complex and multidimensional issue of falls in older adults by using a combination of methods: qualitative examination of falls reporting together with experimental techniques to understand the mechanisms of falls.

The first aim is to explore the extent of falls caused by decreased postural stability as a function of age within UK care homes. This will be achieved through reviewing the existing literature regarding the numbers of falls experienced by older adults, whether in the community or in care homes, and the costs to society and individuals. The number of falls and their consequences will be empirically investigated in a large sample of UK care homes using data from accident reports (Chapter 2). This will also allow for a qualitative exploration of falls reporting practices within care homes.

The second aim is to develop a user friendly system to conduct experimental work with young and older adults to accurately measure their levels of postural stability (Chapters 3 to 6). The equipment will be piloted and developed throughout this thesis as a first step towards producing an 'early warning' system for individuals at risk of falls. The system needs to be affordable, portable, require limited training for use and produce highly accurate measures of postural stability. In a real world setting it could then be used to detect those older adults who are experiencing particularly high levels of postural instability to make them aware of their potential increased risk of falls and receive training and advice.

The third and final aim is to use the balance assessment equipment to conduct experimental work investigating the conditions under which older adults experience most postural instability and to assess their awareness of this increased instability. Certain circumstances can challenge the functioning of the body's postural control system and increase demands resulting in a greater susceptibility to falls. These types of circumstances are when visual information is degraded or when a concurrent visual or visuomotor task is conducted. Typical healthy adults display excellent postural control to a level where it appears to be an automatic process. However, the skill of postural control is complex, as observed by the difficulties experienced by infants when learning this skill, and in some older adults and certain clinical populations. These populations can reveal weaknesses within the postural control system and show the challenges involved in maintaining an upright stable stance. This thesis will examine the development of balance in children (Chapter 4) in comparison to the deterioration that occurs with increasing age (Chapter 5 and 6). Through this, further understanding can be gained into the control processes and establish under which conditions postural stability is most compromised. Additionally, the effects of 'fear of falling' on postural stability will be analysed (Chapter 5) and assessments undertaken to evaluate older adults' awareness of their potential postural control impairments (Chapter 6).

1.2 Background to the research area

1.2.1 The global issue of falls in older adults

For the work in this thesis a fall is defined as an unintentional event that results in a person coming to rest on the ground, floor, or other lower level (Campbell, Robertson, Gardner, Norton, Tilyard, & Buchner, 1997). Falls in older adults are one of the most significant issues facing health care providers in the UK today (Cameron, Gillespie, Robertson, Murray, Hill, Cumming, & Kerse, 2012; Genant, Cooper, Poor, Reid, Ehrlich, Kanis, Nordin, Barrett-Conner, Black., Bonjour, Dawson-Hughes, Delmas, Dequeker, Ragi Eis, Gennari, Johnell, Johnston, Lau, Liberman, Lindsay, Martin, Masri, Mautalen, Meunier, & Khaltaev, 1999; Heinrich, Rapp, Rissmann, Becker, & König, 2010; Peden, McGee, & Sharma, 2002; Sattin, Lambert-Huber, DeVito, Rodriguez, Ros, Bacchelli, Stevens, & Waxweiler, 1990) and they have been estimated to cost the NHS £4.6 million a day (Age UK, 2010). Falls are the primary cause of injury in persons aged over 65 years (Centers for Disease Control and Prevention, 2008; Sattin, 1992); to illustrate, in the UK in one year over 645,000 people over the age of 60 were taken to accident and emergency after falling (Scuffham, Chaplin, & Legood, 2003). Coping with the consequences of older adult falls is currently a serious health care issue across the 'developed world', especially due to the rapidly expanding ageing population (World Health Organization, 2008). The United

Nations recently reported that this changing demographic is no longer just limited to the world's 'developed' countries, showing factors related to ageing are a major global problem of our time (United Nations, 2013):

"*The world is in the midst of a unique and irreversible process of demographic transition that will result in older populations everywhere*"

Through investigating the complex challenges faced in geriatric medicine, four main areas of concern have been identified; these are known as the 'geriatric giants'. They consist of immobility, instability, incontinence and intellectual impairment (usually referred to as cognitive impairment) (Isaacs, 1992). Of these four major concerns two are directly related to falls; immobility and instability, and two have an indirect effect on falls by dramatically increasing fall risk when present; incontinence (J. S. Brown, Vittinghoff, Wyman, Stone, Nevitt, Ensrud, & Grady, 2000; Chiarelli, Mackenzie, & Osmotherly, 2009; Foley, Loharuka, Barrett, Mathews, Williams, McGrother, & Roe, 2012; Morris, Hunter, & Wagg, 2011) and intellectual impairment (Hauer, Pfisterer, Weber, Wezler, Kliegel, & Oster, 2003; Susan W. Muir, Gopaul, & Montero Odasso, 2012; Shaw, 2003; Shaw, Bond, Richardson, Dawson, Steen, McKeith, & Kenny, 2003; Tinetti, Doucette, Claus, & Marottoli, 1995; Van Dijk, Meulenberg, Van De Sande, Herbert, & Habbema, 1993; Van Doorn, Gruber-Baldini, Zimmerman, Richard Hebel, Port, Baumgarten, Quinn, Taler, May, & Magaziner, 2003). The link between falls and all of the geriatric giants highlights the need for further investigation into the deterioration of postural stability in older adults.

Achieving accurate figures on the scale of older adult falls is problematic and may inherently suffer from issues of inaccurate reporting. For older adults residing in care home settings or hospital in the UK, any falls should by law be logged by staff members (Care Quality Commission, 2010). Nevertheless the accuracy of the recording practices within institutions can be problematic and this is explored in further detail within this thesis (Chapter 2). For older adults living in the community, an accurate figure as to how many falls occur each year is very difficult to ascertain as the majority of falls are not witnessed and may not lead to serious injury (Robert G Cumming, Kelsey, & Nevitt, 1990). If falls are reported to a health care professional it will be through self-report which lacks accuracy (Cummings, Nevitt, & Kidd, 1988; Means, Nigam, Zarrow, Loftus, & Donaldson, 1989). Additionally there is some evidence to suggest that older adults could be wrongly attributing the cause of a fall to factors in the environment whereas they could actually be caused by a more serious underlying medical issue which could benefit from treatment (Lord, 2007; Rubenstein, 2006). In the majority of cases only those falls with the most serious consequences (such as injury requiring hospital) are likely to be given serious attention by the individual (Cummings, et al., 1988). This inaccuracy of self-report in fall frequency may stem from several factors, many based upon the features of this age group. Firstly it has been reported that due to cognitive impairment this group may experience falls and not accurately recall the event (Cummings, et al., 1988; Lord, 2007). Also some older adults are particularly adverse to admitting weakness and because falls are typically seen as a sign of old age and frailty (P. Kingston, 2000; Yardley, Donovan-Hall, Francis, & Todd, 2006), and to avoid worrying family or burdening others (Kuzuya, Masuda, Hirakawa, Iwata, Enoki, Hasegawa, Izawa, & Iguchi, 2006; Liddle & Gilleard, 1995) they may be under-reported. Another related factor is the fear of admission to a care home and loss of independence which is often the result following a serious fall (Tinetti & Williams, 1997); many older adults have reported care home admission as a ‘fate worse than death’ (Mattimore, Wenger, Desbiens, & Teno, 1997) so they may hide their deficits from their doctor and family. Accurate evaluations may be difficult in part due to the barriers in accessing a home dwelling older adult population to obtain data on falls, especially if certain individuals are very frail and do not wish to part take in social initiatives (Crombie, Irvine, Williams, McGinnis, Slane, Alder, & McMurdo, 2004).

When researching falls prevention it is important that falls should be regarded as a *symptom* of an underlying health problem rather than a standalone *diagnosis* (Lipsitz, Jonsson, Kelley, & Koestner, 1991). The typical causes of falls in older adults are characteristically multifactorial in nature, often without an easily identifiable health issue for the resulting fall (O'Loughlin, Robitaille, Boivin, & Suissa, 1993; Rubenstein, 2006; Tinetti & Kumar, 2010). Yet frequent falls may reveal an underlying pathology, such as a neurological condition known to affect movement and balance such as Parkinson’s disease (Gray & Hildebrand, 2000; Wood, Bilclough, Bowron, & Walker, 2002). Falls could also expose a marked deterioration in muscle strength and their reflex action so leading to disturbed gait and increased falls risk (Rubenstein, 2006).

In addition to the rise in hospital admissions following a fall due to the changes in population demographics, the medical outcomes of treating an older adult who has fallen can be disproportionally demanding on health care resources relative to other age related conditions (T. M. Gill, Murphy, Gahbauer, & Allore, 2013). Older adult admissions to hospital following a fall are often related to extended hospital stays (Landefeld, Palmer, Kresevic, Fortinsky, & Kowal, 1995; Magaziner, Simonsick, Kashner, Hebel, & Kenzora, 1990; Roudsari, Ebel, Corso, Molinari, & Koepsell, 2005). This can be due to the challenges posed by concurrent co-morbidities (R. G. Cumming, 1998; Johnston, Wakeling, Graham, & Stokes, 1987; Roche, Wenn, Sahota, & Moran, 2005; Stratton, King, Stroud, Jackson, & Elia, 2006) and the time taken to investigate the cause of the fall, as many older adults are admitted (and sometimes discharged) with their medical record simply stating, “fall query cause” with no definitive reason as to why the fall occurred, despite extensive investigation (Bell, Talbot-Stern, & Hennessy, 2000; Sarasin, Louis-Simonet, Carballo, Slama, Rajeswaran, Metzger, Lovis, Unger, & Junod, 2001). Additionally, older adults’ more complex medical needs often require the involvement of many healthcare disciplines including a combined strategy from dieticians, physical therapists, occupational therapists, pharmacists, psychologists and social workers (Tsukuda, 1990). The involvement of social workers highlights the often complicated discharge needs in some older adult cases if they are not able to return home without a care plan in place or they may have to enter a long-term care institution (Crotty, Whitehead, Wundke, Giles, Ben-Tovim, & Phillips, 2005; Scuffham, et al., 2003), the organisation of which can take an extended period of time adding to the already significant costs to the NHS.

Whilst it is important to consider the financial consequences of falls, especially in the current economic climate, for the individuals who have experienced a fall the physical and psychological outcomes are of paramount importance. Not only are falls more likely to occur in adults aged over 65 years but they more frequently result in bone fractures or other serious injuries and even fatality (Rubenstein, 2006; Sterling, O'Connor, & Bonadies, 2001). Additionally, there is the added concern of not being able to get up once a fall has occurred leading to increased risk of serious negative outcomes from time spent unaided on the floor (Fleming & Brayne, 2008; Tinetti, Liu, & Claus, 1993a). As well as the severe physical consequences (such as a broken hip or head injuries resulting in extended hospital stays), there are significant negative psychological outcomes from falling such as diminished confidence or the development of a ‘fear of falling’ leading to loss of independence, increased frailty and reduced quality of life (Arfken, Lach, Birge, & Miller, 1994; Chamberlin, Fulwider, Sanders, & Medeiros, 2005; Delbaere, Close, Brodaty, Sachdev, & Lord, 2010; Delbaere, Crombez, Vanderstraeten, Willems, & Cambier, 2004; Kempen, Yardley, van Haastregt, Zijlstra, Beyer, Hauer, & Todd, 2008; Maki, 1997; Maki, Holliday, & Topper, 1991; Reelick, van Iersel, Kessels, & Rikkert, 2009; Tinetti & Powell, 1993b; Vellas, Wayne, Romero, Baumgartner, & Garry, 1997; Yardley & Smith, 2002).

In an aim to prevent recurrent falls and to treat any underlying health issues causing falls, it is vital to establish the reason why a fall may have occurred. The cause of a fall can be attributed to either intrinsic factors; thus factors dependent on the individual such as balance disorders, muscle weakness, visual problems or confusion, or falls can be from extrinsic factors; factors dependent on the individual's environment such as low lighting, trip hazards or slippery floors (Bueno-Cavanillas, Padilla-Ruiz, Jimenez-Moleon, Peinado-Alonso, & Galvez-Vargas, 2000; L. Nyberg, Gustafson, Berggren, Brännström, & Bucht, 1996). A comprehensive review by Rubenstein (2006) found that between 30-50% of all reported reasons for falls in the reviewed studies were attributed to a specified extrinsic cause (Rubenstein, 2006). However, he suggests that many of the falls that were attributed to an environmental hazard could have been avoided if it were not for inherent intrinsic factors affecting functioning. Rubenstein highlighted that commonly reported intrinsic causes for falls in older adults include balance disorders and unsteady gait, confusion and cognitive impairment, acute illnesses such as urinary tract infection, postural hypotension or certain medications/alcohol. The often co-existing intrinsic factors lead to an '*increased individual susceptibility to hazards from accumulated effects of age and disease*" (Rubenstein, 2006). It is reported that the 'environmental hazards' leading to the fall have only become hazardous due to factors such as reduced muscle strength and reflexes leading to a less stable gait and reduced coordination and proprioception. This can cause behavioural changes such as a reduced stepping height thus increasing the risk of trips from normally non-threatening factors in the environment. There are also the general effects on the body from these intrinsic factors which lead to an overall increase in the number of stumbles from extrinsic factors due to impairments in the sensory system from poorer vision and hearing and also the associated cognitive decline leading to memory loss and confusion (Rubenstein, 2006). All these factors together result in reduced awareness of the surrounding environment and the increased opportunity for an accident to occur.

1.2.2 The causes of older adult falls

The most frequently cited intrinsic risk factor for falls in older adults has been suggested to be balance impairments in the individual causing reduced postural stability (Delbaere, Crombez, Van Den Noortgate, Willems, & Cambier, 2006; J. Gill, Allum, Carpenter, Held-Ziolkowska, Adkin, Honegger, & Pierchala, 2001; Lord, Menz, & Tiedemann, 2003; Susan W Muir, Berg, Chesworth, Klar, & Speechley, 2010; Overstall, Exton-Smith, Imms, & Johnson, 1977; Piirtola & Era, 2006; Pluijm, Smit, Tromp, Stel, Deeg, Bouter, & Lips, 2006; Rubenstein, 2006; Stalenhoef, Diederiks, Knottnerus, Kester, & Crebolder, 2002; Tinetti, et al., 2010). These impairments in balance can be caused by a range of age related factors or co-morbidities, but the key consideration for falls prevention strategy is to identify balance impairments in an individual before a fall has occurred. In this way an underlying morbidity which is causing the instability can be treated or managed before the negative consequences of a fall add to the older adult's problems. For example, postural hypotension can be identified and medication prescribed thus preventing dizziness on standing, or for those experiencing significant balance problems due to more general age related issues (such as reduced muscle strength), an appropriate referral could be made for a balance and strengthening class to improve physical well-being and highlight the need for a sensible approach to fall risk management by the individual.

As adults enter into old age, they have been found to experience increased levels of standing postural sway (Delbaere, et al., 2006; Gu, Schultz, Shepard, & Alexander, 1996; Hageman, Leibowitz, & Blanke, 1995; Horak, Henry, & Shumway-Cook, 1997; Laughton, Slavin, Katdare, Nolan, Bean, Kerrigan, Phillips, Lipsitz, & Collins, 2003; Lord, Rogers, Howland, & Fitzpatrick, 1999; Maki, Holliday, & Fernie, 1990; Maki, Holliday, & Topper, 1994; Rogers & Mille, 2003). However, a marked increase in postural sway is not always directly linked to a greater number of falls. Horak, Henry and Shumway-Cook (1997) have proposed that the increased postural sway experienced by older adults is due to the delayed onset of appropriate muscle reactions to environmental perturbations. If the delayed muscle response to the perturbation is significant and no corrective movement strategy is taken to regain equilibrium then a fall will occur (Maki, 1997; Tucker, Kavanagh, Morrison, & Barrett, 2010). This means a fall is not guaranteed to occur just because an older adult is experiencing increased postural stability. This is because although there are a multitude of external influences for falls such as hazards in the person's environment, these can to some extent be avoided or strategies can be implemented to increase stability for example using supports such as hand rails or walking aids. Nevertheless the link between increased sway and falls has been well documented, with studies reporting it as a significant predictor of falls in an older adult population (Lajoie & Gallagher, 2004; Pfeifer, Begerow, Minne, Schlotthauer, Pospeschill, Scholz, Lazarescu, & Pollahne, 2001; Shumway-Cook, Woollacott, Kerns, & Baldwin, 1997). Delbaere and colleagues (2006) assessed the incidence of falls in 263 older adults at baseline and during a one year follow up. They found a recorded increase in lateral sway at baseline testing was strongly linked to the later occurrence of falls over the following year (Delbaere, et al., 2006).

In researching falls it is important to consider the different risks associated with static balance (maintaining balance whilst standing still) and dynamic balance (maintaining balance whilst undertaking movement). Some of the main risk factors for falls are related to dynamic balance thus aspects such as the use of walking aids and gait problems are significant concerns for falls prevention researchers (Deandrea, Lucenteforte, Bravi, Foschi, La Vecchia, & Negri, 2010; Winter, Patla, Frank, & Walt, 1990). However in this thesis only static balance will be assessed. This is because previous research has demonstrated that standing postural sway alone can reveal a balance deficit as indexed by increased postural sway (Delbaere, et al., 2006; Lord, Sambrook, Gilbert, Kelly, Nguyen, Webster, & Eisman, 1994; Pfeifer, et al., 2001). Therefore persons at risk of falls can be detected solely by assessment on static balance tests. A recent study of a clinical population experiencing postural control difficulties found that in fact the performance of the patient group under dynamic balance conditions was unpredictably very good when compared to their performance on a static balance task (Nardone, Grasso, & Schieppati, 2006). There were numerous confounding variables involved during the dynamic balance task where participants were able to use well practised anticipatory postural control strategies to mask their balance deficit when walking. Many falls in older adults are reportedly due to trips from failing to negotiate obstacles efficiently (Chen, Ashton-Miller, Alexander, & Schultz, 1991; Cohen, Nutt, & Horak, 2011) or when persons are turning whilst walking which can be disorientating (Cao, Ashton-Miller, Schultz, & Alexander, 1997) or due to postural hypotension when standing (Rutan, Hermanson, Bild, Kittner, LaBaw, & Tell, 1992). Dynamic balance is a far more complex action to measure as there are many more variables to consider which can potentially lead to a fall. In such, these confounding variables can cause difficulties with the assessment of falls risk thus the focus of this investigation is solely focused on static balance, which has been shown to accurately express an underlying postural control deficit.

When considering postural control and stability in older adults, it can be useful to look at the progression across the life span; from the development of balance and postural control in early childhood to the gradual deterioration in older age. Postural control may appear to be an automatic process in healthy adults however only when the gradual development throughout infancy to early adolescence is studied or when the processes being to fail with increasing age, does one truly appreciate the complexity of this system. This is because the maintenance of postural control has been shown to function through many different means and use a range of sensory inputs; some using very basic processes such as primary reflexes and others which develop more slowly but obtain optimum functioning using the higher nervous system centres (Woollacott & Shumway-Cook, 1990); this will be explored further in Chapter 4. Through these different systems it is apparent that some routes of balance function are more effective than others, but under typical circumstances even if there is a failure in one system it appears to be possible for another system to compensate to maintain control. Problems may arise when encountering certain environmental conditions or in situations when there is conflicting sensory information; in these circumstances a weakness in a system may be revealed (Woollacott, Shumway-Cook, & Nashner, 1986). A marked effect of older age is the decline in function of certain processes, with two key areas of concern being deterioration in cognitive functioning and the postural control systems. Consequently, if older adults are placed in the wrong circumstances where conflicting sensory information or challenging environmental conditions are found then it may lead to a failure by the system to control postural stability and potentially lead to a fall. It has been reported that most older adult falls are the result of inadequate responses to environmental perturbations (Horak, et al., 1997) however this systems approach also gives hope that should there be a failure in one system of postural control, there are compensatory systems that could be used to take over. Therefore, if these problems can be detected in individuals, potential strategies could be employed to help adapt to using these compensatory systems if the usual system is not functioning at optimal levels. Horak, Henry and Shumway-Cook (1997) state that due to the greater understanding of how the central nervous system controls postural stability, advances can now be made in physical therapy to improve balance. This is because the ability to control balance is no longer seen as a basic series of reactions to environmental stimuli in order to maintain postural equilibrium. Instead balance is now understood as a learnt motor skill and as such therapists can use the fundamental concepts of motor learning in order to retrain the system, using techniques such as practice and feedback (Horak, et al., 1997).

1.2.3 Postural stability whilst undertaking a concurrent cognitive activity

In a comprehensive review by Hsu and colleagues (2012), dual task performance was shown to be closely linked to falls and falls risk (Hsu, Nagamatsu, Davis, & Liu-Ambrose, 2012). Dual tasking involves dividing cognitive resources between a cognitive type task whilst simultaneously undertaking a postural challenge. For some populations the physical challenge of merely maintaining postural stability can prove demanding alongside certain cognitive tasks. Dual task scenarios occur constantly in daily life as postural control is required whilst undertaking posture-unrelated cognitive activity; in this way mild forms of dual tasking are the norm rather than the exception (Huxhold, Li, Schmiedek, & Lindenberger, 2006). However research has shown postural control can be negatively affected by undertaking more challenging cognitive tasks; this is shown in young age groups (Yardley, Gardner, Leadbetter, & Lavie, 1999) but more commonly in older adult groups (Brauer, Woollacott, & Shumway-Cook, 2001; Shumway-Cook, et al., 1997; Teasdale & Simoneau, 2001). Nevertheless the balance of the dual tasking relationship has been found to be highly complex. The theory behind using a dual task to investigate postural stability is that through undertaking a concurrent task, such as a cognitive or visuomotor task, postural control can become comprised. This leads to an increase in postural sway because even quiet standing has been shown to require cognitive resources (Lacour, Bernard-Demanze, & Dumitrescu, 2008; Vuillerme, Nougier, & Teasdale, 2000). Huxhold, Li, Schmiedek and Lindenberger (2006) showed this effect on postural control in an older adult population where increased centre of pressure displacements were found whilst completing more cognitively demanding tasks. A group of young adults tested with the same tasks did not show this effect (Huxhold, et al., 2006). It is suggested that older adults possess reduced cognitive resources available to control balance when compared to a younger age group; as a result the postural control system is competing for attentional resources (Weeks et al., 2003; and Woollacott and Schumway Cook 2002). This theory may partly explain why cognitive impairment increases the risk of falls in older adults (Rubenstein, 2006; Shaw, 2003; Tinetti, et al., 1995; Van Doorn, et al., 2003) as even a mild cognitive impairment has been shown to lead to far greater postural sway and increased fall risk (Liu-Ambrose, Ashe, Graf, Beattie, & Khan, 2008b). Additionally, older adults show a greater independence of sensorimotor and cognitive modalities (Pichora-Fuller et al, 1995, Murphy et al, 2000) so not only can balance performance be compromised but performance on concurrent tasks can be negatively affected by the resource competition. Age-related postural effects are common in dual-task scenarios, although, due to the mixed evidence (see Yogev-Seligmann et al., 2009 for review) several different hypotheses have been developed to explain these findings. These hypotheses have been developed over the past 40 years but the three main and current dual task models in existence are the ‘cross-domain competition model’, ‘the U-shaped nonlinear interaction model’ and the ‘task prioritisation model’ (Lacour, et al., 2008). A summary of these models and their predicted outcomes on postural stability and performance on a concurrent task is shown in Table 1.1.

Table 1.1 Summary of the key models concerning the effects of a concurrent task on postural stability

<table>
<tr><th>Model</th><th>Hypothesis</th><th>Effect on postural stability</th><th>Effect on concurrent task</th></tr>
<tr><td>Cross domain competition</td><td>Postural stability and cognitive activity compete for attentional resources resulting in a negative effect on both</td><td>Negative effect on stability ↓</td><td>Negative effect on task performance ↓</td></tr>
<tr><td>U-shaped nonlinear interaction</td><td>Postural stability can be reduced or improved depending on the task</td><td>Positive or negative effect on stability ↕</td><td>No reported effect on task performance —</td></tr>
<tr><td>Task prioritisation</td><td>Postural stability OR task performance will be affected negatively in the competition for attentional resources</td><td colspan="2">Either a negative effect on postural stability or a negative effect on task performance depending on fundamental goals and prioritisation strategy (e.g. posture first)
↓ —
OR
— ↓</td></tr>
</table>

The cross-domain competition model depicts the idea of attentional resource sharing and the negative outcome on balance performance when undertaking a concurrent task. This model is supported in the main by studies involving older aged participants (Maylor & Wing, 1996; Pellecchia, 2003; Redfern, Jennings, Martin, & Furman, 2001;

Shumway-Cook & Woollacott, 2000) but also some effects have been shown in young adults (Yardley, et al., 1999). However this model cannot be universally applied as opposite effects on balance under the same testing conditions have been found where in fact improvements in postural control are shown from dual tasking; this is found in young adult populations (Andersson, Hagman, Talianzadeh, Svedberg, & Larsen, 2002; Andersson, Yardley, & Luxon, 1998; Dault, Geurts, Mulder, & Duysens, 2001; Swan, Otani, Loubert, Sheffert, & Dunbar, 2004) but also in older adults when undertaking certain cognitive tasks (Prado, Stoffregen, & Duarte, 2007). Therefore although this model could prove useful for explaining an increase in postural sway under certain complex cognitive conditions for older adults there is some doubt cast on this theory as a comprehensive explanation for all dual task effects on postural stability.

Consequently the U-shaped nonlinear interaction model, serves to improve upon the cross-domain competition model as a more complex explanation of the dual task effects on postural stability. The U-shaped model refers to the fact that postural stability may be reduced by the undertaking of a concurrent task, but it also may be improved, thus leading to a U-shaped curve of effect. The positive or negative results on balance are based on the cognitive demands of the concurrent task (Lacour, et al., 2008). An improvement in postural stability is found in young (Vuillerme, et al., 2000) and older adults (Deviterne, Gauchard, Jamet, Vancon, & Perrin, 2005; Prado, et al., 2007) during tasks with low cognitive demands, however in tasks with a significantly more challenging cognitive element, older adults showed considerable detriments in their postural stability (Huxhold, et al., 2006). In young adults the relationship is more complex and it appears postural stability can be improved by both easy cognitive tasks and very challenging cognitive tasks (Riley, Baker, & Schmit, 2003). This is explained to some extent by cognitive ‘arousal theory’ (Kahneman, 1973) which states that cognitive resources are gradually stimulated by the increased demands placed upon them, so leading to more resources becoming available to help negate the negative effects on postural stability (Riley, et al., 2003). Yet this arousal theory has been strongly criticised and has limited supporting evidence (Maki & McIlroy, 1996). The major criticism of this nonlinear model appears to be the lack of explanation behind the well documented U-shaped results demonstrated in postural stability through the varying difficulty of the concurrent tasks. Additionally, the lack of consistency in postural stability measurement across the supporting studies causes some doubt in the validity of the overall findings (Lacour, et al., 2008). Thus this model appears to have good *potential* in explaining the complex results found in postural stability during dual tasking but the limitations described clearly highlight the need for more work in explaining the results.

Finally, the task prioritisation model proposes that when there is a demand for cognitive resources in a dual task situation, there will be a noticeable detriment in either the postural control system or the concurrent cognitive task. This can be especially apparent in older adults where there are more limited cognitive resources available and continuing two concurrent tasks becomes difficult (Lacour, et al., 2008). The task prioritisation model is illustrated in the simple example of older adults stopping walking while talking and has even been suggested to be predictive of falls (Lundin-Olsson, Nyberg, & Gustafson, 1997). Under situations of postural threat older adults have been shown to prioritise postural control over the completion of a concurrent task (L. A Brown, Sleik, Polych, & Gage, 2002), thus leading to the 'posture first' hypothesis in older adults. Task prioritisation has been specifically observed in older adult populations (Lajoie, Teasdale, Bard, & Fleury, 1993; Li, Lindenberger, Freund, & Baltes, 2001; Lindenberger, Marsiske, & Baltes., 2000; Maylor, Allison, & Wing, 2001; Shumway-Cook, et al., 1997; Teasdale, Bard, Dadouchi, Fleury, LaRue, & Stelmach, 1992; Teasdale, et al., 2001), and exists potentially as a critical-survival response to avoid destabilisation leading to falls (Lacour, et al., 2008). The prioritisation of resources by older adults has been suggested to be an adaptive response to the functional declines observed in ageing (Lacour, et al., 2008) and this response strategy has been modelled to be based on three key components; selection, optimisation, and compensation (Baltes & Baltes, 1990). Through these components older adults select and prioritise their fundamental goals (maintaining stability in the case of postural control). Older adults then adapt their cognitive resources to focus on achieving these goals and carry out compensatory strategies to complete the concurrent task, leading to reduced task performance (Baltes, et al., 1990). Interestingly it has been shown in certain scenarios young adults are affected to a greater extent in reduced task performance than older adults (Kemper, Herman, & Lian, 2003). Therefore, even with this increasingly specified age related model, there still appear to be dual tasking research examples that go against the proposed explanations. In this way, as no single model fits all dual tasking research, there is potentially a need for further research and development of these models. It appears that dual tasking is highly context specific with theories needing to account for environmental situation, type and complexity of the postural demands and the cognitive tasks.

1.2.4 Effective interventions for fall prevention

A broad literature search was undertaken to explore the current approaches used to investigate falls in older adults. The search, focussing on papers from the year 2000 onwards, revealed that previous studies have adopted an extremely varied research focus to further understand this complex area. The wide range of approaches used to investigate falls in older adults are shown on Figure 1.1 split proportionally by percentage according to their category of research focus. The miscellaneous category is made up of studies linking falls with the following factors such as dental issues, blood pressure, electroconvulsive therapy and type A personality.

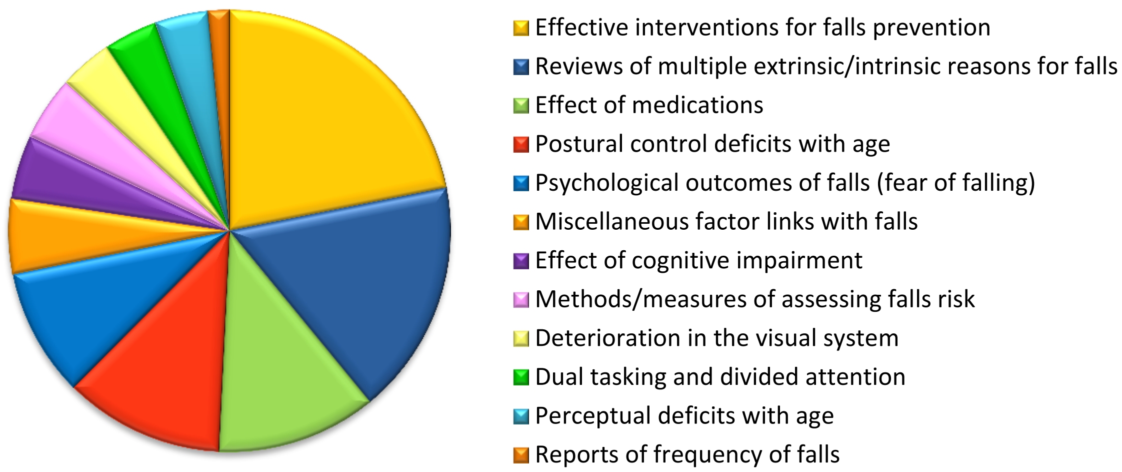


Figure 1.1 The proportional distribution of 923 papers found in the area of older adult falls published between 2000 to 2013 and categorised according to research focus

The key category to explore further was deemed to be 'effective interventions for the prevention of falls'. This is because falls in older adults are all too commonly seen as an inevitable consequence of ageing. Yet research has shown that this need not be the case (Tinetti, Baker, McAvay, Claus, Garrett, Gottschalk, Koch, Trainor, & Horwitz, 1994) and there may be some very effective preventative measures to help reduce the likelihood of falls. If any consistently effective interventions were found to exist then it provides motivation for this PhD to develop an early warning system to identify those at risk so an intervention can be offered before a fall has occurred.

In total, 202 papers were found concerned with interventions to prevent older adult falls, including several systematic reviews (Cameron, Murray, Gillespie, Robertson, Hill, Cumming, & Kerse, 2010; Chang, Morton, Rubenstein, Mojica, Maglione, Suttorp, Roth, & Shekelle, 2004; Gates, Fisher, Cooke, Carter, & Lamb, 2008; Gillespie, Robertson, Gillespie, Lamb, Gates, Cumming, & Rowe, 2009; Michael, Whitlock, Lin, Fu, O'Connor, & Gold, 2010; Sherrington, Tiedemann, Fairhall, Close, & Lord, 2011; Shubert, 2011). Through reading the papers and the systematic reviews some key findings were revealed concerning the most effective interventions to prevent falls in older adults.

An important finding was that there have been a wide range of intervention approaches adopted to reduce falls. The specific interventions within the reviewed papers were categorised to show the diverse methods being used in falls prevention strategy; interventions involving exercise or physical therapy, vitamin D treatment, correction of vision, medication review or withdrawal, surgery (cardiac pacemaker or cataract), podiatry treatment, fluid or nutrition therapy, social dancing classes, cognitive behavioural therapy, assistive technology, home hazard assessment, clinical education, caregiver training, or multifactorial interventions combining two or more of the previous factors. The range of ways to prevent falls reflects the many and varied reasons as to why an older adult may fall and how strategies may need to target many different factors.

Of these studies looking into effective interventions to prevent falls there was a wide range in sample sizes from 10 participants (Lannin, Clemson, McCluskey, Lin, Cameron, & Barras, 2007) up to 9440 participants (Smith, Anderson, Raphael, Maslin, Crozier, & Cooper, 2007). In the latter study, the intervention involved a yearly Vitamin D injection where 50% of participants were in a control group and received no treatment, thus it was a low intensity study to maintain over the three year trial. The most labour intensive studies with high levels of practitioner/older adult contact tended to have the smallest sample sizes as these studies demand most resources hence this is reflected in lower participant numbers.

The main finding from reading the existing literature was that there is evidence to show a great deal can be done to reduce the likelihood of falling in older adult populations. This is true whether focussing on community dwelling active older adults or more frail persons living within care homes or in hospital; effective falls prevention strategies have been proven to exist for all groups. The most effective methods for falls prevention vary depending on the target group and this is a factor which is of the utmost importance when designing these programs and determining who will profit from attendance.

There appear to be significant benefits from interventions even with the most at risk groups of older adults; those living in nursing care facilities and hospitals (Cameron, et al., 2010). The review by Cameron and colleagues (2010) found that there were positive results in fall reduction from multifactorial interventions in hospitals and also to some extent in nursing care facilities. Typically these multifactorial interventions took the form of physical therapy combined with a medical assessment such as a drug review, or a nutritional evaluation or vision examination. Interventions involving exercise proved to be effective in non-acute hospital settings but there were mixed results in nursing homes (Cameron, et al., 2010). However, in the nursing care facilities, a simple increase of Vitamin D in some residents served to reduce falls very effectively. Yet there are draw backs to this method as it is reported that Vitamin D is only effective in those who have a pre-existing deficiency and the supplements can have negative effects with links to gastrointestinal problems, an increase of calcium levels in the blood, and kidney damage (Gillespie, et al., 2009). Therefore as with most fall reduction interventions, they are not necessarily suitable for all older adults but must be used in a targeted approach on a key demographic. In a study by Clemson et al., (2004) it was suggested that their intervention was particularly effective for the male participants only, thus showing a need for specificity of target groups and the importance of tailoring interventions to the individual (Clemson, Cumming, Kendig, Swann, Heard, & Taylor, 2004). Therefore a key finding from the current literature is that effective interventions do exist, but their success may depend on finding the right intervention for the individual.

Exercise programs have been shown to have very positive results in older adults, especially those focusing on two or more of the following components; strength, balance, flexibility, or endurance (Gillespie, et al., 2009). But these positive results are dependent on the type of exercise and the length of intervention. Sherrington, Tiedemann, Fairhall, Close and Lord’s review (2011) found that the most effective exercise interventions were ideally programs which lasted for over 3 months. Sherrington and colleagues also showed that a minimum amount of 50 hours training must be undertaken to see positive falls prevention effects but those interventions who achieved this contact time in a period of less than 6 months were found to be more effective than those who spaced the training hours out over a 12 month period (Sherrington, et al., 2011). This demonstrates that the intensity of an exercise program is very important for effective results with higher intensity programs achieving better outcomes. Shorter interventions have been shown to have some positive results as long as they offer high intensity exercise and frequent contact with the target group. These interventions taking place over a shorter time period have the added benefit that they do not suffer from the problem of maintaining motivation, yet the results are dependent on intensity. Zhang, Ishikawa-Takata, Yamazaki, Morita and Ohta (2006) found Tai Chi to be an extremely effective intervention, but this was when used in a very intensive program where training sessions were held every day for 8 weeks (Zhang, Ishikawa-Takata, Yamazaki, Morita, & Ohta, 2006). Logghe et al., (2009) undertook a study using Tai Chi training and even though their course was 5 weeks longer at 13 weeks there was no reduction in falls, no improvement in balance nor any other biological measures; this was probably due to the lower intensity levels (Logghe, Zeeuwe, Verhagen, Wijnen-Sponselee, Willemsen, Bierma-Zeinstra, Van Rossum, Faber, & Koes, 2009).

Campbell and Robertson (2013) state that as the causes of most falls are multifactorial in nature, the rational solution to attempt to prevent falls would be through multifactorial methods, to address all of the varied contributing factors (Campbell & Robertson, 2013). Yet Campbell and Robertson suggest that this is made difficult by limited funding and the need to maintain older adult adherence to not just one but several streams of intervention. This is in addition to the fact that recent evidence suggests single targeted interventions are as effective as multifactorial (Campbell & Robertson, 2007; Gillespie, et al., 2009). However, in the review by Chang et al (2004) they found most support for interventions that used multifactorial risk assessments and management programmes. These interventions involved screening for and managing factors such as orthostatic blood pressure, vision, balance and gait, conducting drug reviews, assessing activities of daily living, carrying out a cognitive evaluation, reviewing environmental hazards and also screening for other factors such as depression, hearing, muscle strength and environmental lighting (Chang, et al., 2004). Yet the other reviews looking at the efficacy of multifactorial interventions showed the findings of Chang et al. (2004) were not supported as mixed results were found in the outcome measures for multifactorial interventions (Cameron, et al., 2010; Gates, et al., 2008; Gillespie, et al., 2009; Michael, et al., 2010). Cameron et al (2010) explain that the lack of a clear effect of these multifactorial interventions may stem from that to be effective they need to be delivered by a well-co-ordinated health care team with good cooperation between different specialities, and in certain high demand care facilities, this may be difficult to achieve.

One of the papers (Hendriks, Bleijlevens, Van Haastregt, Crebolder, Diederiks, Evers, Mulder, Kempen, Van Rossum, & Ruijgrok, 2008), followed on from this argument by highlighting the important fact that there may actually be discrepancies between the experimental version of the program, the ‘ideal’, and the actual implemented version (Hendriks, et al., 2008). Hendriks’ intervention (2008) improved the structure of medical assessments and increased the frequency of occupational therapist assessment for at risk older adults. This intervention was not found to be effective in any primary (number of falls) or secondary outcome measures (fear of falling, health status, quality of life) compared to the usual care group. Therefore, although a program can be well designed and carefully planned Hendriks’ argument stresses that it may not be put into practice correctly, leading to a lack of effect. This is a difficult matter to overcome as a program could be flawless in design yet the staff involved lack the enthusiasm or motivation to carry it out effectively. As stated by Gillespie et al. (2009) multifactorial interventions are *“complex interventions, and their effectiveness may be dependent on factors yet to be determined”* (Gillespie, et al., 2009). This could be linked to the findings from a study by Kato et al (2008) which served to increase staff/caregivers skills and motivation (Kato, Izumi, Shirai, Kondo, Kanda, Watanabe, Ishii, & Saito, 2008). This 6 month intervention was focussed on improving the expertise and personal motivation of caregivers on long term care wards. The intervention was found to be very effective; fall rate and injuries from falls were significantly reduced on the intervention ward compared to control ward and the caregivers showed increased self-efficacy and improved social support, leading to better care of patients. This caregiver focussed strategy could be used in combination with other interventions to achieve optimum results.

The vast majority of studies evaluated the effectiveness of their intervention using the primary outcome measure of number of falls post intervention. Some of the exercise based studies used additional primary outcome measures such as gait performance, balance, power, measure of falls risk using the Berg Balance Scale, Timed Get up and Go, quantitative movement analysis and interviews to assess psychological function and fear of falling. One of the main findings from reviewing the literature is that the primary outcome measure of number of falls post intervention may be highly problematic and, in addition, many of the other performance measures are subjective assessments based on the person carrying out the testing. Nearly all of the studies in this area appear to use number of falls post intervention as the key determinant of the success of an intervention yet this outcome measure may not be reflecting the overall efficacy of a program in more important ways. To illustrate, an intervention could have excellent efficacy in increasing participant self-confidence, reducing fear of falls and could serve to improve balance and muscle strength. Then an adverse event may occur in the person's environment and they fall due to something quite unrelated to their functioning at that time. This fall may then discount the program from being measured as a success. Alternatively, an intervention could offer nothing to encourage older adults to become more active or increase their confidence, but could simply provide a leaflet expressing the increased risks of falling as an older person. This leaflet could increase concern about falling and an older adult's quality of life may actually decrease as they become less active through a fear of falling, reducing their independence; yet there would be no reported post intervention falls. The latter intervention example is not offering anything positive for older adults yet could be deemed more effective. This demonstrates that number of falls post intervention may not be the optimum measure of effectiveness. From reading the current literature it appears that the causes of falls are still not well understood and existing outcome measures to assess whether interventions are effective are limited due to their use of number of falls post intervention as an outcome measure.

Another key area of interest when reviewing the literature was in attempting to establish the effectiveness of 'falls prevention clinics'. In the UK once an older adult has experienced a fall they are typically referred to a falls prevention clinic (also referred to as a balance and strengthening clinic) for on average an 8 to 12 week fall rehabilitation program. These programs are provided by the NHS and run by physiotherapists. They are designed to offer gentle training to strengthen muscles and improve balance, they also teach older adults about falls risk factors such as environmental hazards at home and the possible interaction effects of medications. In the current literature only 3 papers were found to specifically investigate the efficacy of UK falls clinics in improving outcomes following falls (Hill, Mossman, Stockdale, & Crome, 2000; McMurdo, Mole, & Paterson, 1997; Steadman, Donaldson, & Kalra, 2003). All of these interventions were carried out over 10 years ago thus the findings may be out of date due to the regular updates to health care strategy. The lack of recent studies into the effectiveness of falls clinics in the UK provides motivation for a proposed use of this PhD research. As yet there exists no quantitative evidence as to whether these UK clinics are effective in improving older adult balance and muscle strength, and in reducing the incidence of falls. Through meeting with the Leeds Falls Prevention Group for Occupational Therapists they highlighted the need for research into whether their falls prevention clinics are actually effective in improving older adult postural stability. Additional meetings with Leeds and Bradford based Occupational Therapists revealed they were in the process of developing their falls prevention clinics and making key decisions such as whether an 8 week or a 12 week course was more effective and possibly modifying course content, thus evidence to support this would be extremely useful. Therefore there is a definite need for a way to quantifiable assess improvements in older adults functioning after the falls clinics.

Through this literature review, several specific aims for this thesis have been developed. As shown in the literature review, the causes for falls are usually multifactorial; however deterioration in postural stability has been shown to be one of the main contributors to increased risk of falling. Therefore there could be a significant advantage for developing a quantifiable system to standardise the assessment of postural control amongst older adults to determine those experiencing difficulties. Consequently part of this PhD research is being undertaken with a final goal of developing a balance assessment system which will offer a reliable measure for appraising stability and possibly predicting older adults at risk of falling. The standard measures currently used in falls clinics are subjective with the results based on the attending health care professional’s opinion. Therefore the assessments are based on an individual’s judgment as to whether the older adult can carry out the activity to a level that is ‘good enough’. Due to the non-systematic nature of people, opinions may vary on a different day or it may prove to be an inaccurate or inconsistent way of judging. A standard measure needs to be used so if two different physiotherapists carried out the assessment, the exact same results would be found. This study plans to develop a quantitative measure that will detect postural instability and highlight those persons at risk of a fall before the event occurs. If people can be identified as high risk for falls they can receive preventative advice and training before a fall occurs, so protecting from injury and damage to self-confidence and helping people to remain active and independent for longer. As well as being used to quantitatively assess whether falls clinics are improving stability, the system could be used to develop improvement targets for older adults to work towards each week when undertaking a balance or muscle strengthening class.

In beginning the design process of developing a portable system to assess potential balance impairment in older adults, it was decided that the system must fulfil certain requirements. One of the most important criteria is the need for flexibility to allow the undertaking of stability assessments under different conditions, some of which may by design serve to destabilise the individual. Challenging the postural control system of older adults is of the utmost importance in this research to ensure thorough investigation. This is explained further by Horak et al., (2007):

"a *useful experimental approach to understanding neural control of posture is the disrupting of stable equilibrium and the recording of behavioural reactions to these perturbations*"

In the majority of everyday situations an older adult's postural control system can appear to be functioning at an acceptable level with no risk of falling, even from demanding environmental perturbations. However it is hypothesized that for certain individuals under specific circumstances, flaws in the postural control system can be revealed and stability can be compromised. These types of circumstances were mentioned previously in this chapter and encompass situations where there is conflicting sensory information or challenging dual tasking conditions (Woollacott, et al., 1986). For example, the system is challenged in situations of degraded visual information (Black & Wood, 2005; Lord, 2006) such as when there is low lighting. Additionally, the system is placed under pressure when an older adult's attention is involved in a secondary activity, for example during a concurrent visual or visuomotor task, especially a cognitively demanding activity (Huxhold, et al., 2006; Vuillerme, et al., 2000). These types of situations can compromise stability within the postural control system and increase the risk of falling especially in situations of high environmental pressure (Chapters 5 and 6). The conditions that will be explored for causing detriments to postural stability are based on previous research (Andersson, et al., 1998; Brauer, et al., 2001; Hsu, et al., 2012) but the current work will go further in exploring more precisely the exact circumstances that can compromise stability.

Additionally this work will be investigating a novel research area through looking into older adults' potential fear of falling through their ability to accurately assess how stable they feel compared to how stable the balance assessment system measures them to be. This area has not currently been researched thoroughly but it is vital for older adults to be able to accurately judge their levels of postural control in order to make an accurate assessment of their falls risk (Chapter 6). In a more general sense there are many reasons why older adults need to make an accurate assessment of their personal falls risk. In addition to a fear of falling, inaccurate assessments of fall risk may be based on several beliefs. Some older adults believe that although falls prevention is useful for others, it is not personally relevant for them as they are 'not old' or not going to benefit from it (Braun 1998). They may also believe that falls are not preventable and there is nothing that can be done to stop them from happening (Hughes, van Beurden et al. 2008). Other older adults may be reluctant to ask for help when it comes to issues concerning their perceived frailty, such as in the case of falls prevention (Snodgrass, Rivett et al. 2005). However, an accurate assessment of personal stability is vital to avoid the further risks proposed by dangerous situations, and conversely for those who are fearful but physically able with satisfactory balance abilities to not restrict their activities. For those older adults who have fallen and are attending a falls rehabilitation clinic it is important for their personal motivation and progress to be able to accurately monitor their improvements in their stability. Currently there exists some research investigating fear of falls, but there is still much to investigate in this area.

1.3 Thesis structure

This thesis aims to use different research methods to examine the complex area of older adult falls. A range of research themes will be investigated using a mixed methodology, designed to firstly establish the background and scale of the issue of falls, and then focus on experimental research methods to increase understanding of the fundamental physiological effects of ageing on fall risk. This will be done through developing a system to assess potential balance impairments in older adults under a range of conditions purposefully designed to challenge the postural control system and potentially cause instability. Attitudes towards fear of falling will be gathered through assessments into awareness of balance impairments and then compared to actual postural stability to provide an insight into concern surrounding falls risk.

The thesis will be structured through a series of experimental chapters starting with a review of falls in care homes then building up to more exploratory research, with each subsequent chapter advancing on the previous chapter's methods and furthering the depth of investigation.

Following from the introduction to the research area in this chapter, Chapter 2 will present the findings from the review of falls in care homes. This chapter offers an insight into the actual scale of falls across 30 care homes in the North of England and the serious consequences of these falls. Patterns in falls report data are analysed to highlight the highest risk times and locations for falls, especially those falls leading to the most serious injuries. The incident reports demonstrate the likelihood that in many of these homes a large proportion of falls go unreported. The findings show there are vast differences in standards of reporting across these homes and confirm the fact that the number of falls reported is not necessarily an appropriate measure to use to assess good standards of care; homes with the highest numbers of falls may reflect excellent reporting practices rather than poor standards of care. In line with arguments advanced in Chapter 1, the number of falls is an ineffective measure to use to assess care quality and instead care home managers should be focussing on injury from falls and reducing the time a resident was left on ground following a fall. The results from Chapter 2 have been fed back to the care homes and should lead to improvements in reporting practices and standards of care.

Chapter 3 presents early exploratory work into the suitability of equipment to provide objective measures of motor skills and postural stability. Previous research and practical work assessing balance and coordination have relied on assessments such as the Berg Balance scale (Berg et al., 1992) or the Motor Skills Inventory (Werder and Bruininks, 1988). These measures are dependent on the individual carrying out the assessment and are therefore open to inter-rater variation. Through using the quantitative measures implemented in this chapter, each person is scored on their task performance equally. This chapter presents two exploratory studies which serve to assess the suitability of the equipment and proposed methodology. The first is with young adults only and the second involves a comparison between young and older adults. After testing, a review was undertaken and methodological improvements were made, especially in regards for suitability for older adults.

Chapter 4 explores the potential link between balance development in children and balance deterioration in older adults. Balance was assessed in three age groups of children (between ages 5 to 11 years) to learn more about the postural control system and see whether the mechanisms that develop to assist balance as we mature are similar to the mechanism that decline as we age. Clear differences were found in postural control between the children of different age and the results showed that the youngest children seem to display a similar reliance on vision to maintain stability as has been found in older adults. The study with the developmental age group served to pilot a new piece of testing equipment, the Wii balance board, which proved to be extremely accurate in detecting differences in postural stability between the age groups.

In Chapter 5 a large experimental study of 30 young and 30 older adults builds upon the previous chapters' findings and methodological improvements. The result is a comprehensive study using the Wii balance board to look into the effects on postural stability from several factors; different standing stances, visual state conditions, the effect of a visual task and the effect of a visuomotor task. Significant differences in postural stability were found between the young and older adult age groups, but these are especially pronounced whilst undertaking a concurrent visuomotor task where the older adults experienced significantly impaired balance. The older adults' fear of falling was assessed using an established scale (FES-I) but the results were inconclusive.

Chapter 6 incorporates a further factor for investigation into this research through examining a key element of falls prevention in older adults; self-awareness of stability. An accurate assessment of risk by older adults is essential for reducing their likelihood of a fall or conversely for not limiting their activities due to an unfounded fear of falling. This chapter builds upon the inconclusive fear of falling work carried out in Chapter 5 by introducing a metacognitive scale to establish how aware people are of their own stability. Increasingly challenging testing conditions are undertaken in this study and the results show that older adults have significantly impaired postural control compared to young adults. Of most interest however is the awareness of this impaired postural control because in certain conditions older adults overestimate their stability to a very great extent, potentially leading to a scenario of high falls risk. The older adult participants also significantly overestimated their performance on a memory task and a manual target tracking task whilst the young underestimated, showing consistent clear differences between these age groups.

In Chapter 7 a general discussion of the thesis is presented. This final chapter reviews all of the key findings from the preceding chapters and the novel impact this work has on the field of falls research is evaluated. Additionally, the limitations of the research within this thesis are discussed alongside future directions for this work.

1.4 Original contributions to research area

This thesis aims to contribute to the area of falls research through several novel streams of research. The analysis on the reporting practices of UK care homes is highly original work as no previous research has yet been undertaken into improving accident reports outside NHS institutions. Additionally this work serves to reveal the reality of number of falls per year in care homes, as due to poor reporting practices it is believed that many more falls may occur than have previously been considered. The findings are of practical use as they have been disseminated to the care home management teams. A second original area of this research is in the development of a balance assessment system to ascertain quantitative measures of older adults' postural stability. This assessment system is novel and improves upon the previously used subjective measures of whether an individual appears to be at risk of falling. The research determining which circumstances result in compromised performance of older adults' postural control systems resulting in reduced stability adds to the previous existing literature and help to clarify exactly what effects are observed from placing older adults under these challenging circumstances. The final experimental chapter details an original investigation designed to ascertain if older adults are aware of potential balance impairments and how this may relate to a fear of falling. This has practical uses in real world applications through encouraging older adults to be aware of situations where they may experience decreased postural stability and to strive to make accurate assessments of their abilities.

2 An analysis of falls reporting in care homes

2.1 Introduction

This chapter aims to provide an analysis of the issue of older adult falls in UK care homes. This will be done through a retrospective analysis of 12 months of incident reports collated from 30 care homes. According to care home guidelines, all adverse events affecting either residents or the staff within care homes should be reported. For this analysis, the care home staff recorded adverse events within their homes according to usual practice from January 2011 to December 2011.

Through the reporting of adverse events in health care settings the subsequent data produced can be used to promote learning, inspire change, and improve future working practices. Outcomes identified through the analysis of adverse event reports can potentially be used as a tool to identify high risk situations and develop preventative protocols or structures to design out system errors. The focus on the circumstances and consequences surrounding reported falls in the analysis of adverse event reports in care homes may provide valuable lessons in falls prevention through identifying patterns in the data. These findings could then be transferred into wider environments such as other care home groups or hospital wards.

This chapter has three main research aims:

1. To determine the scale of the problem of older adult falls in a sample of UK care homes
2. To establish patterns in the data to identify high risk situations for falls, especially for those leading to serious injury
3. To investigate if a relationship exists between the number of reported falls and the quality of reporting within care homes

The outcomes of these analyses have been disseminated to the care home management group. It is hoped the feedback may improve future reporting practices and help reduce fall related injuries within their homes. If possible, the findings will also be translated to more general applications within the field of elderly care.

2.1.1 Theoretical background to the study of falls reports

The disproportionally high numbers of injurious falls experienced by older adults pose a serious clinical problem for all health services (Sterling, et al., 2001). This is due in part to the prolonged hospital stays and cost of treatment associated with the consequences of falls in older adults (Scuffham, et al., 2003). Falls can also have a devastating effect on the individual, potentially leading to reduced confidence, mobility and quality of life (Skelton & Beyer, 2003). Amongst the older adult population, it has been well established that the most frequent numbers of falls are within those living in care institutions (Rubenstein, 2006). A review of reports investigating falls established that on average older adults living in care homes fall three times as often as those living in the community (Rubenstein, Josephson, & Robbins, 1994). These significantly higher reported numbers are due to the increased frailty of older adults in care homes but also due to the more accurate reporting of falls within care institutions compared to falls which often go unreported in the community (Robert G Cumming, et al., 1990; Cummings, et al., 1988). However, despite the probable reasons for differences in numbers of reported falls, the existing literature indicates that falls amongst older adults living in care institutions result in significantly more serious consequences, with a disproportionally higher incidence of hip fractures among care home residents compared to community-dwelling older adults and increased mortality rates after hip fracture (Rhymes & Jaeger, 1988; Rubenstein, 2006). This is partly due to the increased frailty of those in care homes and also because one of the main predictors of care home admission is repeated falls and postural instability (Salkeld, Cameron, Cumming, Easter, Seymour, Kurrle, & Quine, 2000; Tinetti, et al., 1997). In summary, those living in care homes already have a high risk of falling but additionally they will suffer more severe consequences when they do fall, thus falls prevention in these institutions should be a top priority for investigation.

2.1.1.1 Incidence of falls in care homes

At present, the level of existing research in UK care homes regarding falls and the quality of incident reporting is inadequate. One of the few pieces of quantitative evidence from the UK is a small scale cohort study investigating accident prevention in selected nursing homes in the North East of England. This study found that *each* resident fell on average between two to six times a year (Dickson & Woodward, 2000). This figure appears to be worryingly high and it would be beneficial to have more UK data for comparison. There are studies from the United States which estimate that between 29% (Kiely, Kiel, Burrows, & Lipsitz, 1998) to 39% (French, Werner, Campbell, Powell-Cope, Nelson, Rubenstein, Bulat, & Spehar, 2007) of nursing home residents had a fall over a twelve month period. These figures suggest a significantly lower number of falls in nursing homes than the UK based study and it highlights the need for more research to be done to establish an accurate range.

Though reports of falls data in UK care homes are limited there are figures available from the NHS concerning falls within a hospital settings. These figures are collated from NHS incident reports which are published by the National Patient Safety Agency (NPSA). A standardised value is used throughout the reports to allow for comparisons of falls rates between organisations of varying size and activity. The value they use is the average number of falls 'per thousand bed days' (National Patient Safety Agency, 2007). This is a simple calculation which works out the total number of patient falls divided by the total number of occupied bed days, thus allowing comparisons independent of ward size or turnover. The incident reports show that the number of falls varies on the basis of hospital type; as few as 4.9 falls per thousand bed days were reported in acute hospitals (ranging between 0.2 to 11.4 falls per thousand bed days across different acute wards), whereas there were up to 8.4 falls per thousand bed days in community hospitals (ranging from 0.8 to 21.5 falls in the reporting hospitals) (National Patient Safety Agency, 2007). The higher numbers in the community hospitals were explained by the NPSA report as these wards had older and less mobile patients who are inclined to experience an increased number of falls. The standardised method of reporting used by the NPSA provides a potentially useful method that could be applied to the evaluation of falls within a care home setting to allow accurate comparisons.

A comprehensive review of eighteen epidemiological studies documenting the injuries resulting from falls in US care homes (Rubenstein, et al., 1994) determined that on average only 4% of falls resulted in bone fractures, with a range in the reviewed studies from 1% to 10%. Other serious injuries such as head wounds, soft tissue damage and lacerations were reported to occur in an average of 11% of falls, with a range of 1% to 36%. The results from this review show that the majority of falls do not necessarily end in serious physical injury. The review is of particular interest as it demonstrates the wide disparities that exist between the numbers of reported injury outcomes of care home falls. It highlights the need for accurate reporting as the variation between the numbers of reported falls is substantial with some homes reporting only 1% of falls ending in serious injury, while in others it is as high as 36%. This range in values may indicate significant underreporting of falls in certain institutions, especially for those falls that do not result in an injury.

2.1.1.2 The quality of fall reporting in care homes

Research has been published based on the incident reporting practices in a range of different speciality NHS hospitals. Within this work there is specific focus on reporting of falls in acute and community hospitals, with community hospitals showing a higher incidence of reported falls due to the generally more frail, less mobile nature of the patients (National Patient Safety Agency, 2007). Yet there is limited literature on the incident reporting practices of falls in care homes, despite the fact that many patient admissions are made due to repeated falls and poor postural stability (Tinetti, et al., 1997). Therefore a key focus for research needs to be on the quality of the reports being produced by the care home staff.

It has been argued that there is a great deal to learn from in depth analysis of incident reports (Vincent, 2003). A seminal report concerning the need to learn more effectively from adverse events and near misses within the NHS, "An Organisation With a Memory" (Department of Health Expert Group, 2000) stated that it was vital to ensure past errors provide an opportunity for learning and are utilised to reduce the risk to patients in the future from preventable events. The need to report and learn from adverse events is extremely important; however it is acknowledged that many barriers exist to prevent effective reporting. These are factors such as the time taken to complete the reports and the perceived utility of doing so (M. J. Kingston, Evans, Smith, & Berry, 2004; Shojania, 2008). There are also the negative perceptions associated with reporting through concerns of being held personally accountable for mistakes or "whistle blowing" on colleagues errors (Firtko & Jackson, 2005). These are factors which must be dealt with and overcome to enable effective reporting practices.

The previously mentioned NPSA report states that the institutions which should cause the most concern are not the ones reporting the most adverse events, but the ones reporting the fewest (National Patient Safety Agency, 2007). An institution with low numbers of falls reports may be demonstrating problems with staff reporting practices which could lead to poor data quality. Institutions with high reporting rates may simply be reflecting conscientious reporting practices where every adverse event or near miss is being recognised. This type of reporting should be encouraged as near miss events can inform future practice as they show where an adverse event could have happened if it had not been prevented in time. Near miss events have the benefit of providing lessons without issues related to the injury of a patient or resident. Changes can be implemented to ensure the event does not occur next time and no one has to suffer any negative consequences to provide a learning scenario.

2.1.2 Objectives and rational for undertaking the analysis

By undertaking this analysis, it is hoped any patterns and trends within the falls report data may be identified and utilised to determine high risk situations for falls and possibly prevent future falls for residents living in care homes. This is especially important for identifying under what circumstances falls with the most serious consequences occur, such as falls ending in hip fracture and other injury requiring hospitalisation. Any key findings can then be disseminated back to the care home management team and may provide practical steps by which they can enhance their incident reporting system. Feeding back the findings may make it easier for the care home managers to reduce future adverse events, for example by directing their existing resources to the highest risk areas and times or through adapting the staff work patterns to focus their efforts on preventing the most serious falls.

The scale of the issue of falls in care homes will also be investigated. This research will attempt to establish an accurate average value of the number of falls in the 30 care homes involved. However, this figure is based purely on the monthly incident reports produced by the care homes. As previously mentioned, existing literature suggests there is a wide disparity in the numbers of falls reported for older adults living in care homes, thus this work will also document the report quality to establish if any links exist between the number of falls care homes are reporting and the quality of their reports.

2.2 Methods

2.2.1 Access to care home falls reports

The data for this study was accessed through contacting a management group of 40 care homes extended across 7 counties in the North of England. The 40 homes were a mix of care specialties; some specifically designed for residents with dementia, some were for residents without dementia and other homes catered for both residents with and without dementia.

The management group was originally approached to ask permission to speak to a small proportion of their care homes about falls prevention and to offer the residents the chance to participate in a short study exploring their balance capabilities. The management team selected five of their ‘worst performing’ care homes for me to visit as they were deemed as being of ‘significant concern’ due to their high numbers of reported falls. On visiting the homes it was quickly decided that the residents were not able to complete the testing due to their level of frailty and poor mobility. This initially disappointing finding was reported back to the management team who expressed their continuing interest to be involved in any work dealing with falls prevention as they felt the high levels of falls in their homes was a serious issue. Consequently they granted access for me to review all of their incident reports recorded in 2011 to ascertain if there were any findings of interest that could be identified from the reports and used to prevent future falls in their homes.

Each of their 40 care homes operates under a standard policy which dictates the expectation of a thorough accident report to be produced at the end of each month. Procedures are in place to ensure all staff members are aware they should report every adverse event that occurs within the home. The incident reporting form is in the format of a spread sheet with specific headings for each section to ensure the key information from each adverse event is gathered. This format has been found to be preferable from the systems that exist in many care homes where staff must complete a semi-structured narrative style report which requires an open ended summary of the event. This lack of structure can lead to the omission of vital information from being recorded about the event (Wagner, Capezuti, Clark, Parmelee, & Ouslander, 2008).

When staff members complete a report of an adverse event they must first select what type of event is being documented; this is under the heading 'Accident Type'. There are four possible options; 'Accident', 'Incident', 'Fall' or 'Near Miss'. According to the care home groups' policies and procedures manual for the correct reporting and recording of accidents within the homes, there are well defined categorisations of the four different types of adverse events;

Accident

Reportable event that results in injury to a resident, visitor or staff member

Incident

Reportable event of an untoward nature, such as resident conflict, a safeguarding event, police involvement, disruption of services

Near Miss

Reportable event that did not result in injury to a resident, but had the potential to do so, such as a vulnerable resident leaving the home unseen and returning/being returned with no harm resulting, equipment damage that has the potential to cause harm

Fall

Reportable event of seen or unseen resident fall

From these definitions staff must decide exactly what events are categorised into which areas. Staff must then complete other basic information such as 'Home Name', 'Date' and 'Time of event', with a choice of times between 8 am - 12 Noon, 12 Noon- 4pm, 4pm- 8pm, 8pm- 12 Midnight, 12 Midnight- 4am and 4am- 8 am. The staff member reporting must also identify themselves through their initials and document who has been involved in the adverse event, 'Resident', 'Staff' or 'Visitor'. There is the option to provide further detail if an adverse event resulted in emergency medical assistance requiring Accident and Emergency in hospital then a 'Yes' should be selected in the 'A & E' column. If the event was potentially serious the staff must report whether a 'Reporting of Injuries, Diseases and Dangerous Occurrences Regulations' (RIDDOR) report is required or whether a breach of safety 'Regulation 18' or the 'Safeguarding' practices has occurred where an external investigation is needed. These three outcomes are recorded with a simple 'Yes' or 'No' selection in the appropriate column; 'RIDDOR', 'REG 18', 'Safeguarding'. Details of where the adverse event occurred are recorded in a free hand entry box entitled, 'Location'. There are two final sections where open ended descriptions are allowed, to encourage as much detail as required. These sections involve a detailed description of the adverse event, under 'AINM Description' (Accident, Incident, Near Miss description) and then there is a final column for residents who fall regularly to describe what interventions have been put in place to prevent future adverse events, 'Extra input implemented for residents who have sustained 2 or more falls'.

At the end of each month the completed reports of adverse events are sent from each care home to the head office where the management group reviews the reports for any 'abnormalities'. According to current procedure within the management group, homes that are found to report particularly high levels of falls are identified as in need of investigation to look into any potential malpractice within the homes that may be causing these high levels of falls. The homes with high levels of falls are then investigated to offer explanations for the above average levels of reported falls and are encouraged to implement changes. If necessary the management group will also contact the Care Quality Commission (CQC), a group that maintains standards for older adult care facilities.

2.2.2 Exclusion of homes for incomplete reports

Out of the total of 40 care homes under the management group, 10 homes were excluded from the detailed analysis. These homes were excluded as they demonstrated a consistent record of incomplete reporting over the twelve month period. It was decided that any homes that were missing four or more months of incident reports over the year should be excluded. The number of months of missing incident reports from each of these homes ranged from a minimum of 4 months up to a maximum of 11 months, with the average as 5.7 months missing from these 10 homes. Due to these incomplete reports, only 30 homes were used for the final analysis. These 30 homes offered a total bed space for 1325 older adults per month between them, thus numbers for the report analysis were still high even after excluding 10 homes.

The monthly reports used in this research were accessed retrospectively at the end of the year of normal reporting practices, thus there was no effect on staff reporting procedure from the involvement in research. The management group stated that all staff received the same training and were briefed that *any* adverse events occurring in the care homes should be recorded by staff members.

2.3 Results

The results of the analysis of 12 months of falls reports in care homes is based on the format of the NPSA report, “Slips trips and falls in hospital: The third report from the Patient Safety Observatory” (National Patient Safety Agency, 2007). This report outlines the significant impact and cost of falls in hospital and presents a detailed summary of an analysis of over 200,000 reported falls logged in the NPSA’s National Reporting and Learning System (NRLS) from September 2005 to August 2006. The study is reported to be based on the largest dataset of falls in hospitals worldwide. The NPSA report documents the causes and circumstances of falls to determine ways to prevent them and reduce injury. The structure of the current analysis of fall reports in 30 care homes attempts to replicate the format of the 2007 NPSA report.

2.3.1 Overall falls report data

Over the 12 month data collection period, 7012 adverse events were reported across the 30 care homes. These 7012 events were categorised by the staff member making the report on initial data entry as either, ‘incident’, ‘accident’, ‘fall’, or ‘near miss’.

Within the policies and procedures manual on the correct reporting and recording of adverse events within the care homes, the manual states that all events will be treated seriously, no matter how minor they may appear at the time. The manual also clearly documents the reasons and the benefits of accident reporting.

2.3.1.1 Number of falls as a proportion of all adverse events

An assessment of the 7012 incident reports over the 12 month period shows that falls represent the greatest proportion of all events in the care homes (Figure 2.1). Falls account for 64% of all adverse events, with a total of **4494** falls being reported in 2011. The other reported categories of 'incident' (22%), 'accident' (12%) and 'near miss' (2%) represented the remaining 36% of the total reports made.

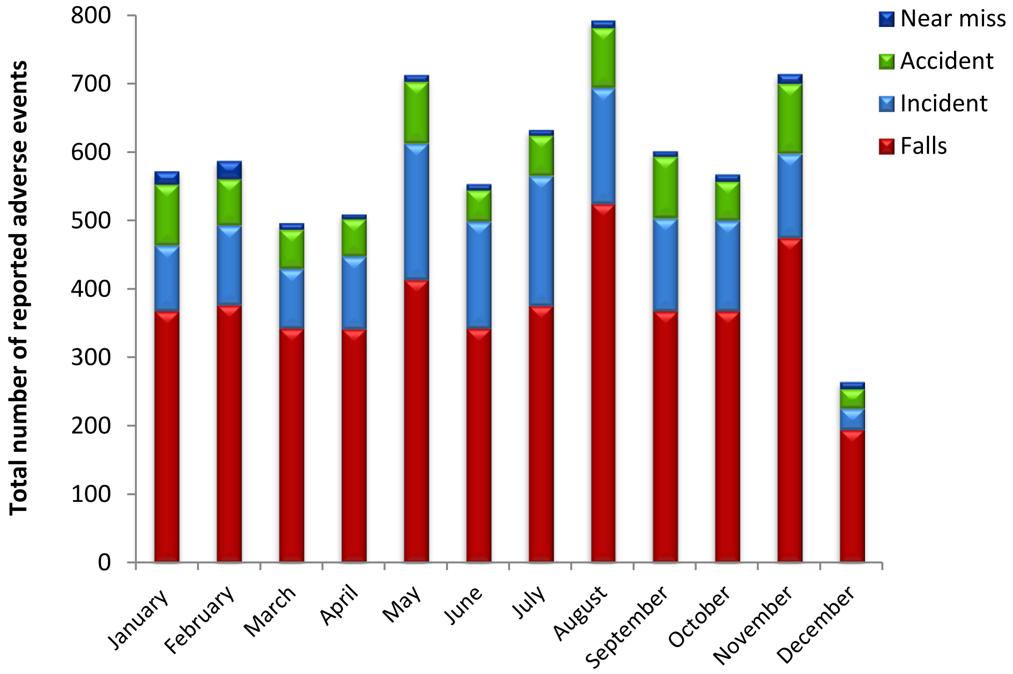


Figure 2.1 The proportions of all adverse events in the care homes

The proportion of reported falls (64%) compared to the overall total number of adverse events in the care homes appears to be broadly in line with a similar analysis carried out on incident reporting within hospitals (Healey & Oliver, 2006). This report noted that from 2004-2005, 60% of all reported adverse events within UK hospitals were categorised as falls. The 30 care homes' reports were further scrutinised and on closer inspection it was revealed that potentially an even higher proportion of the total adverse events were falls. Through re-coding of the 7012 descriptions, it was found that a further 385 adverse events (5.5%) reported as 'incident' or 'accident' were actually falls and should have been categorised accordingly.

This is illustrated through the following example where a report entry, clearly describing a fall, has been categorised as an ‘accident’;

> *“JK took herself to the bathroom, lost her balance and fell, she banged her elbow - skin tear to R arm & bruise”*

Another example of an event categorised as an ‘accident’ within the reports;

> *“WW was found on his bedroom floor, he said he had fallen out of bed, unwitnessed no apparent injuries”*

These two entries even state within the description that the residents had fallen. Within the monthly reports, there are many more examples of incident or accident reports which on closer inspection document a fall. In cases where there was a sufficient description of an adverse event such as the ones shown above, it is possible to see that errors have been made in the categorisation. Yet there were many further entries where no description of the adverse event was made, thus wrongly categorised adverse events could potentially mean there are many more falls but the lack of adequate data prevents recoding. Therefore the total proportion of falls may actually be significantly higher than the 64% reported. However it was not deemed appropriate to calculate a new, possibly more accurate total for all the falls reports as some of the reports were lacking sufficient details to enable confident re-categorisation. Additionally there could have been reasons behind coding these events as incident or accident, despite the seemingly incorrect categorisation based on the description, thus the original value of 64% is maintained.

In addition to the potential incorrect categorisation of falls as ‘incidents’ or ‘accidents’, the category of ‘near miss’ events were examined more closely. As stated earlier in this work and in the care homes’ definition of categories, near miss events are vital to reporting and learning as they highlight an area for concern where potential future adverse events could occur, but no harm has yet occurred.

On closer inspection of the monthly reports it was found that 96% of all of the reported ‘near miss’ events were wrongly categorised as such (Figure 2.2). Only 4% actually detailed a correctly defined near miss event. Nearly all of the near miss report entries described events ending in actual physical harm.

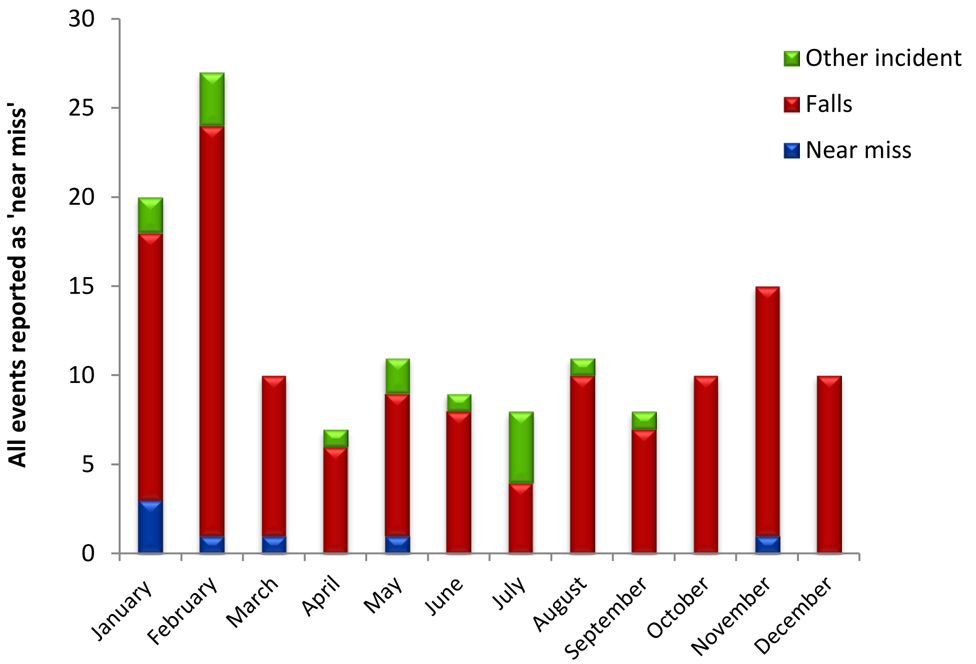


Figure 2.2 Incorrectly coded near miss events re-categorised as falls and other incidents

The majority of wrongly categorised near miss entries described a fall (87%); the others described harmful adverse events not related to falls (13%). The typical types of entries categorised as near miss events were entries such as;

“ES was heard shouting from room 3, when the carer went to investigate ES had slipped off her bed onto the floor. ES was checked over, appeared ok except her spine was slightly red and her neck hurt a little but could move it without any problems”

And;

“At 8.15am BH buzzer went off and when staff entered her room they found her on the floor at the side of her bed. Staff checked her over for injuries and found a skin tear to her R elbow she was assisted onto her commode and the district nurse was called to attend to the skin tear”

This highlights the inaccuracies within the reporting system and shows the need for careful interpretation of the report data. It demonstrates the necessity to train staff in exactly what a near miss event is and why these events are important to report. It also shows again that the proportion of all adverse events reported as falls is likely to be more than 64% initially reported.

2.3.1.2 Reported injury outcomes following a fall

The care home reports do not specifically require staff members to record the consequences regarding any injuries following a fall. If the fall is serious and requires emergency medical attention from paramedics or attendance to hospital then there is an option within the report to select 'Yes'; A & E or emergency medical attention from paramedics was required. However, if the fall resulted in no injury or a minor injury then this information is not explicitly requested within the report. Yet these details are important and interesting to record to determine what the outcome of a fall was within a care home setting; no injury, minor injury or serious injury.

Consequently, to determine this information every report was re-coded by the researcher based on the injury description provided by the staff members at the time of reporting the event. As this information was not explicitly requested within the report there is a small proportion of the entries where no details of injuries were available; these are classified as 'No Information'. Where an injury was reported the severity or type was sometimes unclear, thus it was not possible to categorise further into the type of minor injury as other studies have done, (Rubenstein, et al., 1994).

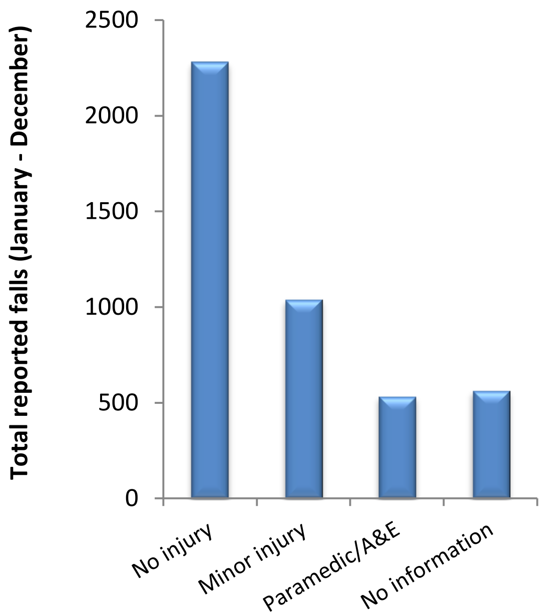


Figure 2.3 Total number of falls according to reported injury outcomes

The re-coded injury outcome data from the twelve month reporting period was divided into four distinct categories (Figure 2.3). The majority of falls were reported as resulting in no injury to the resident (51%). Falls ending in minor injury accounted for just under a quarter of the reported falls (24%), with injuries such as bruising, minor skin tears, red marks on skin and localised impact area pains being listed under this category. As previously mentioned, this category could not be any more explicit as to the type of minor injuries sustained as many report entries had a very limited amount of detail describing the injury. No information for injury consequences for the resident was recorded in 13% of the cases. Of the total reported falls, 12% documented falls with very serious injuries where emergency medical assistance was required, either via paramedics attending the scene or the person being taken into hospital (A & E) immediately after the fall.

This category was difficult to code as many descriptions did not mention any serious injury being sustained, but in the specific section of the report entitled ‘A & E’, ‘Yes’ was recorded. Conversely, in other report entries, the specific ‘A & E’ section was left blank, yet on reading the description of the fall, it clearly stated that the paramedics had been called and the resident had been hospitalised. In Figure 2.3 only the falls which reported ‘Yes’ in the specific A & E section are shown. However Figure 2.4 shows the results from re-coding the serious injury report entries including falls where the A & E section was not completed as ‘Yes’, yet a clear description of emergency medical attention being required was described. The number of inaccuracies in the A & E data across the twelve month reporting period is clearly shown in Figure 2.4.

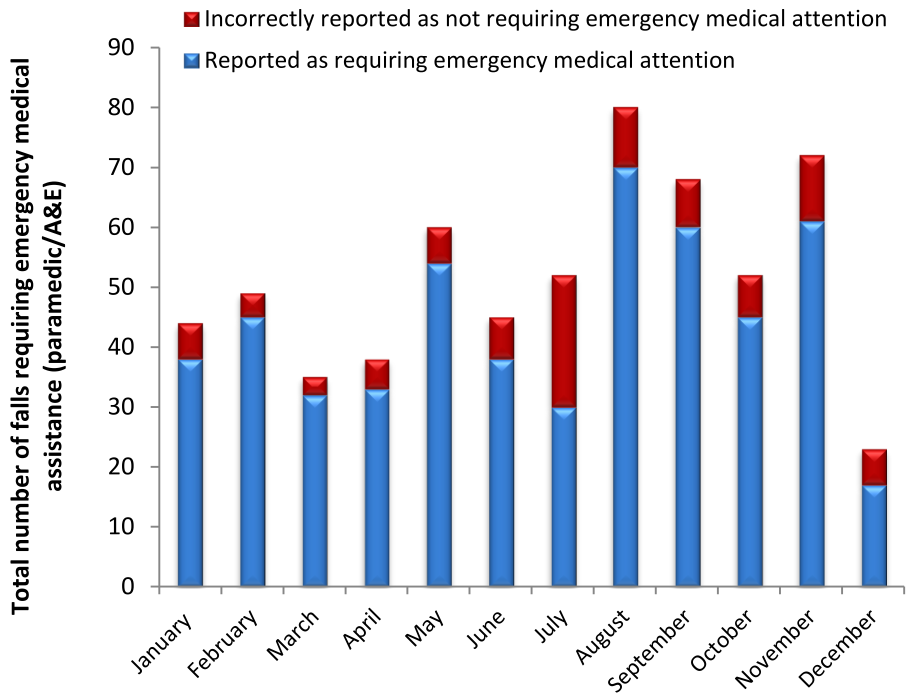


Figure 2.4 Total number of serious injury falls requiring emergency medical assistance correctly and incorrectly reported

Over the 12 month reporting period, 95 separate events were incorrectly reported as not requiring emergency medical attention; this equates to 15% of all serious injury falls. These 95 inaccurately reported falls all required emergency medical assistance yet this was only evident from reading the individual report descriptions. It is highly unlikely that the management group who compile the end of month reports have the resources to review every adverse event description. The practical option is to quickly sort the data according to whether A & E 'Yes' or 'No' had been selected on reporting of the event. Therefore they could be missing important information simply through the basic act of mislabelling events. Additionally this inconsistency raises further concerns for reports where no information on injury is recorded as these could actually be falls ending in minor or serious injury, but no report information is available to be able to detect the error.

2.3.1.3 Proportion of falls witnessed by staff

Within the current format of the care home reports there is no specific section for members of staff to record if falls were witnessed or not witnessed. Subsequently 16% of all falls did not have any recorded information as to whether they were witnessed by staff (Figure 2.5). Of the remaining falls that did record information, 74% were reported as not witnessed and only 10% of falls were witnessed.

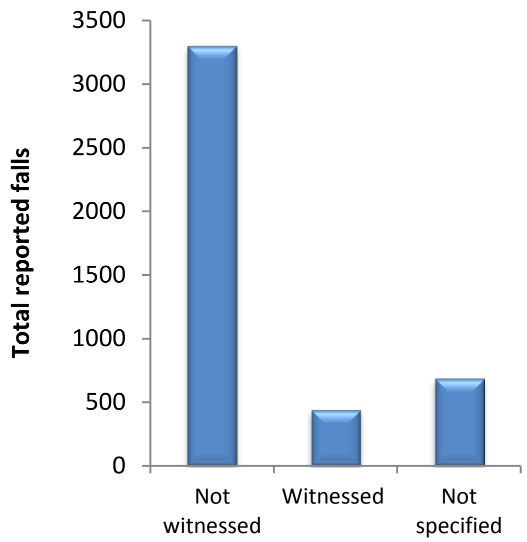


Figure 2.5 Total number of falls according to whether witnessed or not witnessed by staff

The NPSA report on falls in hospitals (National Patient Safety Agency, 2007) states that even when members of staff are in the vicinity to witness a patient fall, they are unlikely to be able to prevent the person from falling. The report states that, within the NHS, staff not witnessing falls is in no way linked to inappropriate care; staff face no personal accountability or disciplinary action from not witnessing a fall. The same rationale of accountability exists within this care home group therefore to report that a fall was not witnessed does not result in negative consequences for staff. This rationale is understandable as it is impractical to contemplate staff can be present when every fall occurs. However, despite staff members not being able to witness every fall, there can be serious consequences for the resident if there is an extended period between the time of a fall and the time to be found. If left unable to get up for an extended period there is increased risk of injuries worsening and prolonged recovery time (Tinetti, et al., 1993a). In fact within the reports, the majority of the entries for not witnessed falls began their description with “resident found on floor”, but without an estimation of how long they could have been there before being discovered. It could potentially highlight the problem that when some older adults fall they are unable to get up unaided, and speed of recovery from a fall can be dependent on length of time spent on the floor (Fleming, et al., 2008) thus they need to be located as quickly as possible. As a result it could be beneficial to add a further section to the falls reports where staff members could report how long the person had spent on the floor before being found, as well as a section to specifically state if a fall was witnessed or not. The time period spent on the floor may not always be possible to report to an exacting level of accuracy but it could serve to draw attention to staff members the importance of finding people as soon as possible following a fall. Additionally the information as to whether a fall was witnessed could be used in future to compare to other information from the reports such as the time of fall and the location. Staff members could then implement extra checks on residents for the peak time and locations for these falls that are not witnessed to reduce the possible amount of time residents spent on the floor following a fall.

2.3.1.4 Time of day of falls

The time of day of reported falls is based on data from March to December 2011 only. Before March 2011 the falls report format split time of day into two time periods; 8am-8pm, and 8pm-8am, therefore January and February could not be included in the full analysis. From March 2011 onwards the falls report format improved to request more details on time of fall, splitting the day into 6 sections; 4am-8am, 8am-12pm, 12pm-4pm, 4pm-8pm, 12am-4am. The change of report format to include extra detail on time of day highlights the effort made by the management group to improve their reporting system. However, there is still scope for even more detail to be recorded. As stated by the NPSA report (National Patient Safety Agency, 2007) as the time of day of the fall should be reported within a one hour period, rather than the four hours currently used by the care home group. This way more useful trends can be observed related to precise daily activities that occur at certain and set times of day. The four hour time period currently used allows many daily activities to be captured under the time window, therefore a more accurate one hour report would increase accuracy and conclusions could be drawn as to exactly which daily activities are high risk. As it is, the current falls reporting scheme splits the time of day into 4 hour sections, as shown on Figure 2.6.

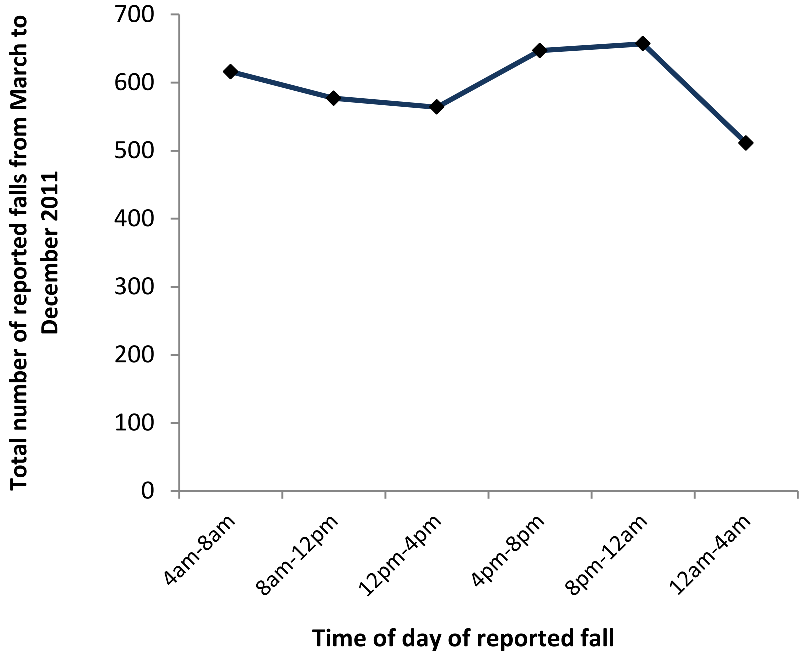


Figure 2.6 The time of reported falls, using data from March to December 2011

There appears to be no difference between each time period in the reported number of falls. This is an interesting finding as one may expect that the differing levels of activity within the homes throughout the day would result in significantly different numbers of falls across the time periods, especially at night time when residents would be expected to be sleeping (although there is a slight drop in the number of falls between 12am and 4 am).

2.3.1.5 Location of falls

The reporting system explicitly requires the location of where an adverse event occurred to be documented. Figure 2.7 shows the data for falls according to their reported location.

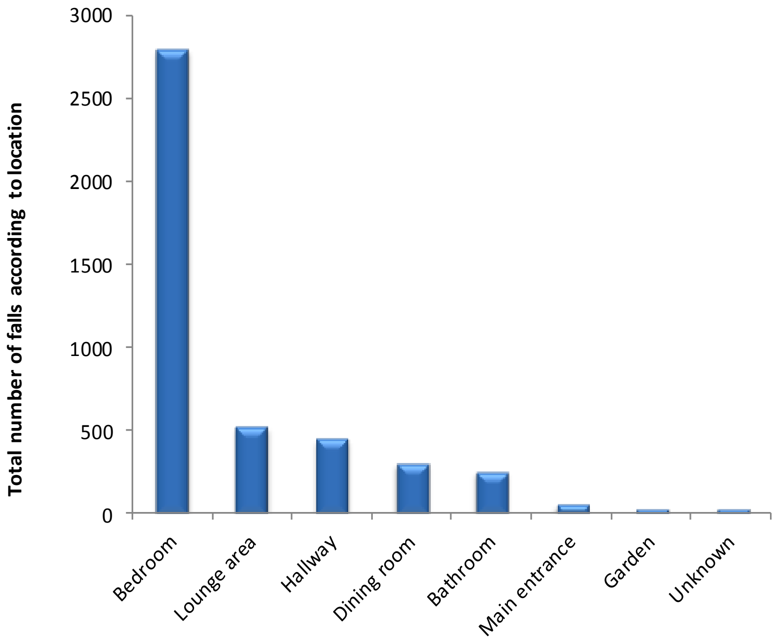


Figure 2.7 The location of all reported falls

Through reviewing falls according to their reported location, it is readily apparent that the significant majority of falls occurred in the residents' bedrooms (63%). Considerably fewer falls were reported in the communal areas such as the residents' lounge (12%), the corridors (10%) and the dining room (7%). A small percentage of falls were reported to have occurred in the private bathrooms (6%) and even less were reported as occurring in the garden (0.6%) or an unspecified/unknown location (0.5%). None of the reports were missing an entry for location information. As the majority of falls occurred in the bedroom, further attention was given to these falls to determine the circumstances and consequences surrounding them.

2.3.1.6 Focus on falls occurring in the bedroom

Witnessed falls in the bedroom

Inspection of the data revealed that of all the falls reported in the bedroom only 4% were witnessed, compared to the group average of 10% for falls occurring elsewhere in the home. Falls in the bedroom had a much higher proportion of not being witnessed, 87% compared to 74% in all other areas. The remaining 9% of these falls did not specify the witness circumstances compared to 16% of all falls occurring elsewhere in the home.

Injury outcomes of falls in the bedroom

Of the total falls reported in the bedroom, 51% resulted in no injury to the resident, 28% resulted in some form of minor injury and 8% in serious injury (requiring emergency medical assistance). Falls with no recorded information were the remaining 13%. The bedroom has been established as the place where most falls occur, so it is interesting to see a relatively large percentage of total falls leading to some form of injury, minor or serious (36%). This issue is compounded by the fact that falling in a private room is the most at risk location for a fall not being witnessed (as previously mentioned 87% not witnessed) thus leading to the possibility of a long wait on the ground before help arriving.

2.3.1.7 Location of fall according to time of day

The location of a fall was plotted according to the time of day the fall was reported. This data provides a useful representation to see when and where most falls were occurring in the homes across the 24 hour period (Figure 2.8).

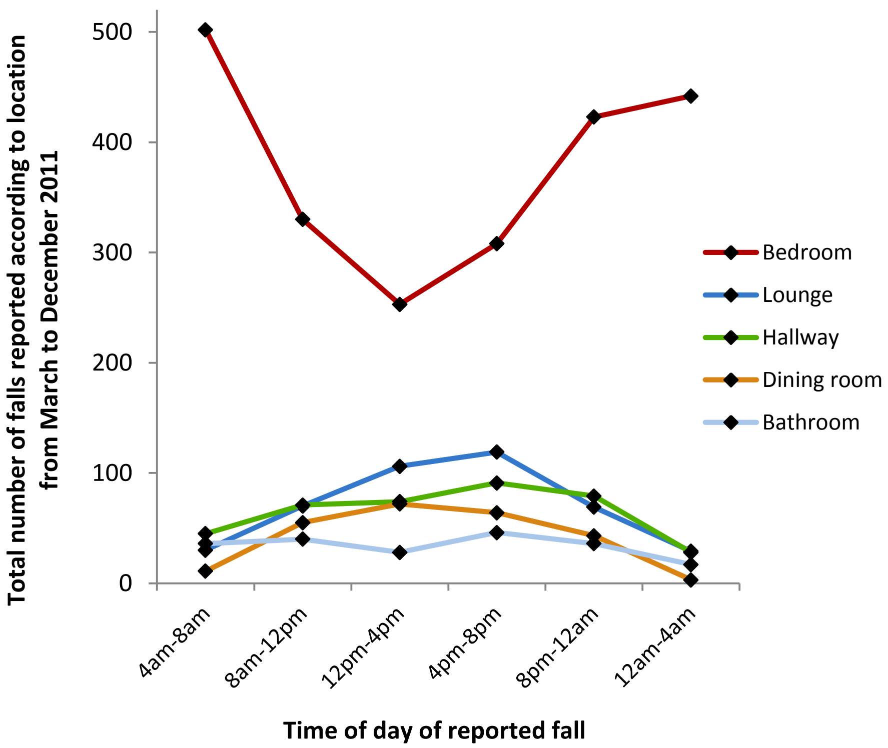


Figure 2.8 The total number of falls according to location and time of day, using data from March to December 2011

Interestingly the time of day when the most falls in the bedroom are reported to occur is between the hours of 4am-8am. The numbers of falls in the bedroom then reduces throughout the day with the lowest numbers occurring between 12pm-4pm. The numbers then steadily rise through the evening and into the early morning between 12am-4am, though not to the peak level of between 4am-8am. Although there is a considerable dip in the numbers of falls in the bedroom in the middle of the day (12pm-4pm) presumably when residents are involved in other activities in different areas of the home, the level to which the numbers reduce, even at its lowest level, is still higher than falls occurring in any other locations. Falls in the communal areas of the lounge and corridor show a similar trend to each other as they both have a peak in the number of falls between the hours of 4pm-8pm, while the highest numbers of falls in the dining room occur slightly earlier, between 12pm-4pm, presumably the times when the residents are moving in the room to eat meals. The communal areas (lounge corridor, dining room) all have their lowest numbers of falls between the hours of 12am-4am, and 4am-8am when residents would presumably be in their bedrooms. Falls reported in the bathrooms show a fairly constant rate across the day, with a slight reduction in numbers between 12pm-4pm and then 12am-4am.

The general trends in these numbers may help adjustments to be made to staff schedules to ensure they are carrying out appropriate checks on residents at the key times of day in the most high risk areas. As previously mentioned in this chapter, these data would be more meaningful if precise times of day for the time of fall could be recorded.

2.3.2 Focus on falls resulting in serious injury

It was considered important to undertake further analysis on the 12% of the total falls that resulted in emergency medical treatment. Falls which lead to serious injury have the greatest associated costs, to both the health service and to the individual, therefore preventing these falls is especially beneficial. The circumstances surrounding falls with serious injury outcomes were examined to determine if patterns in the data could reveal when and where most injurious falls were occurring so they could potentially be prevented in the future. The times and locations with the highest numbers of serious falls could be identified and used to adapt the care homes staff schedules to ensure regular checks were carried out at the key times, to prevent long periods on the floor for residents after a serious fall.

2.3.2.1 Location of falls resulting in serious injury

The frequency and the location of falls ending in serious injury varied quite significantly over the twelve month period (Figure 2.9). For example, in January 2011 no falls requiring emergency medical assistance occured in the hallway, however in November 2011, twelve very serious falls occurred there.

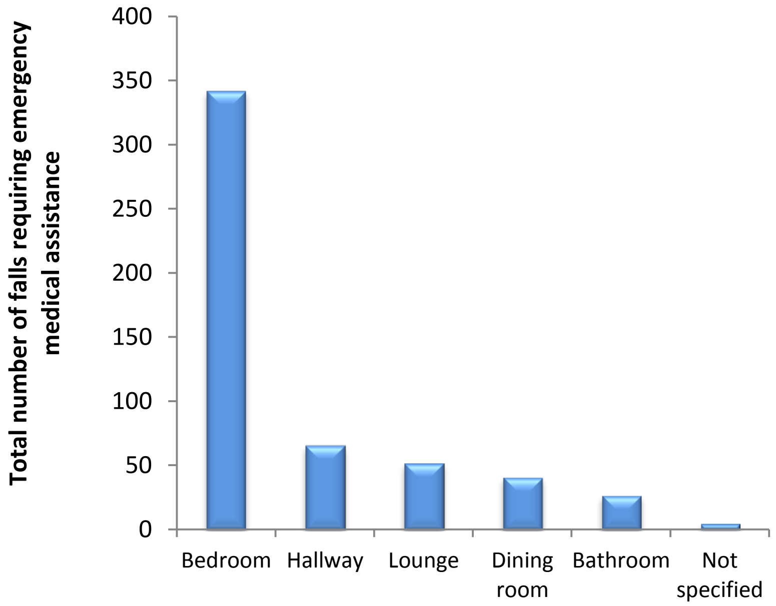


Figure 2.9 The location of falls resulting in serious injury requiring emergency medical assistance

To determine the highest risk locations for serious injury falls, the proportion of falls ending in serious injury was compared to the total overall falls in that location. This was done as residents spend differing levels of time in the different locations each day so it was to see if one location was particularly high risk for resulting in the most severe injuries. The proportion of serious injury falls compared to total falls in each location is shown in Figure 2.10.

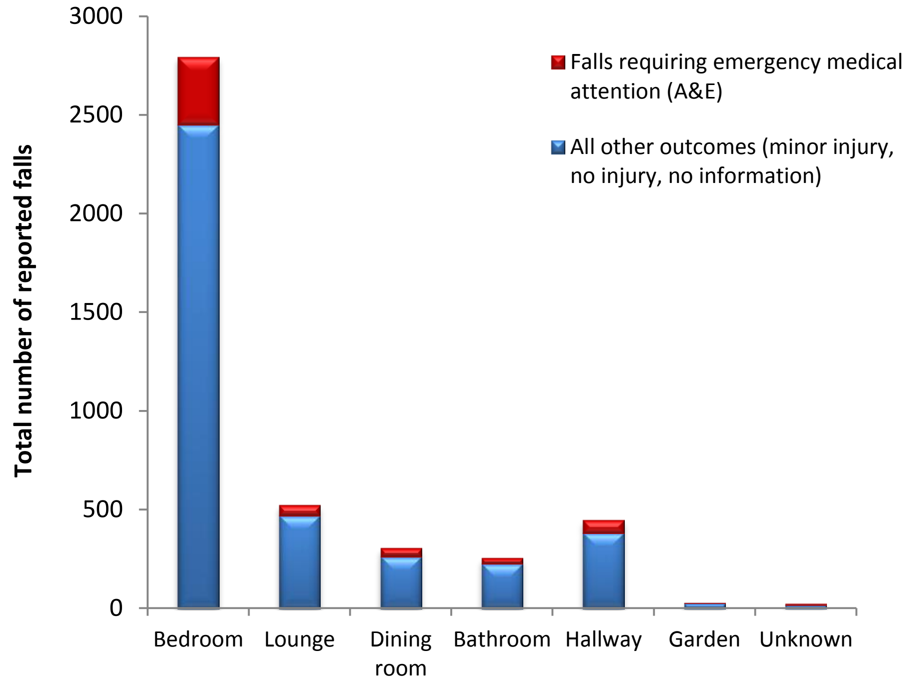


Figure 2.10 The proportion of serious injury falls according to location

Inspection of the data reveals that the highest proportion of falls ending in serious injury, when compared to the total number occurring in that particular area, were for falls occurring in the hallways of the home with 15% of these ending in serious injury. For the other locations, in descending order, the proportions of total falls ending in serious injury were for falls in the dining room (13%), the bedroom (12%), the bathroom (11%) the lounge (10%) and the garden with the lowest proportion (4%). Therefore from reviewing the proportional data, it would appear that falling in the hallway has the most harmful injury consequences.

2.3.2.2 Time of day of falls resulting in serious injury

The time of day for falls ending in serious injury was investigated to see if any trends would emerge to show which time period was the highest risk for these falls.

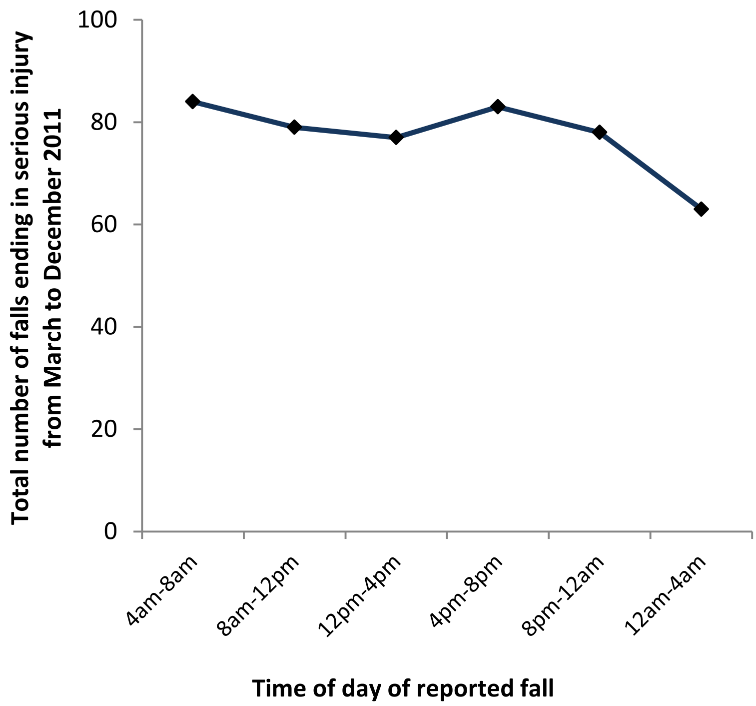


Figure 2.11 The time of most serious injury falls, using data from March to December 2011

The total serious injury falls within each time bracket remains fairly consistent with no significant differences for number of falls at each time period; this is shown through an independent groups ANOVA, F (5,54), = 0.35, p=0.88. The lack of variation in the levels of serious injury falls across the 24 hours shows that these falls are happening consistently, regardless of day or night time or when residents are asleep.

The highest numbers of falls resulting in serious injury were reported between the hours of 4am-8am (Figure 2.11), presumably the time when residents are waking up. There are several significant risk factors to consider when people first wake up; these include reduced alertness, postural hypotension and stiff muscles from lying down all night, also low lighting levels in the room. Potentially this higher risk scenario coincides with a time of day when staffing levels could be low following the end of the night shift. This is especially concerning if residents are waking very early, therefore less staff are available to provide assistance or find a resident following a fall.

The time of day of the reported falls were broken down into their location (Figure 2.12). Figure 2.12 shows a similar pattern to Figure 2.8 (which showed the location of all falls regardless of outcome, according to location across the whole day); the majority of falls occur in the bedroom, with the peak numbers between 4am to 8am, dropping to the lowest point between 12pm to 4pm, rising steadily up between 12am to 4am.

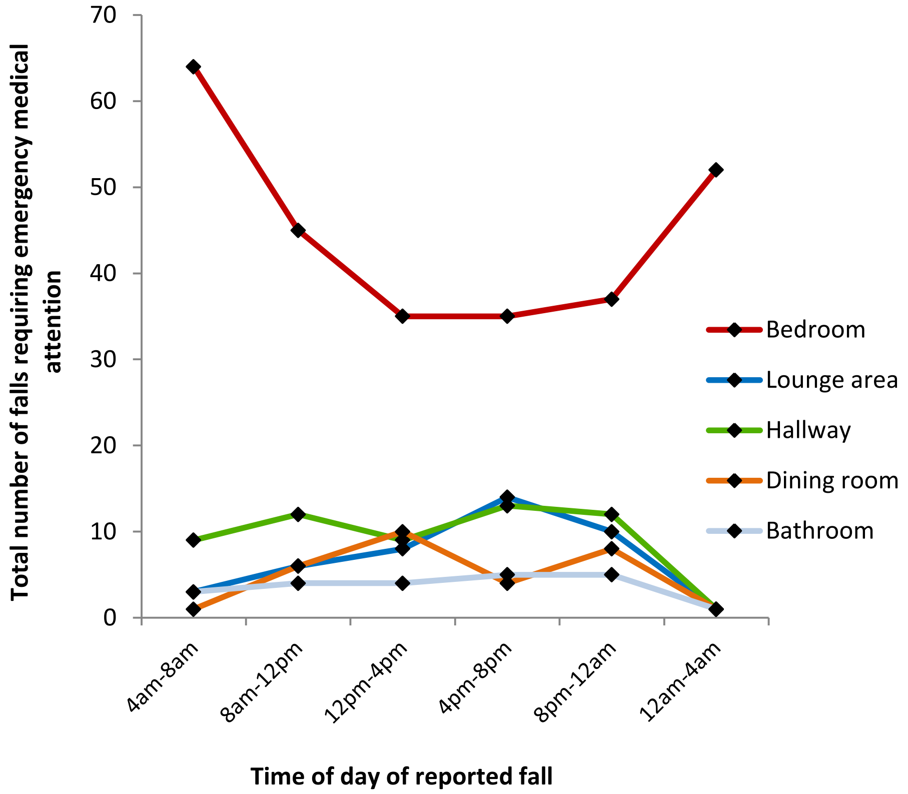


Figure 2.12 Total number of falls requiring emergency medical assistance according to their location and reported time, using data from March to December 2011

The data from this graph could be used to provide rationale for increased night time checks of bedrooms as the highest number of falls with serious injury outcomes are occurring in the bedrooms in the night time hours (12am to 8am). Additionally, the hallway appears to be a high risk area with the second greatest number of falls ending in serious injury occurring here. This is despite the potentially short amount of time residents would spend in the hallway.

2.3.2.3 Not witnessed falls resulting in serious injury

Of the falls that ended in serious injury, 76% were not witnessed by members of staff (Figure 2.13). This high value of falls that were not witnessed could be of concern as many of the reports simply stated, "*resident found on floor*" with no explanation of how long the resident might have been there for.

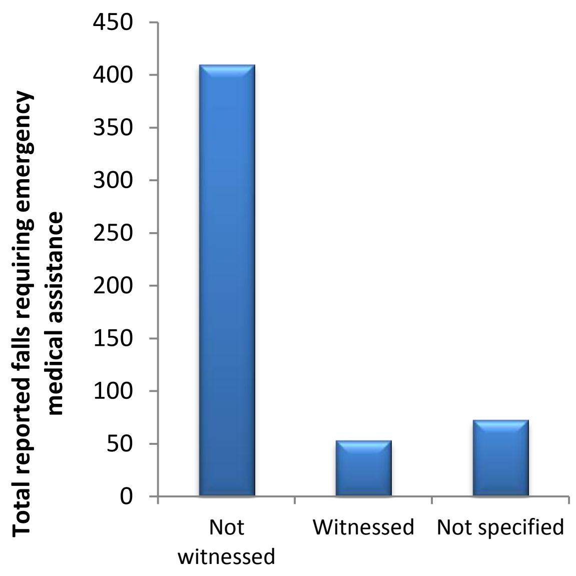


Figure 2.13 The proportion of serious injury falls that were not witnessed

As previously mentioned in this chapter, the time between a fall and help arriving affects recovery outcomes for the resident. Thus it could be speculated that potentially some residents may not have initially needed emergency medical treatment if they had been discovered sooner. For falls where the resident is seriously injured, the factor of length of time spent on the floor could play a significant role in their recovery. The high proportion of falls ending in serious injury that are not witnessed should potentially be bought to the attention of the management group and the staff working within the care homes. Through this increased awareness staff could be encouraged to improve their resident checks to make sure that even if a fall was not witnessed, the resident is not left for an extended period of time without help. To improve safety for the residents within the homes, 'estimated length of time since fall' could be an important factor to record on the monthly falls reports. This could help improve staff motivation for better care and raise awareness of the importance of more regular checks to prevent a potentially damaging long wait time on the floor post fall.

2.3.3 Outcomes for residents who have sustained two or more falls

The final column of the falls report required staff to write freehand, without any structured format, the 'extra input' that should be implemented for residents who have fallen two or more times. There is limited guidance given to staff completing this section of the report and as such there is significant variation in the quality and detail provided between the 30 different care homes. Frequently many of the homes leave this section of the report blank, offering no extra input for the resident on how to prevent further falls. For those homes that did make entries, the different recorded responses were categorised by the researcher into 15 sub sections to encompass all the varied responses. The number of categorised entries and the number of reports left blank are shown in Table 2.1.

Table 2.1. Total number of times each categorised entry of 'extra input' was recorded from January to December 2011 for the 30 care homes

Categories of reported 'extra input' for resident who has fallen <2 times	Total number of recorded entries
No information provided	**2998**
Involve the falls team in residents care	194
Provide pressure mat to alert staff to movement	180
Involve GP or nurse	166
Advise resident to call staff for assistance	95
Record as "isolated incident"	80
Fall caused by a co morbidity (excluding UTI)*	86
Fall caused by a water infection (UTI)*	69
Implement safer changes to living environment	53
Conduct a medication review	39
Provide crash mat next to the bed	29
Involve physiotherapists	23
Advise to use walking frame	21
Specified 'first fall'	3

The recorded entries in this section of the falls report should document actions taken to prevent the resident from further falls, however many staff appear to use this column to record the suspected reasons for the current fall. These are highlighted in Table 2.1 using an asterisk. The recording of the suspected cause of a fall is interesting information to collate, but within the falls report there should be a marked separation of the reason for a fall and the action taken to prevent future falls.

As shown on Table 2.1, the main concern from the reported extra input entries is the amount of entries where no input is detailed at all. Of the 4494 reported falls, 2998 entries (67%) report no extra input. Of these blank reports, many could be justified, as the column heading requests input for those who have fallen more than 2 times. Yet it seems unlikely that 67% of all falls would be first time falls, especially according to the multitude of research which states older persons often fall multiple times (Kiely, et al., 1998) and the fact that many older adults move into care homes because of their postural instability (Salkeld, et al., 2000; Tinetti, et al., 1997). There are also 80 reported falls over the year where the extra input simply states, “isolated incident”. These reports were all made by the same care home, and again, based on the research into older adult falls happening frequently to the same persons, it seems unlikely that over a one year period there were 80 isolated incidents in the same home; this could highlight a case of poor reporting and possible lack of training that needs feeding back to the care home management.

A way to improve the reporting within this section of the falls reports and encourage more complete reports could be to introduce a structured approach to the extra input report column. There could be a selection of responses to choose from, based on the 11 *relevant* sub sections listed in Table 2.1, but with the option to choose multiple preventative actions if needed. This is because falls are often caused by a combination of factors, which may require a multilevel approach to prevention. There should also be an option for when the fall has been a genuine first time event so it is not simply left blank based on that assumption. In addition, an extra report of the suspected cause of the fall could be introduced to promote awareness of prevention measures within the homes.

2.3.4 Assessing falls report quality

One of the most challenging aspects of undertaking the analysis of incident reporting in care homes is the considerable difference in the quality of reports between the homes. As mentioned at the beginning of this chapter, ten homes from the original 40 were excluded from the analysis due to incomplete reporting over the 12 month period. However despite the exclusions and the fact the all the care homes operate under the same management group, closer inspection revealed that significant variation exists in the completeness and detail of the reports. There is also a significant difference in the overall numbers of falls reported each month between the homes. This key finding requires further examination.

2.3.4.1 Focus on the difference in number of reported falls between care homes

As significant variation exists in the numbers of falls being reported between the different care homes each month, it was deemed necessary to explore where this variation could stem from. The 30 care homes included in the analysis are all under the authority of the same management group thus the very different levels of total fall numbers between homes was unanticipated. To allow direct comparison between larger and smaller homes, a percentage value of the total number of falls per month was calculated to take into account the different numbers of residents in the home, therefore showing the percentage of residents who fell, rather than the total number of falls reported. Yet even after the analysis took into consideration the percentages of total falls rather than the overall total number of falls, there were still vast differences in the levels of reported falls across the different care homes.

From reviewing the reports from all 30 care homes, the percentage of residents who fell during the 12 month period ranged from the highest value of 64% in one home to 2% at the lowest value. Figure 2.14 shows the wide variation that exists between the different homes in percentage of residents falling each month. The home names are not specified for reasons of anonymity but their care specialty is given. Homes reporting a monthly average of 50% or above of their residents falling are shown in blue, while homes reporting under 10% are shown in red.

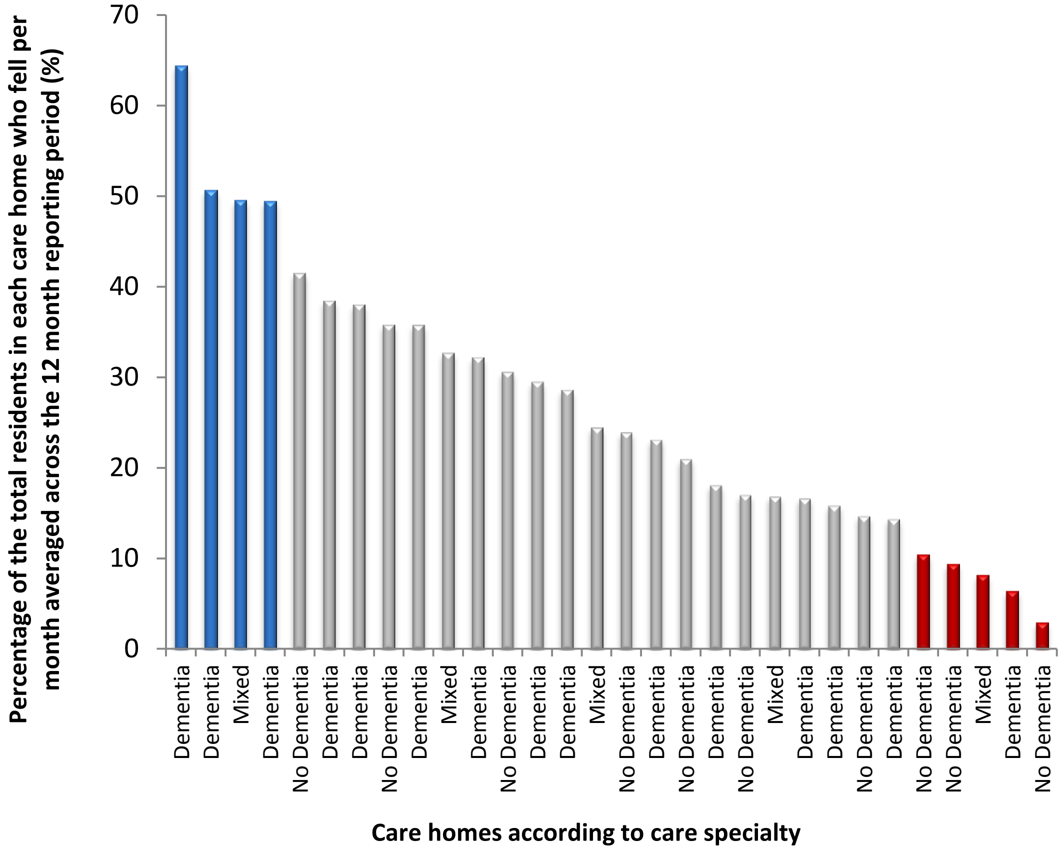


Figure 2.14 Average number of falls in each care home as a proportion of total residents, presented according to care speciality: Dementia, No Dementia or Mixed residents. Blue bars = homes reporting an average of over 50% of residents falling each month, grey bars = homes reporting between 50% and 10% of their residents falling each month, red bars = homes reporting less than 10% of residents falling each month

Four of the thirty care homes report an average of over 50% of their residents falling in the 12 month recording period. Unfortunately from the reports it was not possible to ascertain if these values of over 50% stemmed from a few residents falling multiple times, or if they were first time falls for many residents. In the context of the current literature on falls in older adults this number appears to be comparatively high, as studies in care homes in the USA have reported average levels of falls within a home as between 29% to 39% of residents falling per year (French, et al., 2007; Kiely, et al., 1998). At the other end of the scale, five care homes reported less than 10% of their residents experiencing a fall over the 12 month period. These values appear to be very low compared to the existing literature and consequently they could be a cause for concern. The mean number of falls across the thirty care homes over the 12 month period was 26.7% of residents reported as having a fall; this value appears consistent with the existing literature, as cited previously.

There could be several explanations for the differences in reported fall numbers between care homes, for example, as mentioned previously a few residents falling multiple times per month in one home could inflate the average falls for the whole home making the numbers exaggerated. Additionally the characteristics of the residents of each care home, including age and health status, play a significant role in frequency of falls recorded. Older adults with cognitive impairment are known to experience a higher frequency of falls than those without (Tinetti, et al., 1995). Of the four care homes reporting the highest proportion of falls, three of these homes are specifically for older adults with dementia and the other one is a mixed care dementia/no dementia home. In the five care homes reporting the lowest numbers of falls (less than 10% of residents having experienced a fall) only one of these five care homes is for dementia sufferers; there is one dementia/no dementia care home and then the other three homes have no residents with dementia. As it has previously been shown that residents with dementia are more likely to fall, this fact may go some way to explain the difference in numbers that are reported in the highest and lowest reporting care homes. Additionally this theory is supported by looking at the mean proportion of falls across the homes according to care specialty; the fifteen care homes specifically for residents with dementia record a higher average proportion of resident falls (30.83%) when compared to the five homes with mixed dementia/no dementia residents (26.34%) and the lowest percentage of falls is reported in the ten care homes with no dementia (20.73%). When the percentage of falls reported are averaged across care specialty (dementia/no dementia/mixed) the numbers appear more in line with previously reported percentages of residents falls in care homes; 29% to 39% (French, et al., 2007; Kiely, et al., 1998). Yet when looking at the individual care homes, the numbers at the higher end of the scale (4 homes with over 50% of residents falling) and numbers at the lower end (5 homes with less than 10%) do not appear to fit this general trend and causes concern for the circumstances surrounding these abnormal numbers.

In addition to the health status of the residents, there could be several other reasons as to why some homes are potentially reporting significantly higher or lower numbers of falls. Homes reporting less than 10% of their residents falling are not in line with predicted numbers of falls older adults experience thus there could be a case of under reporting of falls occurring. This may be due to staff not being fully trained as to the importance of reporting even very minor adverse events, especially those near miss incidents and other instances where a fall occurred but there was no associated injury. In these circumstances some staff may feel there is no beneficial reason to report an event. Additionally, the context of the care home management environment appears to show that there are negative consequences associated with reporting high numbers of falls wherein care homes are in effect 'reprimanded' for reporting high numbers and this may discourage reporting. Under reporting should be a major concern rather than homes who are reporting high levels of adverse events because, as research in the area of incident reporting in health care has shown, those homes who under report are likely to be experiencing a similar level of falls to other homes due to the very nature of the older adult residents. Therefore not reporting these events is a serious matter that could be a symptom of a deeper underlying issue with the quality of care (National Patient Safety Agency, 2007). Conversely, at the other end of the scale, if a home is reporting a significantly higher number of adverse events, the home should not be ignored by the authorities because it is displaying good reporting practices. Instead it provides an excellent opportunity for learning to occur; to explore the circumstances surrounding the adverse event and to see how outcomes can be improved to improve practice in future. It also further reinforces to care home staff that the reports they make are useful and the results are being put to good use.

The fact should also be addressed that potentially the reported figures of number of falls is correct, and homes are indeed accurately reporting their numbers of falls. From the falls reports, it can be inferred that homes are over or under reporting, but it cannot be categorically proven. Instead all that can be done is to look at the potential reasons for the differences in percentages of reported falls with some homes. Thus the next section of this research carries out further analysis of staff reporting practices to identify whether there is a link with the quality of falls reporting and the quantity reported.

2.3.4.2 Under reporting falls compared to the detail of the falls report

The NPSA report (National Patient Safety Agency, 2007) specifies that the key to reducing falls is through detailed and meaningful reports from which thorough analysis can be undertaken to learn more about the contributing factors that led to a fall. The NPSA report states that through systematically analysing the circumstances surrounding a fall, NHS staff can target resources to high risk areas and times. Therefore a complete and meaningful report is essential. The NPSA report states that the quality and detail of the incident reports included in their analysis varied greatly with some reports providing complete descriptions of events while others offered extremely brief accounts lacking any detail. An example of this is cited with many of the reports simply writing "*Patient fell*". The NPSA report states that just over 10% of all reported adverse events had a description of 30 characters or less. These types of reports have very little value for analysis of circumstances surrounding falls as they contain so little description that no useful information can be collated.

Reports of a similar poor standard were observed within the 'description of event' section of the care home falls reports, with a very limited number of characters used to describe the circumstances surrounding the fall in some report entries. However, there was significant variation in the overall quality of the reports made in the care homes and it was found that the yearly average for all the care homes, even the lowest reporting homes averaged at least 30 characters per report (Figure 2.15). The top three highest detail reporting homes recorded an average of over 200 characters per description. The lowest three homes reported an average of fewer than 45 characters.

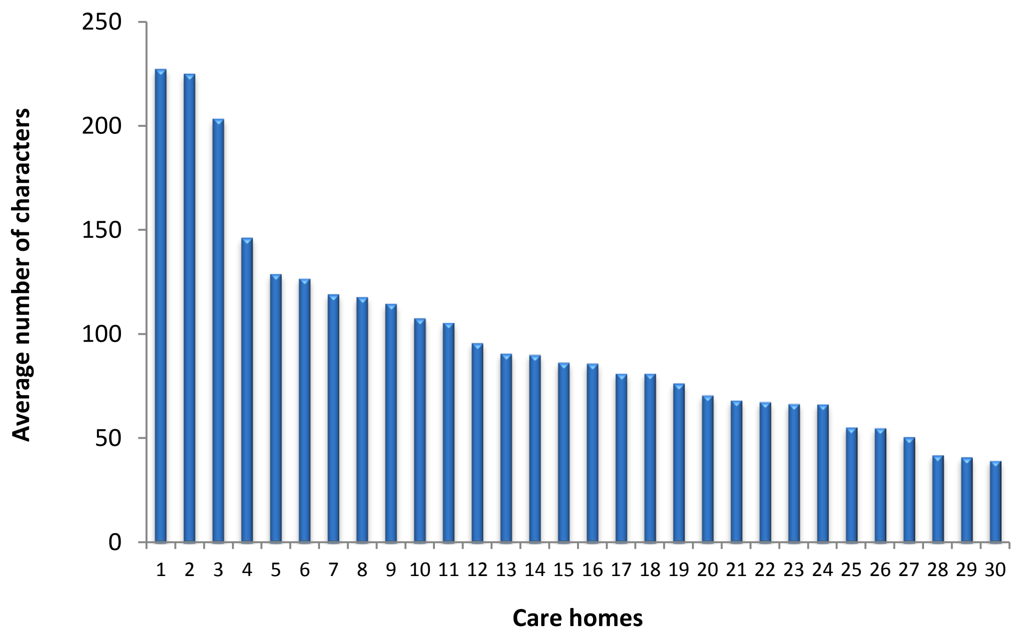


Figure 2.15 The average number of characters used for the description of the reported fall

Two examples of actual reports of around 200 words have been included to demonstrate the length of these reports and how much detail is included. The two reports demonstrate the importance of reporting relevant information with reports both detailing the time taken to assist the resident, cause of fall, injury status, however example 2 contains additional details that are not necessarily relevant in the report;

Report 1 (206 characters)*:*

"Staff alerted immediately by pressure mat. On entering the room they found KJ on floor at the side of her bed. She explained she had rolled out of bed. Body check carried out by staff member. No apparent injuries apart from red mark to temple and l. hip"

Report 2 (216 characters):

"MM was bending down to pick something up from the floor, by the window in the lounge. Staff member said she would pick this up for her. MM carried on trying but lost balance and ended up sat on the floor. Checked over by senior staff, no apparent injuries were found"

The average number of characters used in the description of falls across the 30 homes was 97.98 characters per description (SD 49.50). This is a sufficient amount to provide the required information in a succinct manner. A brief report containing all the necessary information makes the recording of adverse events less time consuming for staff and the analysis easier. Through staff receiving basic training in how to identify what critical information is required, it could lead to large scale improvements in report recording. Three examples taken from the falls reports of how much detail can be recorded in an entry of just 60 characters is shown below:

Report 1:

"*Witnessed, EM appeared to loose footing in corridor, no injuries found*"

Report 2:

"Not witnessed, JP found on wet bathroom floor, minor skin tear right leg"

Report 3:

"*Unwitnessed, resident explained he fell out of bed, skin tear to head*"

These three examples show how only a short report is needed to gather all the key information needed for a complete analysis. These reports can be especially brief as other key information is recorded elsewhere in the main structure of the report, for example, the location and time of the fall.

To assess the quality of the falls reports, an analysis was undertaken to see if there was any relationship between the percentage of reported falls and the level of detail in the description in the reports. It was hypothesised that the care homes who were reporting high numbers of falls would be those with a good safety culture that supports reporting and would therefore provide more detailed reports. These high reporting homes should be reprimanded for having high numbers of falls as they are simply reporting the adverse events thoroughly. Therefore it could be suggested that the homes at the lower end of the reporting scale are the ones who need to improve their reporting behaviour so an investigation was undertaken to see if these low reporting homes also had the least thorough, poor quality reports.

A correlation was carried out to assess if there was a significant relationship between homes who regularly under report falls and the thoroughness of their falls reports. To clarify, it is hypothesised that a high number of characters within a report would equate to a high percentage of reported falls within the home. However, no significant correlation was found between report detail (assessed by number of characters within the description of the fall) and the average percentage of total falls for each care home; ($r=0.02$, $n=30$, $p=0.92$). If a correlation had been found then these low reporting and low report quality homes could be easily identified and given increased training on correct reporting procedure, as quality of reports is a tangible measure which can be assessed accurately, whereas number of falls within a home is a harder statistic to judge. However, the fact that the correlation was not significant between these two measures makes it difficult to interpret the lack of report detail.

2.3.5 Falls resulting in most serious injury compared to detail within report

With the aim of further assessing the quality of the falls reports, the relationship between the number of characters within an event description and the percentage of the total falls resulting in serious injury was carried out. Serious injury falls are important events to record since they have the most severe consequences for both the resident and the staff members. Additionally, it may be considered more important by staff to record an event with serious consequences to protect themselves from potential action in the event that the case is investigated at a later date. Therefore, the hypothesis is that any homes with an exceptionally high *proportion* of their total falls resulting in serious injury may offer insight into the number of other falls with minor or no adverse consequences that may *not* have been recorded.

The analysis focused on those homes reporting significantly above 15% of their total falls resulting in serious injury requiring emergency medical assistance (ambulance/A & E). This number is calculated based on an existing review of work within care homes, where it was found that the average proportion of total falls ending in serious injury for institutionalised older adults was around 15%; made up of 4% resulting in bone fractures, with the other 11% being injuries deemed as serious (head trauma, soft-tissue injuries, and severe lacerations) (Rubenstein, et al., 1994). Therefore in the current study, any care home reporting more than the average of 15% of their total falls resulting in a serious injury was deemed 'of interest' for further investigation.

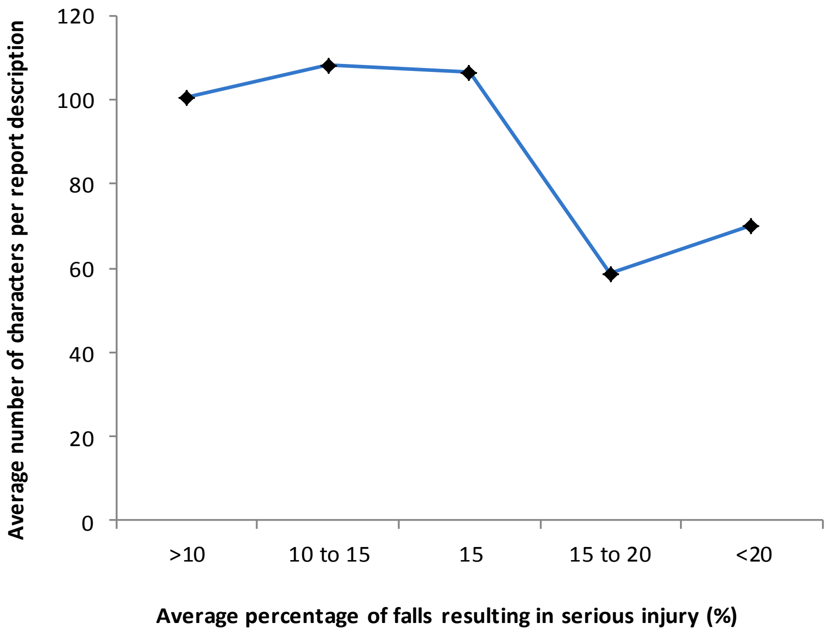


Figure 2.16 The percentage of serious injury falls reported compared to the average number of characters per report description

Figure 2.16 offers some indication that there may be a link between the quality of reports, as indicated by the number of characters per description, and unreported adverse events, indicated by the percentage of reports ending in serious injury. Homes reporting the highest percentage of falls ending in serious injury (15%-20% and greater than 20%) record the lowest number of characters per report description (Figure 2.16). The fact that in this data those homes reporting over 15% of the total number of falls ending in emergency medical treatment are linked to limited detail within their reports may show that these homes may be undertaking poor general reporting practices.

2.3.5.1 Analysis of completeness of falls reports using the missing data

To further assess the quality of reporting within the care homes, additional analysis was undertaken to see if the reports which were of a low standard in description detail, were of a similarly low standard throughout their reports. The measure used to assess report quality was achieved through classifying reports based on missing data within the 'extra input for residents who have fallen 2 or more times' column. As documented previously in this chapter, this extra input column showed great variation between the different care homes. When extra input information was provided by the care homes it demonstrates a level of conscientious reporting as they have used the reports to consider how to avoid further falls. Therefore this section of the report is now being used to assess the general quality of reports amongst the different homes.

The percentage of the total reports which included extra input entries was calculated. It was found that the top percentile of the homes (n=6) had an average of 82% of their total reports including extra input while the bottom percentile (n=6) had an average of 9% of their total reports including extra input. The average number of characters per description was plotted against care homes' percentage of reports which included an extra input entry (Figure 2.17). This was done to assess if those homes who reported a low percentage of extra input descriptions were also reported a low number of characters in their falls description entries. A significant correlation was found between the average number of characters per description and percentage of reports which included extra input, $r = 0.46$, $n = 30$, $p < 0.05$.

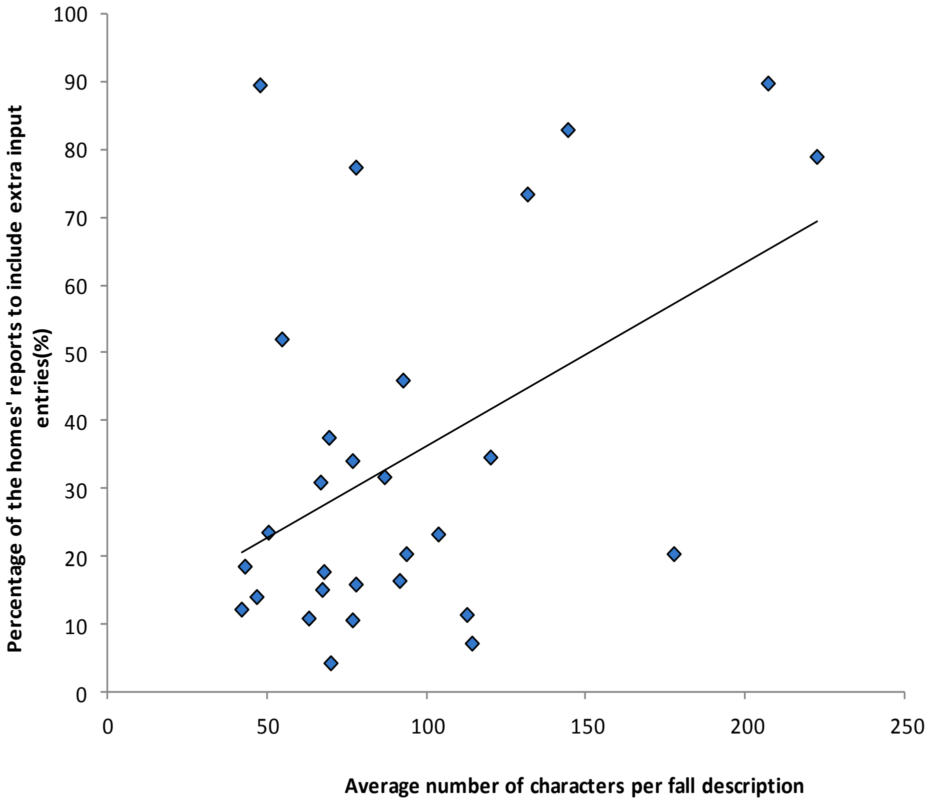


Figure 2.17 The percentage of care home reports to include 'extra input' compared to the average characters per falls description within the report

2.4 Discussion

The analysis of care homes incident reports has resulted in several key outcomes concerning the frequency and circumstances of falls, with specific focus on those falls resulting in the most serious injuries. In addition the analysis focussed on ways to assess the quality of the care home reports, producing interesting findings offering relevant applications to improve current reporting systems.

2.4.1 Summary of findings

The conclusions from this chapter could be of practical use to staff from all organisational levels, from the carers up to the management board, providing the tools needed to upgrade their homes' falls prevention strategy. The recommendations could lead to enhanced reporting and better quality of data allowing care home managers to improve reporting systems and target critical training areas. The key findings can be split into two main categories; the circumstances of the reported falls, and the quality of the incident reports.

2.4.2 Circumstances of reported falls

The analysis of the incident reports in care homes revealed five main findings:

1. Falls accounted for the significantly largest proportion of all adverse events reported within the care homes;
2. A very low proportion of all falls were witnessed by staff members, and an even smaller proportion of serious injury falls were witnessed;
3. In general there were no significant differences across the time of day as to when most falls occur; this included those falls which ended in serious injury;
4. When fall numbers are reviewed in terms of location, it is found that the greatest number of falls occur in the bedroom, especially in the early morning and late evening;
5. Falls occurring in the hallway are proportionally the most likely to result in a serious injury, although the greatest volume of serious injury falls occur in the bedroom at night time between 12am and 8am.

It is important to note that the majority of all adverse events occurring in care homes are reported to be falls; 4494 of 7012 adverse events were falls (64%). This is similar to the proportion of all adverse events reported across the NHS (National Patient Safety Agency, 2007). However, due to problems revealed by the report quality analysis with the incorrect categorisation of the adverse events, it is likely that an even higher proportion of all adverse events are actually falls.

A very small proportion of falls were witnessed by members of staff. As previously mentioned in this chapter, the literature has shown that there is little a staff member can do to prevent a fall even if present at the time of the event (National Patient Safety Agency, 2007). However, the serious issue is that if a fall is not witnessed then the resident may remain on the floor for an extended period of time. Therefore the very high proportion of falls that are not witnessed should be fed back to the staff as it could serve to raise awareness and help increase motivation for staff checks of residents. Adaptations to staff members' daily schedule could be implemented based upon the findings in the report, to increase these room checks according to high risk times and locations. The report highlighted a higher number of falls in the bedroom compared to any other rooms, and when examined according to time of day, the early morning and late evening were found to be the peak times for falls. Therefore bedroom checks should be encouraged throughout the day, but especially in the early morning and late evening periods. Reasons for the high numbers of falls in the bedroom at night could be from factors such as simply falling out of the bed while sleeping, but also they could be from intrinsic causes such as a low cognitive state when first awakening from a deep sleep or from no/low lighting in the bedroom in the hours of darkness. Later work in this thesis will aim to establish what it is about the bedroom environment in the night-time hours that make it very high risk for falls. The effects of reduced cognitive capacity and the simulation of night time through the deprivation of vision will be investigated.

According to the report data, falls which occur in the hallways although fewer in total number than the overall number of falls in the bedroom end in the highest proportion of injury requiring emergency medical assistance. Consequently further work could be carried out to try and make the hallways a safer area for the residents. Some of the homes have reported recent renovation schemes where the hallways have rails along the length that are painted a bright colour to attract attention to use. Work like this in other homes may help reduce the number of falls ending in serious injury.

2.4.3 Quality of incident reports

Analysis of the incident report quality from the care homes revealed 5 key findings;

1. There were issues of miscoding within the categorised data;
2. There were significant differences in quality of falls reports between homes, despite all the homes being managed by the same group;
3. More information would be useful regarding the injury outcome following a fall to allow further analysis;
4. Further breakdown of time of day of fall is needed to identify specific high risk time periods;
5. Guidance on exactly what information is needed in the reports could lead to shorter report entries with fuller details.

If these five issues could be attended to and the recommendations followed, then the care homes' reporting system would be dramatically improved with easier to analyse monthly reports and more reliable data from which to draw conclusions.

Within the incident reports, there were many instances where data were wrongly categorised, such as falls being listed as accidents or incidents, actual harmful events being described as 'near miss' and falls ending in A & E not being reported as such. All these issues within the reports may not have otherwise been detected if this analysis had not been undertaken; it is impractical and unlikely that the management group have the resources to spend time every month looking through reports with over 500 entries. Thus, the problems of miscoding within the reports needs to be addressed, ideally through improved training of the staff making the initial reports. The reports need to be accurate at the point of entry and quick to produce summaries from each month. As they stand, the reports appear susceptible to the reporting practices within each specific care home, with some homes being thorough and others having a laissez faire attitude. The management group needs to be able to trust the accuracy of the different categories and know that the data they are viewing covers all reported adverse events, especially in the case of A & E falls, where many instances of serious injury falls were missed in the reporting process. Consistency in reporting across the homes is needed, and a few small changes in the falls reporting system could help achieve this. From the definitions provided within the care home group's policies and procedures manual it is easy to see how the category of accident could lead to staff reporting a fall as a general accident. These categories need a more clear definition of the different adverse events that can be included. For instance a relatively simple advancement would be to include in the definition for accident, "does not include accidents relating to a fall".

Other improvements are needed which could be simple for the care home managers to implement and should make completing the reports quicker and easier for staff. This will lead to increased reporting and easier to analyse reports being produced. The basic improvements that are recommended to the falls reporting system are:

- time of fall specified further to record one hour periods
- specific section to record injury outcome following fall

- specific section to record estimated length of time resident lay on floor post fall
- training on what information is needed/not needed within the report description
- training on the importance of the different categories of adverse events and the correct definitions.

More precise details are needed regarding the exact time of day of the fall so that trends can be analysed more closely with precise times linking falls to definitive daily activities. Although there have been vast improvements made since March 2011 to bring in four hour time slots rather than simply splitting the time into day or night, the four hour time window currently covers too many daily events. Within each four hour time bracket multiple different activities are potentially taking place, such as waking up and mealtimes within one time bracket, therefore an hourly breakdown could further highlight the most risky activities where increased checks are needed. Daily activities could be assessed into high and low risk times and the additional information could be used to draw attention to high risk times of days based around the activities that took place over the one hour periods. This would enable more specific analysis and targeted fall interventions. An increased specificity of time could also raise awareness amongst staff of the importance of finding residents quickly following a fall, and encourage staff to consider how long the resident could have been on the floor. If there is the option to report a rough estimate of the time of fall, anywhere within a large four hour time window then staff may not consider the time it has taken to find resident post fall. If however they need to more explicit about exactly when the fall may have happened then it may motivate more regular checks.

Although the injury outcomes following a fall were not specifically requested within the reports, detailed injury outcome information is useful. This could be an area of improvement to develop the effectiveness of falls reports. From analysing the incident report data that was available it was found that on average a slightly lower percentage of falls resulting in serious injury and fracture was found (12%) compared to the current levels reported in the literature (15%). This lower figure could be accounted for by the 13% of falls reports where an injury consequence was not specified. It was found that large differences existed between care homes with some reporting an average as low as 0% of falls ending in serious injury over the 12 months, with others reporting 26%. Because of this wide variation in numbers, it was important to break down the falls reports and more closely examine the individual homes. Through this analysis it was decided that it would be useful to have a specific section to describe the consequences for the resident following a fall. This is a useful statistic to have as the injury sustained following a fall is a good measure for improvement in falls prevention. For example, it could show if crash mats next to the bed are working by detailing the type of injury sustained, if any, from the impact of falling.

There was significant variation between the general quality of reports between the different care homes. This was despite all the homes being supervised by the same management group so all homes receiving the same reporting practice instructions. This variation between homes may reveal the priority each specific care home manager gives to the incident reports; some homes appear to be very thorough in their reports, with an average of over 200 characters per report description entry and over 80% of their reports having extra input for those residents who fall multiple times, compared to homes with consistently less than 50 characters per report and less than 5% of their reports having extra input documented. The report quality analysis showed a link between the percentage of falls resulting in serious injury and the number of characters per description entry, suggesting that certain homes may be enlisting better reporting practices than other homes. These findings have been fed back to the care home management group and hopefully this will encourage a new way of targeting improvements within the homes that is not based on those homes who are reporting the most falls being listed as a concern. In the current system, care homes are far from being encouraged to report and rewarded for doing so, but instead they are reprimanded and effectively undergo a disciplinary procedure if they report high numbers of falls. Yet as stated in the Good Clinical Practice training and the 2007 NPSA report (National Patient Safety Agency, 2007), the main concern should not be homes that are reporting many adverse events, but those who are reporting very few. Thus, a significant change is needed in the culture of the management group to focus their attention on homes that are underreporting. A key message from this analysis for the management group is that those homes who regularly display poor reporting practices with very low numbers of falls should be investigated rather than those homes who appear to be reporting high numbers of falls with very thorough and detailed reports. However, the reports do not necessarily have to be long in content, as long as they contain all the relevant information.

From looking at the reasons why underreporting occurs, one of the best ways to improve reporting practices is to involve staff in the process and ensure results of the analysis are fed back to them. Studies of staff working in health care professions report feeling frustration from making incident reports as they see no utility of doing so and do not see the data being utilised (Kingston, Evans, Smith, & Berry, 2004; Shojania, 2008). Through feeding back the data in a concise report summary it ensures the people at the 'front line' get to see that their effort is important for learning and something is being done with the data they have helped to produce. Staff need to see that their reports are being used to improve procedures, whether this is from employing more staff to cope with falls at the peak times of day or simply looking if some of the high risk locations need redesigning for increased safety. If staff could see that the information they are providing is helping to make changes for the better, they may wish to spend more time ensuring their reports are accurate with all the detail that could be useful.

2.4.4 Objectives and implications for next phase of research

Undertaking the analysis of falls reporting within a sample of UK care homes has helped to develop the next phase of research into the area of falls prevention. A primary aim of the falls report work was to establish the true scale of the problem of falls in UK care homes and understand further the associated injury consequence. The results from this study build on the limited existing literature as they show a similarly high level of falls compared to previous research; 64% of all adverse events within the care homes are reported as falls, although this figure is almost certainly higher due to confirmed inaccurate reporting practices. The analysis of the falls reports within care homes has proved that falls are a significant issue facing older adults as over the 1 year recording period, 4494 falls were reported within the care homes sampled. The falls report work has shown how common falls in older adults are, especially for the more frail older adults living in care homes. It has provided a justification for carrying out further research working with older adults into the specific environmental circumstances or personal factors that can increase falls risk.

This links in with another aim of the falls report work which was to identify high risk situations and patterns in the data concerning falls, especially those recorded falls with the most serious injury outcomes. The falls report analysis revealed that the majority of the most serious injury falls occur in the resident's bedrooms between the hours of midnight and 8am. This is when residents would be expected to be asleep so a high number of falls would not be predicted over night. However it appears that the night time hours are the most high risk time for falls and as a result it raises interesting questions for the later research in this thesis. These questions will be based on the fact that a disproportionately high number of falls compared to predicted daily activities are occurring in the hours of darkness, therefore the link between visual input and postural stability will be explored. The theory behind this exploration is that in situations of reduced lighting, the eye is deprived of visual input and signals, especially in an older aged person who may already be experiencing some difficulty with their eyesight from more commonly occurring age related conditions such as macular degeneration or cataracts. Consequently if older adults are reliant on visual signals to maintain stability it could lead to a situation where reduced visual cues, such as in dark environments, could cause significant difficulty for maintaining balance. This will be investigated in relation to decreased proprioception in older adults and testing their reliance upon vision.

Additionally, the hallways were reported as proportionally the most high risk areas for serious injury falls and further work needs to look into the possible reasons for this. The hallways in care homes can be busy thoroughfares with people trying to pass in narrow spaces. In the hallways divided attention is required for ambulating and navigating to avoid collisions with other residents, often with walking aids. Consequently there are many distractions in this environment and something about this situation means a high number of serious injury falls occur. Therefore the series of experimental chapters following the falls report findings need to use testing scenarios that have a divided attention element, so full concentration will not be allowed to focus on postural control. The experiments also need to have a motor element involved to simulate walking in the hallways so the participants will be required to divide their attention between carrying out a movement effectively and maintaining postural control. Ideally the movement will be measurable so performance on the motor task can be quantified and compared between individuals.

With the UK's current ageing population and with the largest increase predicted in the "oldest old" (Office of National Statistics, 2009) it is apparent that this further research into falls prevention is of the utmost importance as the issue of older adult falls is set to increase. Following the analysis of the falls reports which found most falls occur whilst residents are potentially alone in their bedrooms in the hours of darkness, continuing research in this thesis needs to focus on exactly what factors make this a high risk situation. As well as experimental work looking into factors concerning the effects of reduced lighting and carrying out a concurrent task, work also needs to be carried out to see who may be at the greatest risk of falling. Often once someone has experienced a fall their quality of life reduces dramatically with reduced mobility leading to loss of physical condition and a lack of confidence (Tinetti, et al., 1997). Therefore another important area of research is investigating older adults' attitudes towards daily activities based on a fear of falling. Anecdotal evidence from visiting some of the care homes featured in Chapter 2 showed that many of the residents were admitted into the homes following a loss of independence caused by a fall; the damage was sometimes physical but often it was effects on the older adult's confidence. This fear of falling will be investigated and a link between actual postural stability and perceived stability will be explored. The following chapters will conduct experimental work with a view to further understand the specific mechanisms behind the serious issue of falls in the older adult population. This will be undertaken with a view to developing an early detection system to improve falls prevention strategy in older adults.

3 Methods and postural stability pilot work

3.1 Introduction

In the previous chapter, the scale of falls in UK care homes was established. This chapter will use an experimental approach to assess postural stability in older adults and potentially ascertain the mechanisms that can deteriorate with age and lead to problems with postural control. It is hoped that those most at risk of falling can be identified with a view to early prevention. This chapter will be the start of a documented process to design a system for carrying out postural stability assessments. Through this, specialised equipment using innovative testing methods will be trialled to assess suitability to collect quantitative data detecting changes in postural sway.

The aetiology of falls in older adults is often complex as falls can be due to a combination of many factors. These factors have been loosely identified as general age related physiological and psychological decline, multiple prescribed medications, and also environmental factors (Bueno-Cavanillas, et al., 2000; R. G. Cumming, 1998; Rubenstein, 2006; Scuffham, et al., 2003; Tinetti, et al., 1994; Tinetti, et al., 1995; Tinetti, Speechley, & Ginter, 1988). The reason for a fall is frequently attributed to a combination of several of these factors (Rubenstein, 2006; Tinetti, Franklin Williams, & Mayewski, 1986). This combination of factors can account for the difficultly experienced by health care professionals and researchers in understanding and preventing falls. It also accounts for the high frequency of falls reported in older adults, as demonstrated in Chapter 2. The commonly experienced poor balance and stability which can occur in older adults can be symptoms of many underlying age related conditions and as such falls prevention strategies can require solutions from a range of different sources. Poor postural stability can be a symptom of several age related pathologies such as Parkinson’s disease, multiple sclerosis, vertigo, stroke, Alzheimer’s disease, labyrinthitis, Meniere's disease or forms of cerebrovascular disease (Cattaneo, De Nuzzo, Fascia, Macalli, Pisoni, & Cardini, 2002; Lars Nyberg & Gustafson, 1995; Pothula, Chew, Lesser, & Sharma, 2004; Shaw, 2003; Wood, et al., 2002). Falls prevention strategies need to take into account the often complex co-morbidities that can exist in older adults to cause balance problems and consider a full medical history to assess the relationship between disease and postural control difficulties.

For many years, one of the main suggested causes for falls in older adults has been age related changes affecting postural stability (Brocklehurst, Robertson, & James-Groom, 1982; Chandler, Duncan, & Studenski, 1990; Overstall, et al., 1977; Sheldon, 1963). Studies have shown that standing postural sway can accurately predict likelihood of falls (Fernie, Gryfe, Holliday, & Llewellyn, 1982). More recent research has found that certain aspects of postural sway may be stronger predictors than others for future falls risk. For example, a recent and comprehensive study has suggested that mediolateral sway amplitude (side to side motion) when participants are deprived of visual input (blindfolded) was found to be the strongest predictor of falls risk (Maki, et al., 1994). Nevertheless, this area is not straightforward due to the multifaceted nature of the causes of falls. As stated by Maki et al. (1994):

"*for any fall that is not caused by some transient physiological event (such as seizures or transient ischemic attacks), there must be: (a) a perturbation, and (b) a failure of the posture control mechanisms to compensate for the perturbation*" (page M81).

This statement suggests that if an environmental 'perturbation' is strong enough to override the normal functioning of postural control mechanisms, then a fall may be inevitable. Thus, external influences can have a significant influence on older adults' falls risk, even if they do not have any predisposed postural control failures. The current work aims to further investigate this area by assessing the standing postural sway of young and older adults in a range of different standing stances designed to purposefully destabilise the participant and challenge their normal standing postural control. The different standing stances that will be used have been shown to influence postural stability (Berg, Wood-Dauphinee, Williams, & Gayton, 1989). Additionally, a range of destabilising standing stances with increasing levels of difficulty provides a way of assessing the testing equipment to see if it is detecting the changes in variance of postural sway between conditions. The influence of vision on maintaining postural control will also be examined as older adults have been shown to rely on visual cues to maintain balance (Black, et al., 2005; Tinetti, et al., 1988; Woollacott, et al., 1990).

It is normal for the healthy adult body to experience a small amount of postural sway while maintaining an upright standing stance. Residual adjustments are undertaken continuously to uphold a standing position. In most situations and in healthy adults these adjustments are undertaken automatically and do little to threaten the body's postural equilibrium. However, work with patients with central nervous system damage shows that the vertical maintenance of the body's centre of mass can become extremely difficult to preserve due to excessive sway (Day, Steiger, Thompson, & Marsden, 1993). A characteristic of age-related decline in older adults has been reported to be high levels of muscle activity which is strongly correlated with increased postural sway; however whether the increased muscle activity is a compensatory response to the high levels of postural sway or whether the increased muscle activity is causing the postural sway is still undetermined at this stage (Laughton, et al., 2003; Manchester, Woollacott, Zederbauer-Hylton, & Marin, 1989). Nevertheless, it is an established fact that older adults who show increased levels of standing postural sway due to age-related postural control declines exhibit an increased risk of falling (Lajoie, et al., 2004; Melzer, Benjuya, & Kaplanski, 2004).

This chapter documents the early pilot work which serves as the foundation for later experimental work in this thesis. Novel testing equipment is used to develop a portable early detection system to identify postural instability in older adults. To ensure the equipment is appropriate for use with more frail older adult populations a certain amount of pilot testing is necessary, to be undertaken with both young and older adult participants. This work serves to highlight initial areas for development and improvement. Additionally, the pilot testing needs to ensure the measures of postural stability are consistent and reliable to enable an investigation into the potential changes that can occur with increasing age to postural stability. It is thought that if older adults at risk of a fall can be identified then they could receive preventative advice and training before a potential fall occurs. This could avert any resulting disability and help older adults to remain independent and active for longer. The system could also be used to quantitatively assess whether falls clinics are improving the postural stability of attendees. Moreover the attendees of falls clinics could have a tangible goal to work towards by using early measures of their stability as a benchmark to improve upon.

3.2 Experiment I. Piloting of postural stability measures in a young adult group

3.2.1 Rationale for pilot study

Early in the experimental design process it was decided that a short pilot study should be carried out with young adult participants as they were an easily accessible population who could provide an initial insight into the potential difficulties that could arise with postural sway measurement. The pilot work carried out to assess methodological practicalities and identify any potential issues with the testing before beginning working with an older adult age group.

A key aim of this preliminary research into postural sway was to assess the suitability of the experimental methods for measuring variability in human postural sway. Therefore, in the testing design it was deemed useful to have increasingly challenging standing positions, in which higher levels of postural sway were expected to be observed in predictable increments. These different standing conditions allowed for a test of the measurement capabilities of the equipment. An inertial sensor specifically designed for the measurement of human body movement (supplied by Xsens Technologies) was selected for the pilot testing. It was essential to make sure the suggested methods and the sensor would be accessing the key measurement areas that were required to assess postural stability. The outputs from the sensor would need close inspection to decide which measure was the best representation of postural sway.

The pilot study was carried out to ensure that any issues that may occur during testing were solved before beginning work with an older adult population and also to ensure the testing protocols were well established and practiced.

The pilot testing needed to establish factors such as:

- Which of the Xsens inertial sensor outputs was most indicative of postural sway?
- Where on the body should the Xsens device be attached?
- How should the Xsens device be attached?
- Which manipulations of a typical standing position were feasible?

- Which computer based task would be best and how many trials were needed?
- Was a hand held stylus the best input device for the computer task or should a joystick be used?
- Were there any potential issues of participant safety?

After some early exploratory work, it was decided that the Xsens sensor would be best worn on the top of the participant's head, in order to capture the greatest range of postural sway. This was through observing the sensor output and conducting preparatory trials with members of the lab group. The pilot study hypothesis was that as standing stance becomes more challenging to participants' postural control mechanisms, the higher the recorded levels of postural sway will be.

3.2.2 Methods for testing and equipment

3.2.2.1 Participants

The pilot study involved 12 young adults (7 females, 5 males), recruited from the student population in the Institute of Psychological Sciences, University of Leeds. Participant ages ranged from 20 to 26 years (mean age 22.4 ±1.68).

3.2.2.2 Equipment

The main apparatus used in the pilot study was the Xsens inertial sensor to measure participant postural sway, and a Toshiba tablet laptop to run the visuomotor computer tasks using KineLab software.

The Xsens MTx Miniature inertial 3DOF Orientation Tracker

The MTx Xsens inertial sensor is a small and light weight orientation tracker that provides accurate kinematic data, including 3D acceleration, rate of turn and magnetic data. It uses 3 rate gyroscopes to track changing orientations in 3 dimensions. It provides a stable reference through measuring the directions of gravity and magnetic north making it ideal for investigating human postural sway. The Xsens sensor was positioned on the superior coronal suture of the participants head using an adjustable plastic cap as shown in Figure 3.1.

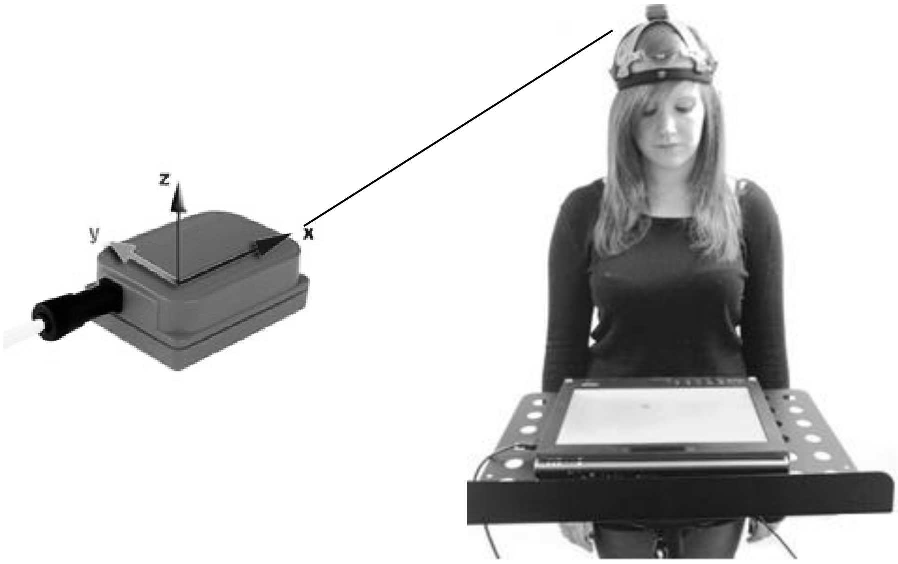


Figure 3.1 The Xsens MTx miniature inertial orientation tracker shown in situ

The Toshiba Portégé M700 Series tablet laptop and KineLab

The Toshiba Portégé tablet laptop was used to run KineLab software to present the visuomotor tasks. KineLab, (designed by Culmer et al., 2009, and originally referred to as 'KAT') is a program implemented through LabVIEW which delivers kinematic assessment trials containing interactive visual stimuli. The participant undertakes the task using an input device, usually a hand held stylus, during which continuous data acquisition of the participant's kinematics takes place. The key advantage of the system is that a wide age range are able to use it (Raw, Wilkie, Culmer, & Mon-Williams, 2012) mainly due to its similarity with a pen and paper. It makes an excellent assessment system for fine motor skills as the kinematic measures are automatically and accurately collected through the touch screen laptop so there is no need for timely analysis of post movement measures, such as the main current tool in use, the movement ABC. The Toshiba Portégé tablet folds down into a flat screen so can be used with a stylus to be like a pen and paper to assess participants' fine motor skills.

Figure 3.2 The Toshiba Portégé M700 Series tablet laptop

The KineLab software and visuomotor tracking task

The KineLab software was used to produce and run a simple visuomotor target tracking task. It involved a circular visual target moving in a figure of eight motion around the horizontal laptop screen at three different speeds; slow, medium, fast. Participants were instructed to track the movement of the target using the stylus as accurately as possible. Participants' scores for the task were calculated by how far they deviated from the moving circular target's route, measured by root mean square error (RMSE). Kinematic measurements are taken 120 times per second (120Hz), thus the movement recording is temporally precise.

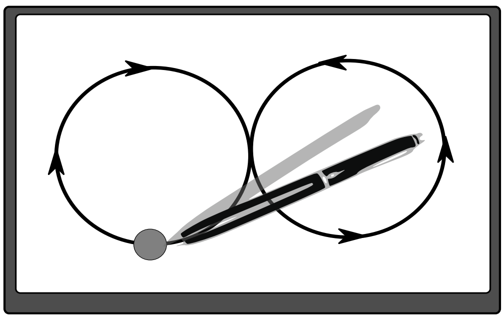


Figure 3.3 The visuomotor tracking task run by the KineLab software

3.2.2.3 Design and Procedure

To ensure consistency for all participants, testing took place in the same setting of a large laboratory within the Institute of Psychological Sciences at the University of Leeds. This location offered an ideal space where testing could be done in the middle of the room, thus reducing factors that could have affected postural stability such as close proximity to a wall. The laptop was positioned on a wooden lectern which could be adjusted for height of the standing participant. The Xsens sensor was fitted to the top of the participant's head using a secure plastic cap. The cap size could be adjusted for each participant. Participants were instructed to follow the movement of the circular target with their hand but to try and keep their head as still as possible. A hand held stylus was used to manually track the movement of a target at three different speeds; slow, medium and fast. Each tracking task speed lasted 30 seconds so in total each lasted for a total of 90 seconds. Participants were asked to undertake the KineLab visuomotor tracking task at the three different speeds in 3 different standing conditions:

1. Stood in comfortable stance: feet shoulder width apart;
2. Stood one foot in vertically in front of the other (referred to as the Tandem Romberg position);
3. Stood on one leg; participant selected their preferred leg and maintained this choice until completion of all testing.

3.2.3 Results

From exploring the early data gathered from the pilot testing and also observing a real time display to see which sway movements related to which output measures, it was determined that the most suitable measure produced by the inertial sensor to assess postural stability was the angular velocity. Angular velocity denotes the time rate of change of angular displacement, and consequently, it is a highly suitable measure to accurately ascertain how fast an object is rotating. In the case of this experiment, the object in question is the participant's head on which the Xsens sensor is positioned. An example output from this measure is shown in Figure 3.4. To accurately capture the participants' sway motions during testing, two measures of angular velocity were analysed;

the side to side sway, ('Gyr X', Figure 3.4) which is referred to as the mediolateral sway, and the forwards and backwards sway, ('Gyr Y', Figure 3.4) referred to as dorsoventral sway.

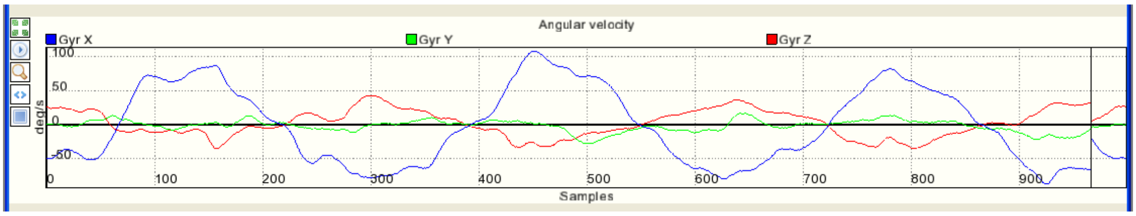


Figure 3.4 Example output measures from the Xsens inertial sensor. X, Y and Z refer to movement in the side-to-side, forward-back, and up-down axes. Sample rate was 100Hz

To assess participants' mediolateral and dorsoventral sway, the standard deviation (SD) of the angular velocity across all samples of the recorded trial time period was calculated. The SD was selected as an appropriate measure to reflect how much variation there was in the angular velocity across each participant's timed testing period. This SD was then used as a measure of postural sway with low SD reflecting stable posture (where the trial data points were very close to the mean) and high SD reflecting increased postural instability (reflected by the data points being spread out over a large range of values). To clarify this measure, the SD of the angular velocity reflects how much variation there is across a trial for the rate of change of the rotation of the participant's head on which the Xsens sensor is positioned. The sample frequency of the Xsens sensor was 100Hz which is appropriate to measure postural sway in humans (Black, et al., 2005; Tinetti, et al., 1988; Woollacott, et al., 1990). All Xsens data were smoothed after collection using a 10 Hz zero-phase Butterworth filter to remove any noise or high frequency (non-human) artefacts in the signals.

3.2.3.1 Postural sway in a young age group across three different standing stances

The results showed that there were clear differences in postural sway between the different standing conditions with the lowest sway found when participants were stood in the most stable stance, with their feet shoulder width apart (Figure 3.5). The next two standing positions were purposefully designed to destabilise the participants, and the results showed the expected pattern. The 'Tandem Romberg' position (where participants were stood with one foot in front of the other) produced higher levels of sway than when stood normally, with feet shoulder width apart, and the greatest amount of sway was unsurprisingly shown when the participants were asked to balance on one leg which was predictably designed to be the most unstable standing stance.

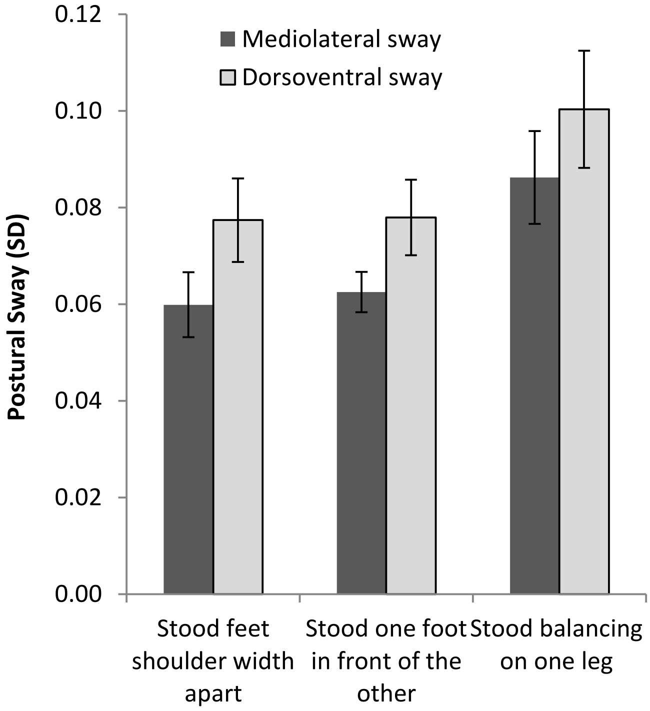


Figure 3.5 The postural sway of a group of young adults across three different standing stances while undertaking a visuomotor tracking task. Two axes of sway are shown: dark grey = side to side sway motion, light grey = back and forth sway motion. Bars = Standard error of the mean.

A 3 (standing position 1, 2 or 3) × 2 (mediolateral, dorsoventral) repeated measures ANOVA was carried out to examine whether there were significant differences between the amount of sway recorded across the three standing stances in the mediolateral and dorsoventral sway axes. There were significant differences in levels of recorded sway between the standing stances, $F(2, 22) = 5.13$, $p<0.01$, $\eta^2_p = 0.32$, and between the axes of sway; mediolateral sway or dorsoventral sway, $F(1, 11) = 15.63$, $p<0.005$, $\eta^2_p = 0.59$, however there was no stance by axes interaction, $F(2, 22) = 0.12$, $p = 0.89$, $\eta^2_p = 0.01$. These results show that there is a marked variation between the axes of sway with consistently higher sway observed on the dorsoventral axis than the mediolateral. It was considered that the different stances may cause postural perturbations to differing effects in the two axes of sway yet these results do not show this as there is consistently more dorsoventral sway, irrespective of stance.

The significant differences that were found between the standing stances demonstrate that this methodology is effective and that the sensor is accurately detecting sway changes between conditions thus showing it is suitable measure to use for further testing. Additionally this pilot work shows that the standing stances used are suitable for causing perturbations in participant's postural stability.

Ideally the hand accuracy data from the target tracking task would have been available. This would have enabled an examination of whether the standing stance had an impact on the performance of the secondary task. Unfortunately this was not possible in this pilot work since additional software development was needed to integrate the Xsens inertial sensor and the KineLab software. At this early stage there were timing accuracy issues within the KineLab tasks which meant it was not possible to analyse the results.

3.3 Discussion

As the pilot study was carried out before the Xsens device was fully integrated with the KineLab system the hand tracking performance data could not be analysed. However, despite the issues caused by the non-integration of Xsens and KineLab, the pilot testing process and postural sway data satisfied all the initial aims for the piloting work. Firstly the testing sessions proved to be very easy to run and quick to complete (a total of around 6 minutes per person). The manipulations of standing position worked well and showed clear differences in postural stability in the predicted directions. Additionally they did not prove too challenging for the young participants. The KineLab tracking task that was used was found to be appropriate for the testing and was to be used again in the next phase of the study. Using the hand held stylus as the KineLab input device worked very well and the use of a joystick was not considered necessary.

There were still some issues of participant safety as the later phases of testing would involve older adults with higher falls risk, therefore appropriate measures would need to be put into place to reduce risk, such as placing a chair behind the participants and always having two researchers on hand during testing, one either side of the participant. The plastic cap worked well at attaching the Xsens device to the head, however the cap was given some small adjustments, mainly for aesthetic reasons to make the system appear less 'clinical'.

From considering the experimental set up and the results of the pilot study, the following modifications were made for the next phase of testing:

- The order of standing conditions were randomised to ensure no effects from practice or fatigue
- The hand not used for the KineLab tracking task was to be kept flat against the participant's side, so as not to be used to aid balance in difficult standing stances
- When standing on one leg, the participant must keep their other leg up at right angles at the knee so it is high off the ground, causing increased postural instability and consistency amongst participants
- Participants' footwear was potentially important to postural stability therefore they were asked to wear shoes with firm flat soles offering support to the front of the foot
- A more stable metal lectern was purchased on which to mount the laptop computer for the standing trials to replace the original wooden lectern
- A tape measure was used to adjust the height of the testing lectern so it was at the exact same proportional level for each participant to allow for different heights
- The testing environment was to be kept as quiet and free from distraction as possible and the participants were to stand in the middle of a large empty room

As the KineLab tracking task only lasted for a total of 1 minute 30 seconds (30 seconds each for slow, medium and fast trials) it was thought extra manipulations could be utilised in the next phase of the study.

The testing time was increased from 1 minute 30 up to 6 minutes which was still not considered to be an excessive length. These extra manipulations included conditions which were to investigate the basic influence of vision on postural sway. The extra conditions were:

1. Stood with feet shoulder width apart with eyes closed for 30 seconds.
2. Stood with feet shoulder width apart with eyes only tracking the moving target at medium speed only on the computer screen for 30 seconds.

These additional conditions were used to investigate the claims of previous literature which suggests older adults will increasingly use their visual systems to control their postural stability with advancing age (Black, et al., 2005; Woollacott, et al., 1990). These two conditions were selected as the first condition, where the participant must close their eyes, deprives them of all visual information leaving them to rely on their vestibular and somatosensory systems for balance control, while in the second condition the visual system is affected as the participant's eyes are required to track a moving target around a screen, thus reducing the visual cues available from the surrounding environment. Both these conditions were expected to cause increased postural sway in the older adult group due to the potential age related deterioration in the postural control system.

3.3.1 Objectives for next phase of testing

The main improvement made following the pilot testing was the complete integration of the KineLab software and Xsens sensor system. These two systems were now fully integrated and ready to work in parallel for the next phase of testing to produce reliable results. This meant the recordings from the two devices were synchronised so the timings of the postural readings and the kinematic data from the hand were possible to analyse together.

The standing conditions for the second pilot study were based on the documented capabilities of older adults in previous research. Additionally, a senior geriatrician was consulted to offer some practical advice for working with older adults. The typical capabilities for older adults were discussed and based on the perceived capabilities of healthy older adults the range of standing positions used in the pilot study was not deemed too challenging. However, it was suggested that for safety not to attempt some of the more challenging standing conditions if the participants did not seem able or feel comfortable.

3.4 Experiment II. Piloting of postural stability measures in a young and an older adult group

3.4.1 Rationale for postural stability study

The second exploratory study aimed to investigate postural sway in a group of young adults (less than 35 years) and a group of older adults (over 70 years) in a range of different standing conditions during completion of computer based visuomotor tasks. The study served to determine if postural sway is affected by age, and also how progressively demanding visuomotor tasks and standing stances can affect postural stability.

3.5 Methods for testing and equipment

3.5.1 Participants

The study involved a group of 15 young adults (8 females, 7 males) aged between 16 to 26 years (mean age 21.4 ± 2.59) and a group of 10 community dwelling older adults (7 females, 3 males) aged between 70 to 87 years (mean age 77.1 ± 5.20). The young adults were recruited through a participant pool scheme of student volunteers at the University of Leeds. The older adults were recruited through contacting a sheltered housing complex in the Leeds area. The researcher visited the housing complex to talk about work concerning falls prevention. At this time, the opportunity to volunteer for the study was explained to the residents in a group meeting and information leaflets and a signup sheet were left in the communal lounge. Residents then had time to decide if they wished to take part and to choose a time that was convenient for them. A week was left between the researcher visiting and the testing times so the older adults could take their time to decide to volunteer once the researcher had left, therefore there was no pressure to be involved. The older adults were all living independently and were physically active. They were free from any neurological conditions or any diagnosed movement related conditions affecting balance. This was established through a medical history and activity questionnaire *(Appendix A).* The questionnaire also revealed that all of the older adult sample were categorised as at least ‘fairly active’, meaning the whole sample undertook some form of physical activity every day. The activities ranged from lower energy activities such as walking around the garden or shops daily, to mid range activities of walking the dog to the most strenuous activities of swimming, folk dancing and badminton. Five of the ten older adults reported having high blood pressure for which they were taking medication. Three participants were taking more than 4 medications per day. It has been reported that taking a high number of medications (>4 per day) has been shown to increase the risk of falls (Tinetti, et al., 1994). Six older adults reported suffering from arthritis which is another reported risk factor (Tinetti, 2003) but none felt it affected their balance in any way. The data from the medical history and activity questionnaire was used further when exploring how well the older adult sample performed in the later postural stability tests.

3.5.2 Equipment and materials

The postural sway measurement system included an Xsens inertial sensor connected to a Toshiba tablet laptop. The laptop was positioned on a metal stand and the Xsens sensor was attached to the head by a plastic cap.

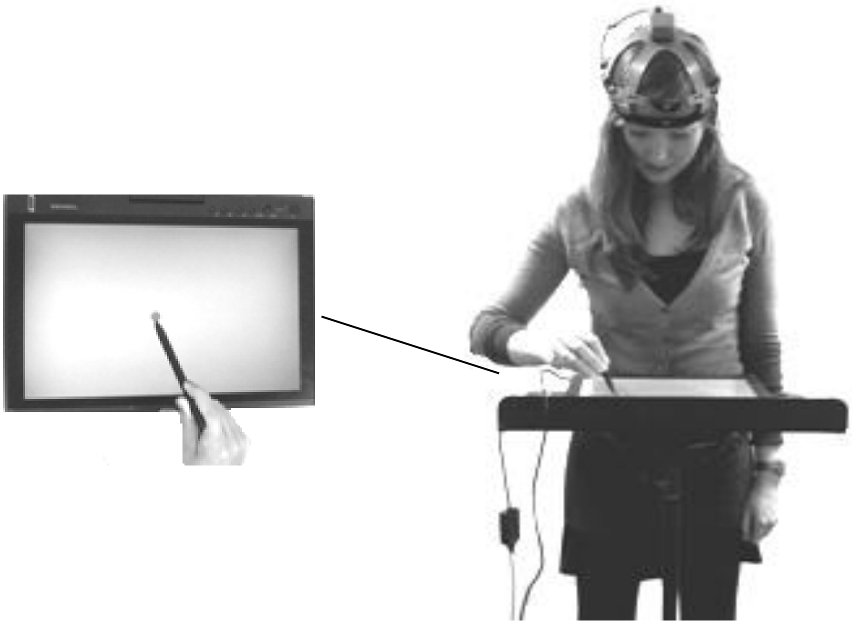


Figure 3.6 The experimental setup with a participant beginning the KineLab task

3.5.3 Design and Procedure

Participants were tested in the standardised setting of a large, empty room free from noise or other distractions. The testing system was based in the middle of the room, so participants were not stood close to walls to allow them any immediate visual stability cues. A chair was positioned behind them for safety.

Before beginning testing, participants completed the brief activity questionnaire about their past and current activity levels. In addition, the older adult group completed the short medical history. The medical history assessed relevant factors such as if the participant had previously had a fall or if they were currently taking any medications which have been linked to increased falls risk.

To counter any possible effects of postural hypotension in the participant sample, all participants were asked to rise slowly when standing from a seating position. They were given a few minutes to prepare before beginning the testing; this was to ensure their blood pressure had time to stabilise after standing.

The testing lectern for the laptop was measured and adjusted for participant height; the lower lip was the same height as the participant's elbow. The inertial sensor was fitted securely to the participant's head using the adjustable plastic cap. Participants were informed to remain focussed on the computer screen and not to look away from the screen during testing. The researcher ensured not to distract the participant in any way.

Postural stability was then measured in the different standing conditions whilst carrying out the computer based visuomotor tracking task. In the young adult group, there were 5 conditions to complete; two lasted 30 seconds each, the first involved standing with eyes closed, the second involved standing with eyes open visually tracking a moving target at a slow speed using eyes only (not with the hand held stylus). The other three conditions lasted 1 minute 30s each and in these the participant tracked a moving target at three different speeds using the hand held stylus whilst stood in one of the following stances; Position 1: stood with feet shoulder width apart, Position 2: stood in a Tandem Romberg position (one foot in front of the other), Position 3: stood balancing on one leg. In Position 3 the participants were allowed to have a brief practice and choose which leg they felt was preferable to stand on. After choosing and beginning testing, they were not allowed to change legs.

In the older adult group, participants were given the option to complete the same 5 testing conditions as the young adult group. The number of standing positions varied depending on the individual's ability and confidence. Participant safety was always the key issue to consider; if a participant did not feel comfortable attempting a position they were encouraged not to continue. After testing all participants were fully debriefed and were given the opportunity to ask questions.

3.6 Results

The results from this phase of testing are not directly comparable to the original pilot study (previously presented in this chapter) due to the improvements made with the integration of the KineLab software and the Xsens inertial sensor. These modifications mean that now within each trial the results can be broken down into the different speeds of target motion; slow, medium, fast. This allows further analysis of each condition as the effect of target speed on postural sway can be specifically analysed. In the previous pilot study the standard deviation of postural sway results for all three tracking task speeds had to be combined into one end result; the total of slow, medium and fast speeds.

3.6.1 Results of eyes closed and visual tracking for young and older adults

Standard deviation (SD) was calculated as a measure of postural sway in both mediolateral and dorsoventral axes; low SD indicates postural stability, high SD reflects more sway and increased postural instability. The SD was examined to see if there were differences in postural sway between age groups; young or older adults, condition; eyes closed or visual tracking, and axes of sway; mediolateral or dorsoventral (Figure 3.7).

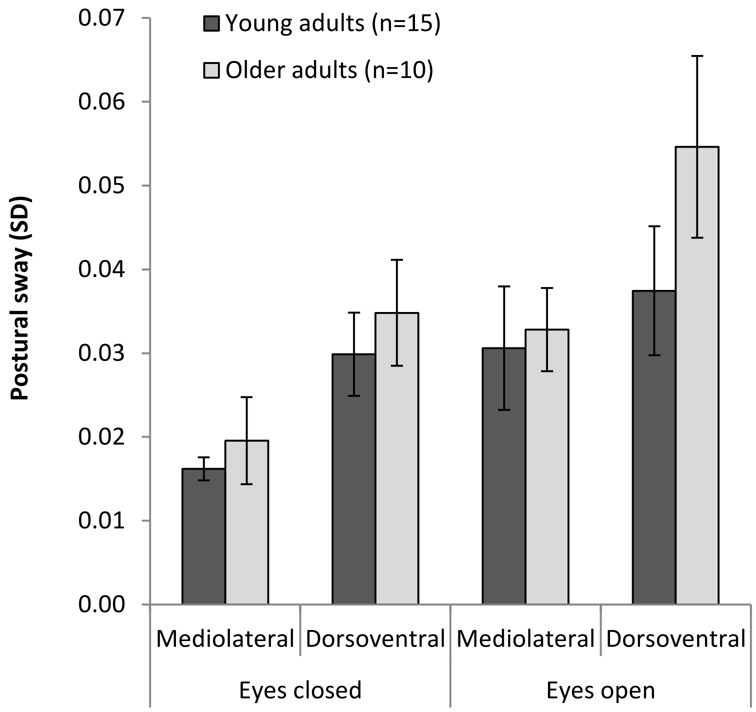


Figure 3.7 The postural sway recorded in a young and an older adult group during two 30s testing conditions; stood with eyes closed and stood visually tracking a slow moving target. Two axes of sway are shown; mediolateral and dorsoventral. Bars = Standard error of the mean.

From Figure 3.7 it would appear that the older adult group show higher levels of postural sway across all testing conditions compared to young, especially when focussing on the dorsoventral axis of sway. A 2 (young adults, older adults) × 2 (eyes closed, eyes tracking) × 2 (mediolateral, dorsoventral) mixed methods ANOVA was carried out; no significant main effect of age group was found between the recorded levels of postural sway in the young and older adults, $F(1, 23) = 1.22$, $p=0.28$, $\eta^2 p = 0.05$. The ANOVA found a significant main effect of condition between postural sway in the eyes closed and visual tracking conditions, $F(1, 23) = 5.67$, $p<0.05$, $\eta^2 p = 0.19$, and a main effect of axes of sway, $F(1 ,23) = 30.27$, $p<0.001$, $\eta^2 p = 0.57$. No significant interactions were found; condition and axes of sway, $F(1, 23) = 0.001$, $p = 0.98$, $\eta^2 p = 0.02$, or between age group and axes of sway, $F(1, 23) = 2.53$, $p = 0.125$, $\eta^2 p = 0.09$, or age group and condition, $F(1, 23) = 0.25$, $p = 0.62$, $\eta^2 p = 0.01$.

In summary, although there did appear to be differences between the postural sway of the young and older adult group, these age related differences were not found to be significant between the eyes closed and visual tracking conditions. Although there were no age group differences found, after closer inspection of raw data and as observed during testing, some individuals within the older adult groups appeared to be very influenced by the two visual testing conditions showing high levels of postural sway during testing. There appeared to be much less variability found between the results for the younger adults. The results show that potentially the Xsens sensor is not detecting the differences between older and younger adults to an adequate level.

3.6.2 Results of standing stance manipulations for young and older adults

The postural stability results from the young and older adult participants undertaking three different standing conditions were again compared by calculating the standard deviation (SD) to represent variance in postural sway. All young participants (n=15) carried out the tracking task in all three standing stances with no difficulty, however not all of the older adults were able to undertake all three of the standing stances. The number of older adults who were able to complete each standing condition decreased as the positions became more physically demanding. All of the older adult group were able to complete testing in standing position 1, stood unaided with feet shoulder width apart (n=11); however in position 2, one foot in front of the other (Tandem Romberg), three participants declined to continue; and in position 3 (standing on one leg) another four participants declined to take part. Therefore the final testing condition, position 3, only had three older adult participants able to complete it.

During the standing positions, participants were required to carry out a dual tasking condition which was a visuomotor tracking task. Performance on the task was assessed using the root mean squared error (RMS error) of hand tracking accuracy. RMS error gave an accurate representation of how far the participant’s hand held stylus deviated from the moving target’s route, thus a low score reflects good performance (low error). The postural sway SD results will be presented first, followed by the RMS error results from the visuomotor tracking task.

3.6.2.1 Postural sway for young and older adults tracking a target while standing feet shoulder width apart

The postural sway recorded in standing position 1 confirms older adults experience higher levels of postural sway in both axes (mediolateral and dorsoventral) across all three speeds of visuomotor target tracking (Figure 3.8). There is also an increase in postural sway as the tracking task speed increases; this is shown in both young and older adults, although older adults appear to be affected to a greater extent from increasing tracking task speed than young adults.

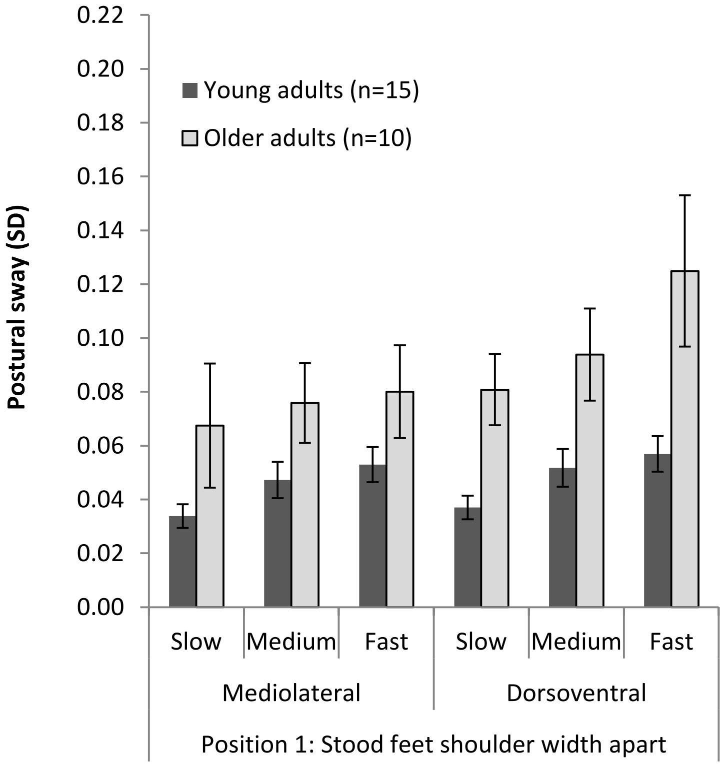


Figure 3.8 Standing Position 1: Postural sway (SD) in young and older adult groups while undertaking a three speed target tracking task. Bars = Standard error of the mean.

As expected from the clear pattern of results shown on Figure 3.8, a 2 (age) x 3 (speed) x 2 (axes) mixed measures ANOVA found a main effect of participant age group, $F(1, 23) = 10.55$, $p<0.005$, $\eta^2_p = 0.31$; showing older adults experienced significantly higher postural sway compared to young adults. There was also a significant main effect of task speed, $F(2, 46) = 4.81$, $p<0.05$, $\eta^2_p = 0.17$, showing that tracking task speed significantly affected postural sway, and a significant effect of axes of sway, $F(1, 23) = 4.88$, $p<0.05$, $\eta^2_p = 0.18$, showing different levels of sway between mediolateral and dorsoventral axes. There were no significant interactions found between axes of sway and age group, $F(1, 23) = 2.99$, $p = 0.09$, $\eta^2_p = 0.12$, or speed of tracking task and age group, $F(2, 46) = 0.31$, $p = 0.73$, $\eta^2_p = 0.01$, or axes of sway and speed of tracking task, $F(2, 46) = 1.42$, $p = 0.25$, $\eta^2_p = 0.06$. Therefore both young and older adults' postural sway was affected by the tracking task speed increases to similar levels, and the axes of sway were not affected differently due to participant age group or tracking task.

3.6.2.2 Postural sway for young and older adults tracking a target while standing in a Tandem Romberg position; one foot in front of the other

In standing position 2, the number of older adults able to confidently complete this condition has reduced by three to a total of only seven. These three older adults did not feel comfortable continuing the testing and for safety reasons they were made to feel reassured that they could stop at any time. The SD results of the postural sway in standing position 2 did not appear to show the same linear increase according to the increase of speed of target tracking as shown in the results from standing position 1. However, again there appeared to be large differences in postural sway between the young and older adult age groups, as well as notable differences in the axes of sway, but mainly for the older aged group (Figure 3.9).

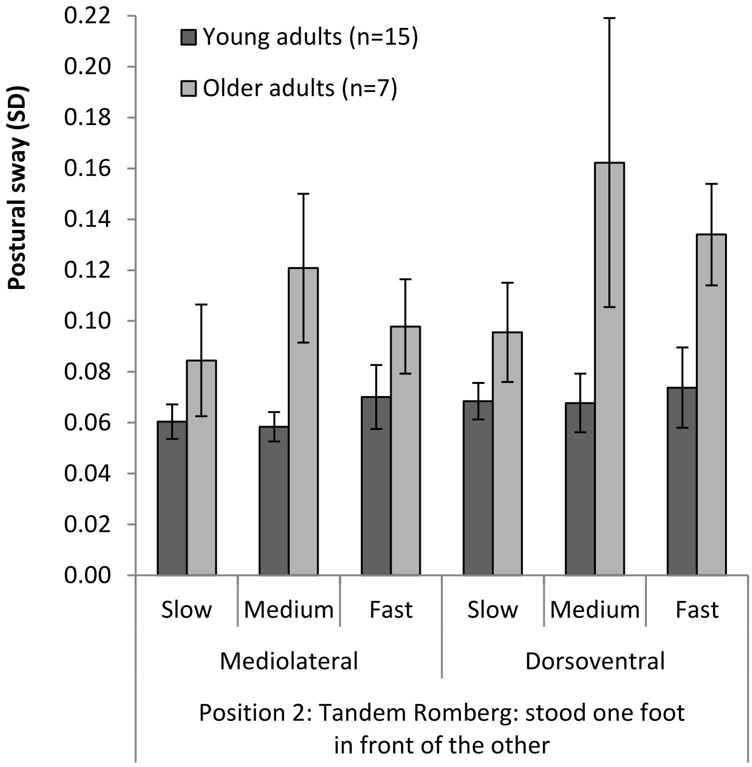


Figure 3.9 Standing Position 2: Postural sway (SD) in young and older adult groups while undertaking a three speed target tracking task. Bars = Standard error of the mean.

For standing position 2 Tandem Romberg, a 2 (young adults, older adults) × 3 (slow, medium, fast) × 2 (mediolateral, dorsoventral) mixed measures ANOVA found the only significant main effect was for age group, $F(1, 20) = 7.09$, $p<0.05$, $\eta^2_p = 0.26$ where older adults showed a substantially higher postural sway than young adults. There was no significant effect of speed of tracking task, $F(2, 40) = 2.59$, $p=0.09$, $\eta^2_p = 0.12$, or the axes of sway, $F(1, 20) = 3.22$, $p = 0.09$, $\eta^2_p = 0.14$. In standing position 2, the pattern shown in standing position 1 of gradually increasing postural sway according to the increasing speed of tracking task are no longer shown in the older adult age group. This is most likely due to the difficulty of the standing condition which negates any previously seen effect of difficulty of testing condition. In this task the older participants appear to be more negatively affected by the difficulty of the postural task, however there were no significant interactions between axes of sway and age, $F(1, 20) = 1.07$, $p=0.31$, $\eta^2_p = 0.05$, speed of tracking task and age, $F(2, 40) = 2.69$, $p=0.08$, $\eta^2_p = 0.12$ or axes of sway and speed of tracking task, $F(2, 40) = 1.15$, $p = 0.33$, $\eta^2_p = 0.05$.

3.6.2.3 *Postural sway for young and older adults tracking a target while balancing on one leg*

The results from the final standing stance, balancing on one leg, provide interesting results, but they need to be interpreted with caution. This is because only a very small number of older adult participants were able to undertake the final standing position (n=3). However, these 3 older adults who were able to undertake this most challenging position appear to do so extremely proficiently, achieving similar levels of sway to those observed in the young adults on the mediolateral axis. On the dorsoventral axis the older adults do appear to show higher levels of sway compared to the young adults, and both age groups appear to be affected by task speed.

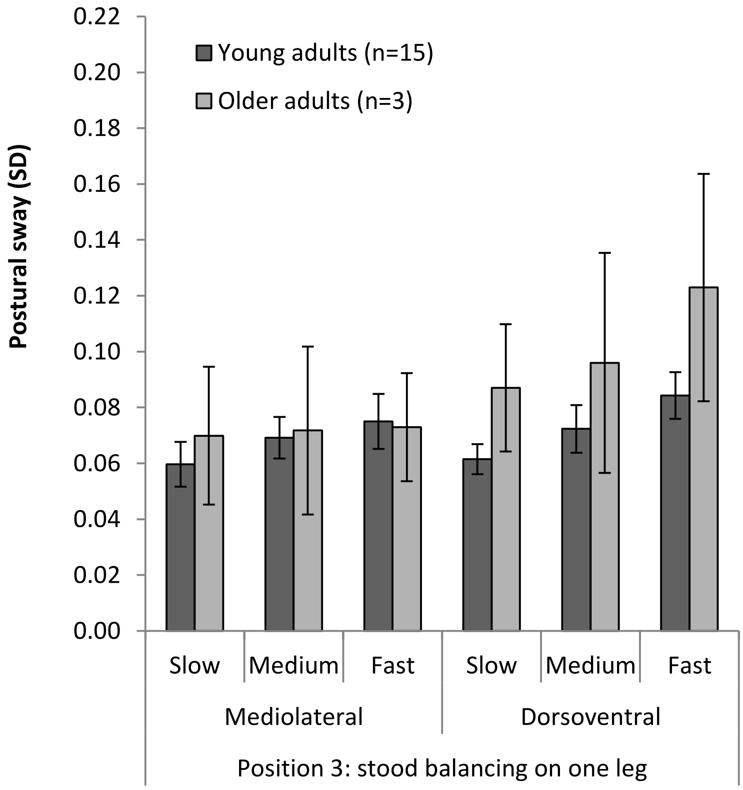


Figure 3.10 Standing Position 3: Postural sway (SD) in young and older adult groups while undertaking a three speed target tracking task. Bars = Standard error of the mean.

Unfortunately in standing position 3 stood on one leg, there were too few older adult participants able to undertake this condition to allow statistical analysis using ANOVA. The fact there was no observable difference in sway on Figure 3.10 between young and older adults on the mediolateral axis will be explored in further detail in the next section concerning older adults who appear to have excellent postural control compared to their peers of similar age.

3.6.2.4 *Highly functioning older adults demonstrating the difference in functioning within a cohort of similar aged older participants*

One of the most interesting findings from the second pilot study was the difference that exists within a small cohort of similar aged older adults. Although all older adult participants (n=10) managed to complete the first standing position for the whole testing duration, the other standing conditions proved to be more challenging for certain members of the group. Due to issues of safety and participant confidence only 7 of the 10 participants managed the Tandem Romberg position (position 2) and then only 3 of the remaining 7 participants managed to complete the condition of balancing on one leg (position 3). Those remaining few older adults who were able to undertake standing position 3 appeared to do so with considerable ease and achieved levels of sway that were of a comparable level to the young adults (Figure 3.10). Due to the relatively low levels of postural sway in the most challenging standing position for these older adults (n=3), their results were compared to the postural sway shown by the rest of the older adult group (n=7) in standing position 1; the results are shown on Figure 3.11.

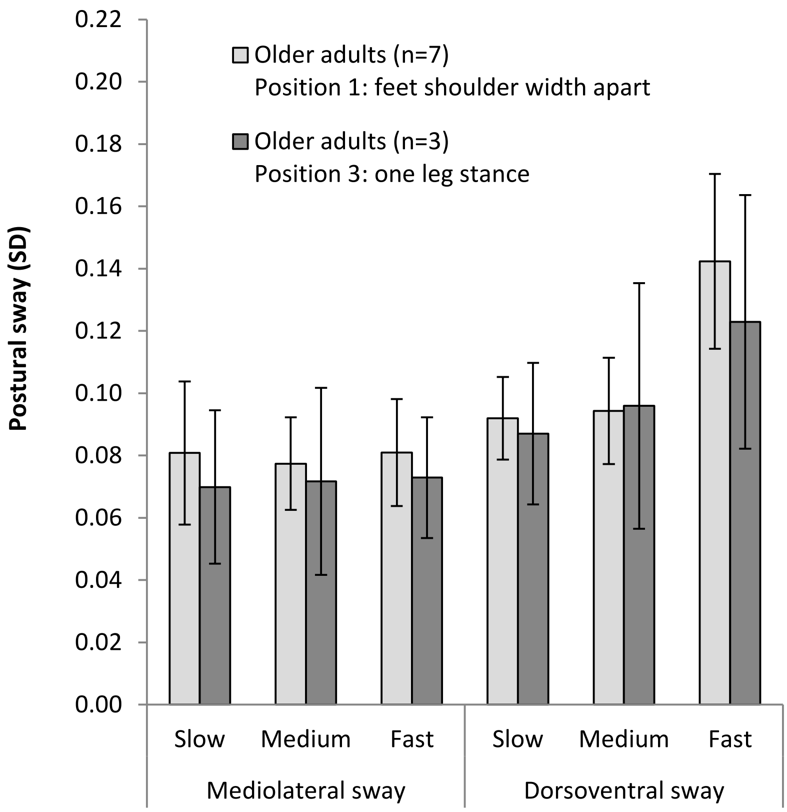


Figure 3.11 Older adult postural sway after dividing the group into two according to ability to complete the standing positions; one group (n=7) were unable to complete Position 3, therefore their postural sway is shown from standing Position 1 compared to other older adult group (n=3) who were able to complete standing Position 3. Bars = Standard error of the mean.

As shown in Figure 3.11 very similar levels of postural sway were found in the group of older adults (n=7) when undertaking testing in the stable standing position 1, compared to those older adults (n=3) in position 3 when stood on one leg. In fact, consistently across all testing conditions, except for dorsoventral sway at medium speed, the postural sway of the older adults stood on one leg is remarkably less than for those older adults who were stood with feet shoulder width apart, a typically much more stable position.

This finding demonstrates the difference in ability amongst a group of similarly aged older adults of comparable health and activity levels. The older adults who were not able to undertake standing position 3 had an average age of 77 years (SD 5.88) while the participants who were able to undertake this most challenging standing position had an average age of 74 years (SD 2.31), so the groups were not dissimilar in age. Therefore, although there was a wider range in age of the less able group it shows age is not necessarily a simple predictor of ability.

This difference in ability between the older adult participants who were able to complete all three of the positional tasks compared to those participants who completed only the first one or two of the positional tasks was further investigated. The older adult sample was divided into three sub groups depending on which positional tasks they were able to complete; Position 1 only (n=3), Positions 1 and 2 (n=4) and Positions 1, 2 and 3 (n=3). Although the numbers in the older adult sample are small, the postural sway results from Position 1 when divided according to sub groups (Figure 3.12) reveal that there were differences in the postural sway of the three sub groups even when tested in a normal standing stance (Position 1). As shown on Figure 3.12 the older adult group who are able to complete all three positional tasks have far lower postural sway in both mediolateral and dorsoventral axes across all three testing speeds in Position1 compared to the other two groups. Additionally the expected effect of task speed on postural sway (increase in task speed resulting in increase in sway) is observable only in the group who were able to undertake all three standing tasks; in the other two groups the effect on postural sway from task speed is negated. There is a general trend for the group who were able to complete Positions 1 and 2 to show a lower postural sway across the testing conditions than the group who were only able to undertake Position 1, however the differences between these two groups is far less than the group who were able to perform all three positional tasks.

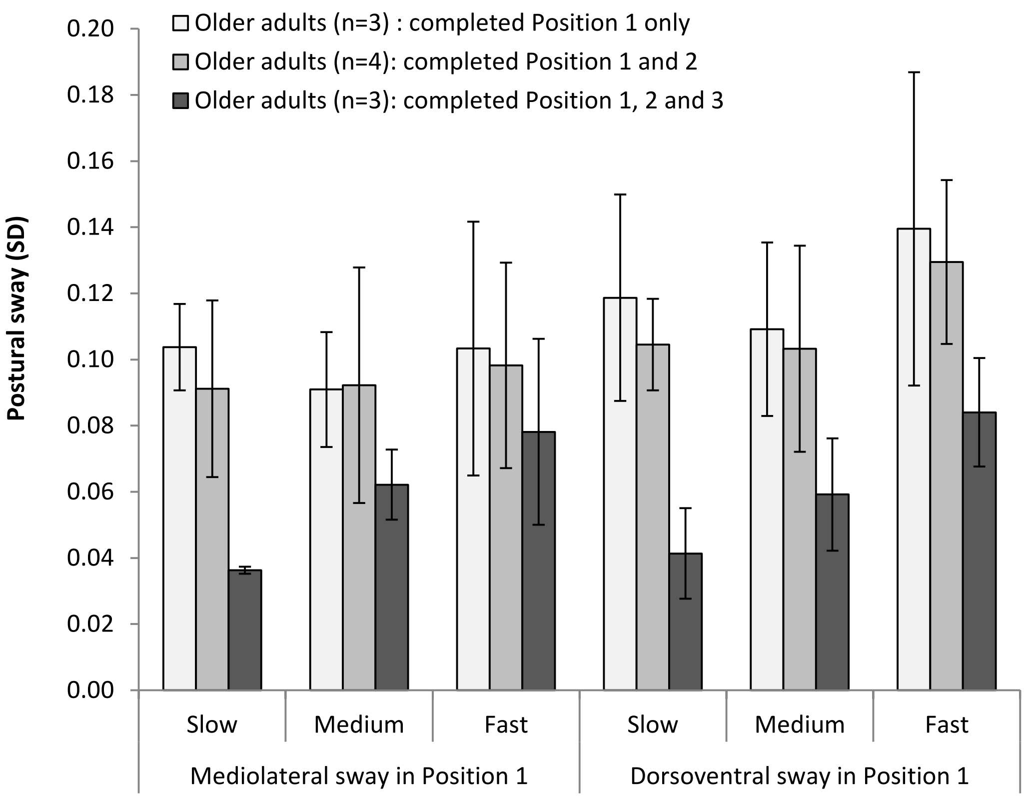


Figure 3.12 Older adult postural sway in testing Position 1 after dividing the group into three sub groups according to ability to complete the standing positions; Position 1 only (n=3), Position 1 and 2 (n=4) and Position 1, 2 and 3 (n=3). Bars = Standard error of the mean.

From looking at the medical history and activity questionnaire in more detail, some differences were detected between the older adult participants when split according to ability. Firstly there was a notable difference in the average age of the participants within each of the three groups; those who were only able to perform the first positional task had an average age of 83 years compared to those able to undertake the two positional tasks and the three positional tasks having an average age of 75 years and 74 years respectively. The participants with the lowest self reported daily activity (n=3) were all in the group only able to undertake the first positional task, with those undertaking the most strenuous daily activities (swimming, badminton, dance classes) (n=3) all in the group who performed the full three tasks. However, despite the differences in average age and activity levels, some similarities between the groups in their medical history were reported. A similarity was found across the groups in their number of reports of the presence of arthritis, and additionally in each of the three groups there was at least one person taking over 4 medications per day. However, in the group who were able to perform all three positional tasks, apart from the one participant taking over 4 medications per day, the other two participants were not taking any medications; there was not a noticeable difference between these three participants' postural sway results.

3.6.3 Performance on the visuomotor tracking task

Analysis of the Root Mean Square error (RMS error) showed how performance on the visuomotor tracking task was affected by the speed of tracking task, the different standing position and the age of the participants. The results also explored whether there was a 'trade-off' between maintaining postural stability and achieving a good performance on the tracking task. The mean RMS tracking error for young and older adult participants in the different standing conditions and the number of participants taking part in each condition are shown in Figure 3.13.

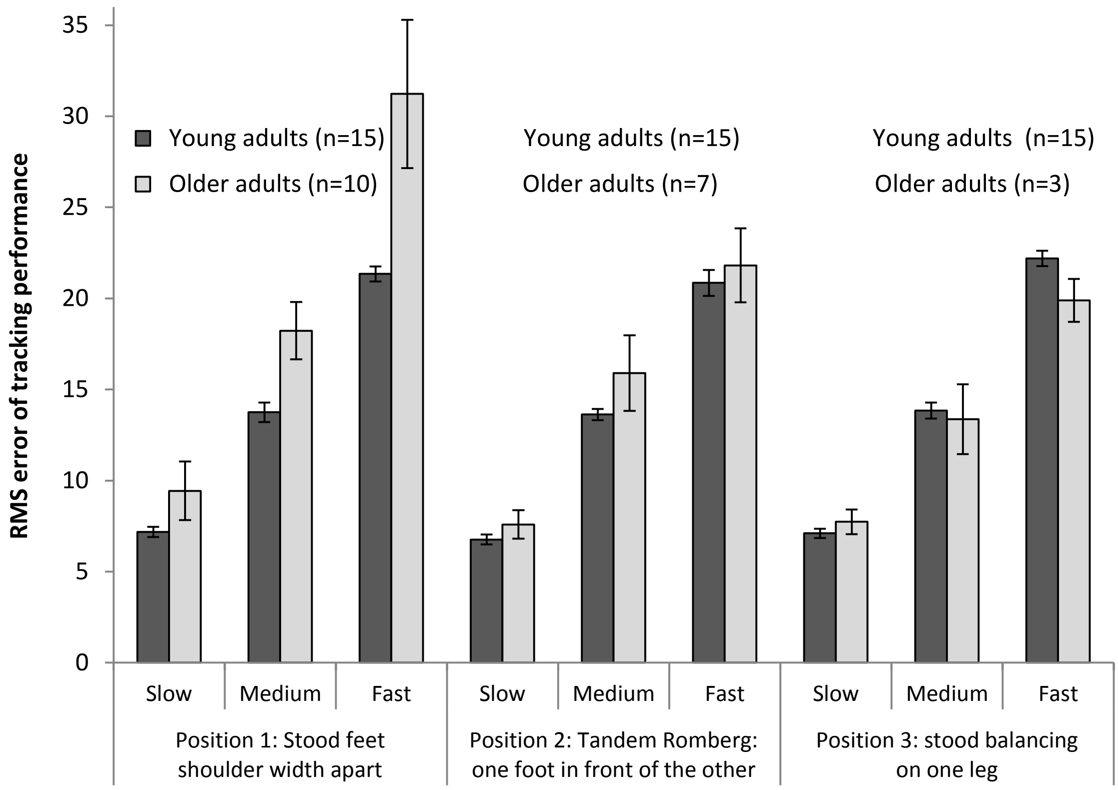


Figure 3.13 Tracking task error shown by the young and older adults according to standing position and tracking task speed. Bars = Standard error of the mean.

For standing positions 1 and 2, a 2 (age group) by 3 (tracking speed) ANOVA was carried out using the RMS error scores for the young and older adult groups to see if there was an effect of age or tracking task speed on task performance. The Greenhouse-Geisser correction was used when there was a violation of sphericity within the data.

In standing position 1 there was a significant effect of age, $F(1, 23) = 8.36$, $p<0.05$, $\eta^2_p = 0.27$, and tracking speed, $F(1.17, 26.98) = 144.72$, $p<0.001$, $\eta^2_p = 0.86$, and a significant interaction between the two, $F(1.17, 26.98) = 6.14$, $p<0.005$, $\eta^2_p = 0.21$. This suggests that in position 1 as the tracking task became faster and more challenging, the RMS error scores, as would be expected, became higher reflecting worse performance on the task. This effect was more prominent in the older adult group and their performance become significantly worse with increasing speed.

In standing position 2 there was no effect of age, $F(1, 20) = 0.24$, $p=0.63$, $\eta^2_p = 0.12$, but there was still a significant effect of tracking speed, $F(1.52, 30.48) = 278.51$, $p<0.001$, $\eta^2_p = 0.93$. The interaction between the two groups was not significant, $F(1.52, 30.48) = 0.53$, $p=0.59$, $\eta^2_p = 0.03$. These results show that those older adults who were able to undertake standing position 2 performed at a similar level as the young adult group on the visuomotor tracking task.

As described in the previous analysis section concerning the postural sway, as the different standing conditions became more challenging, the older adult participants who were not as physically able or confident in their abilities did not continue the testing. In standing position 3 there were only 3 older adults able to undertake the testing, thus not enough participants to carry out statistical testing. However from looking at the RMS error means in position 3 (Figure 3.13) it is interesting to note that the remaining older adult participants performed at a comparable level to the young group in their tracking performance. In fact, in the medium and fast tracking speed conditions in position 3, the older adults achieved less tracking errors than the young participants, even though they were undertaking this task balancing on one leg. This interesting finding is most likely due to the fact that those older adults able to undertake the final testing position were the most physically able and so in addition were not showing effects of ageing on their fine motor skills required for accurate tracking. Therefore they were able to achieve an RMS error score of tracking task performance equivalent to participants 50 years their junior.

3.7 Discussion

The results from the second postural sway pilot study provide an interesting starting point to continue the development of research into the differences in postural stability between young and older adults. Previous research has shown that as people age they demonstrate increased low frequency postural drift (Williams, McClenaghan, & Dickerson, 1997). The differences in postural sway of the young and older adults in the least challenging standing position (stood feet shoulder width apart) provide an interesting insight into how the older adults are affected to a greater extent by the tracking task and how the task serves to increase their postural sway.

In standing position 2, the older adults who were able to undertake this condition show significant detriments to their standing postural sway whilst undertaking the task; however their actual tracking performance on the visuomotor task is excellent. The older adults show no significant differences in their task performance compared to the young. This demonstrates that perhaps the older adult group are not able to complete both tasks to an optimum level; therefore they place their focus on achieving good performance on the visuomotor task. This supports the task prioritisation model (Lacour, et al., 2008) as discussed in Chapter 1 which states that in a demanding situation with two tasks competing for cognitive resources, one must be given priority. It has been suggested that from a survival point of view, people with reduced postural control will typically use the 'posture first' model (Shumway-Cook, et al., 1997) however in this case the concurrent visuomotor tracking task appears to have priority over postural stability.

Statistical analysis could not be undertaken on the postural sway or the RMS error in standing position 3 due to reduced numbers of older adult participants able to complete the condition of balancing on one leg. This pilot has served to highlight the fact that less challenging standing positions will be required in future testing with older adult groups. Due to the excessive difficulty of these positions, it meant that only the most physically able older adults were capable of completing standing position 3. The older adults who were able to undertake this condition were exceptional in their postural control and motor skill abilities, neither of which appeared to be affected by their older age. This led to the remaining older adult group (n=3) achieving better results in their visuomotor tracking task performance than the young adults. While this is an interesting finding and shows the wide variation that exists in the abilities of a group of older adults, it does not reflect the functioning of the whole group due to the very small sample size. Therefore, because the standing positions were too challenging, a key data collection opportunity was lost in the second pilot study. However, the conditions used in this study did prove of interest to observe the differences in physical capabilities of an older adult sample. Even though all participants tested were active and independent living older adults, some found the conditions too challenging while others found them apparently easy. Appropriate balance conditions are needed to ensure all participants can undertake all of the testing. Further reading has shown that such extremes in stance are not needed in order to produce perturbations in postural sway in older adults (Melzer, et al., 2004) and other research has shown there are significant differences in postural stability by simply standing in a narrow or wide stance (Day, et al., 1993). In the next phase of testing these previously used challenging standing positions may not be necessary to assess older adult postural stability; future work will examine simpler manipulations in standing posture, such as stood in a narrow or wide standing stance.

Another noteworthy finding from the second pilot is that although the young and the older adult group received the same instructions before beginning the eyes open target tracking task (‘keep your head still and track the target with your eyes only’), it would appear the older adult group found this difficult and tended to track the target by moving their head as well. This revealed differences in how the age groups interact with their environment, with the older adult group becoming much more physically involved with the task stimuli and moving their heads with the movement of the target. From retrospective reflection on the experiment design, it would be extremely beneficial to have had an eyes open fixating condition with no target motion, as well as the eyes open tracking a target. This would have allowed better comparison between the eyes open and eyes closed conditions with no additional moving stimuli. This condition was added to the next phase of testing to allow further investigation and interpretation of results.

The head movement also raises questions as to whether it is suitable to attach the Xsens sensor to the head of the participant. A way of assessing the postural sway of the whole body would potentially be a more useful measure. Through using a secondary measure of whole body postural sway it would serve to determine whether the Xsens sensor is measuring postural sway or whether it is simply reflecting head movements. As the Xsens sensor was placed on the head, the measurements may accurately detail the motion of the head which could be directly related to the sway of the body, but head movement can also be independent of the overall body sway. This will be discussed in the plans for the next phase of testing.

The difference in the eyes open condition between young and older adult has important consequences for further research. It appears that the older adult group are being driven by the movement of the visual stimuli much more than the young and are showing increased postural sway as they focus their attention on the visual cue. The results show that the older adults' postural sway was affected by testing condition far more than the younger adults; this has practical implications for falls prevention. The older adult groups' postural sway appears to have been driven by the moving visual stimuli and they have become affected by the external influence of the movement on the screen. This may have repercussions for an older adult's postural stability being compromised in a similar real world setting where there is a strong moving external visual stimulus.

3.7.1 Objectives and implications for next phase of research

Much of the initial pilot testing was to assess the suitability and the capabilities of the Xsens inertial sensor to measure postural sway. The pilot experimental work has identified which of the calibrated data output measures were most meaningful to measure postural sway in an upright standing stance. The Xsens inertial sensor was appropriate to use at this phase of the testing of postural sway, however further work still needs to be done as there are issues relating to the suitability of the sensor positioning on the head as overall body sway and head movement could be independent from each other. Therefore a secondary measure of body sway is deemed appropriate to ensure postural sway is being accurately assessed. The integration of the Xsens sensor with the KineLab software proved extremely beneficial in accurately testing participants' postural sway whilst carrying out a visuomotor task and using this set up there are many further experiments that could be easily run using this software configuration.

The improvements to the research methods and protocol identified in the second postural sway pilot study are easy to implement; adding additional visual state conditions (eyes fixating on a stationary target while postural sway is assessed) and also using less challenging standing conditions more suitable to the older adult participants (narrow stance and wide stance). Consequently the next phase of testing can proceed quickly and the results will offer further insight into postural sway that were lacking in this study.

Another key factor for the next phase of testing is to include more qualitative assessments to measure psychological outcomes of falls and to further investigate fear or falling. The development of this aspect of the thesis will be used to produce novel research data. As identified in the earlier review of the literature (Chapter 1), number of falls is not necessarily the best outcome for assessing effectiveness of falls prevention strategy. There are other important measures such as psychological state as this is directly related to quality of life, which is ultimately what this research is trying to help improve in older adults. An additional measure which is essential to include for the next phase of testing with older adults is an assessment of cognitive functioning. Cognitive decline is linked to an increased risk of falls (Susan W. Muir, et al., 2012; Shaw, 2003; Van Dijk, et al., 1993) therefore a measure to assess cognitive functioning is critical for the next phase of testing.

4 The development of postural stability in children

4.1 Introduction

4.1.1 The introduction of the Wii balance board to the testing set up

The previous chapter presented pilot work investigating testing protocols and suitability of equipment to measure standing balance in a group of young adults and older adults. The pilot work was important to establish key testing elements such as the appropriateness of the varying visual conditions, the visuomotor task, the suitability of the range of standing stances and the physical capabilities of older adults undertaking the testing. As documented in the previous chapter, some elements of the pilot testing were found to be appropriate, such as the visual conditions and the visuomotor task. However, other elements were unsuccessful or needed further development for use in later testing. One such element was using the sole measure of the head mounted Xsens sensor. On reflection, it was thought that future testing could benefit from the incorporation of an additional measure of postural sway as head movement can occur independently of the body's overall postural sway (Scharli, van de Langenberg, Murer, & Muller, 2013). A major adaptation in this current chapter is therefore the introduction of a new piece of testing equipment to assess whole body sway. The rationale for this addition is that two measures would allow for the relationship between the head movement and body sway to be explored. In previous research assessing standing balance, large scale clinical force plates have been used as they are considered to be the 'gold standard' for measurement. However, force plates have some major limitations due to availability, cost and size, especially when transportation of the testing setup is required to access hard to reach participant groups, for example older adults or children. Consequently, when research started to emerge showing the reliability and validity of an 'off the shelf' piece of inexpensive gaming equipment (the Wii balance board; Nintendo, Kyoto, Japan), it offered an opportunity to accurately assess standing balance with an affordable and portable measure (R. A. Clark, Bryant, Pua, McCrory, Bennell, & Hunt, 2010; Gras, Hummer, & Hine, 2009; Young, Ferguson, Brault, & Craig, 2011). The Wii balance board was found to have excellent test retest reliability and function at a comparable level to laboratory grade force platforms (R. A. Clark, et al., 2010) however it was available at a fraction of the price. The Wii balance board measures force distribution on the standing platform via four in built transducers. This force distribution information is communicated wirelessly via Bluetooth, normally to the associated games console. In the case of my research, the Wii balance board was configured to communicate with a laptop which ran the accompanying computer tasks using the KineLab software. KineLab was able to process and record the total Centre of Pressure (CoP) force distribution data from the Wii balance board across a trial, and with some further processing in MATLAB (MATLAB, 2010) an overall measure of the total CoP path length (mm) was calculated. Subsequently, due to its ease of use, excellent experimental validity, availability and cost, the Wii balance board was deemed appropriate to be used in conjunction with the Xsens sensor to provide a more complete measure of postural sway. An improvement was made from the previous chapter with regard to the Xsens sensor data, through the development of a more complete measure to assess movement from the Xsens sensor. The pilot testing chapter had used the standard deviation of the Xsens sensor’s X and Y angular velocity to reflect postural sway, and although this measure worked to some extent, a more sophisticated measure was needed to allow more detailed analysis. With further consideration from looking at the pilot chapter’s results it was decided that the angular velocity measure did not accurately capture head movement. It was an accurate measure of the timed rate of change of the head’s rotation but that was not exactly what was required in this testing. Therefore the results from Chapter 3 pilot testing were still useful but it was felt that the measure could be improved upon further to reflect a more appropriate measure. To advance upon the basic measure of SD of angular velocity a calculated output of the summed angular rotation of the Xsens position over three axes was developed to provide a fuller output metric for movement of the head. The multiple streams of recorded data were time locked so the head rotation data (°) from the Xsens head sensor, the kinematic data (mm) from the KineLab tracking task and the CoP path length data (mm) from the Wii balance board were all recorded simultaneously.

Although the Wii balance board has been used in other research studies (Bainbridge, Bevans, Keeley, & Oriel, 2011; R. Brown, Sugarman, & Burstin, 2009; R. Clark & Kraemer, 2009; Yamada, ·Aoyama, Nakamura, Tanaka, Nagai, Tatematsu, Uemura, Nakamura, Tsuboyama, & Ichihashi, 2011), before beginning the large scale work with older adult populations, the limitations and capabilities of this new piece of equipment for the current study need to be explored. This is one of the reasons that led into this chapter’s work on the development of standing postural stability in children.

4.1.2 Rationale for working with a developmental population

The overall aim of this thesis is to explore human postural stability and the changes that occur with age. The principle focus of this work is investigating age related decline in postural control in older adults. This is a high priority due to the significant numbers of injuries that are caused from falling in this older age group. However, there is another age group who are known to experience significant difficulties with their postural control leading to a high frequency of falls; infants and young children exhibit failures in their postural control system with numerous falls throughout childhood as they develop their postural control abilities. Falls in children are not such a serious clinical concern as they are for older adults but this investigation is important as a young age group could provide further insight into the mechanisms of balance. A developmental population of primary school aged children aged 5 to 11 years were selected for this phase of testing. This age group was used because distinct and detectable differences should exist in postural stability between the ages that the Wii balance board should be able to discriminate (Assaiante, 1998). Thus, this age group provided an excellent opportunity to test measurement capabilities. Some researchers have found that typically developing children follow a fairly well defined trajectory of postural control development, with clear differences shown between discrete age groups (Assaiante, 1998). Therefore the Wii balance board can show its efficacy in detection of subtle differences in postural sway between age groups. Testing the new equipment on typically developing children initially rather than an older adult group will allow these early results to be uncomplicated by the potentially complex co-morbidities that can be present in an older adult population. The results collected from the different groups of primary school aged children will provide a way of determining if the equipment is suitable to detect subtle differences between other groups.

Research into how infants and children develop their postural control has an application in the study of the decline experienced through the ageing process. Some strong similarities between postural control development early in life and deterioration towards the end of life have been found (Woollacott, et al., 1990) and will be explored further in this chapter. This exploratory work into the development of balance in children may help to build a more comprehensive account for the later work to be presented in this thesis concerning the decline of postural control in older adults. As described by Woollacott and Shumway-Cook (1990) in their comprehensive review of the changes that occur in postural control systems over a lifetime, they suggest many parallels can be drawn between early life development of control in children and the late life deterioration that can occur in ageing through the same subsystems that regulate postural stability (Woollacott, et al., 1990). The changes that can occur within the musculoskeletal system through rapid growth as infants develop have been compared to the adaptations which must be made due to weakening muscle strength and decreased muscle response that older adults may experience. In both the young and old the musculoskeletal and body morphology changes can happen quite quickly and leave the individual at risk due to the need for ready adaption to overcome these changes. Both young and older adults may need to rapidly alter their muscle responses, or use compensatory strategies to overcome deterioration, especially in situations with external threats to balance. As well as musculoskeletal changes to the body during periods of transformation, there are also neural changes to consider due to the nervous system's role in the maintenance of balance. It has been proposed that as children develop their control of balance, which is initially controlled by the more primitive reflex systems, it is gradually taken over by more refined higher central nervous system functions using increasingly complex somatosensory information (Woollacott, et al., 1990). As we age, it has been suggested that the deterioration of function begins first in these higher systems resulting once again in reliance on these lower level processes (Baloh, Enrietto, Jacobson, & Lin, 2001), theoretically leaving the older adult at risk of postural instability leading to a fall.

To further understand the development and the deterioration of the different systems that control balance we first need to understand the complex nature of this seemingly automatic process. The maintenance of a stable standing stance can appear effortless in most adults and it is only during development or when some part of a system fails to function that the complexity of the process is realised. The ability to stand unaided and ambulate successfully involves constant monitoring and adjustments to our balance through the integration of many streams of sensory information by the central nervous system (Mergner & Rosemeier, 1998). The maintenance of a stable independent stance takes many years to develop and requires both internal and external sensory cues from a range of modalities within the nervous system and the musculoskeletal system. It relies upon information from systems such as the semi-circular canals in the inner ear, from muscle and joint positions and from haptic sensors in the feet. Some of these critical neural and mechanical components that interact to lead to the eventual development of effective postural control are thought to be ‘rate limiting’ in their maturation (Woollacott, et al., 1990) meaning that the whole system for achieving independent stance develops at the rate of the slowest maturing critical component. These components involve key neural and mechanical factors such as the ability of different muscles to interact and work together to maintain balance control as well as the general functioning of the visual, vestibular and somatosensory systems to detect the loss of postural control. However, the theory of postural control development being rate limited to follow set developmental milestones is not universally accepted. More recent work by Adolph and Berger (2006) claims that development requires an infant to be motivated to learn a new motor behaviour and this can be dependent on external factors. Current work with infants shows that new motor skills are developed and enhanced with the help of the child’s care-giver and through interactions with the environment which encourages new behaviours (Adolph & Berger, 2006). An increasingly well regarded theory is Esther Thelan’s dynamic systems theory which supports a non-linear developmental trajectory. The premise is that in order for an infant to develop a new motor behaviour it must perceive a stimulus in the environment which motivates it to act (Thelen & Smith, 2006). A new motor skill is then developed in order to achieve the desired goal regarding the stimulus. The infant is further motivated to improve these new movements and develop their accuracy through perception and practice to achieve their end goal quickly and efficiently. Therefore motor development does not just occur depending on age related maturation but it needs to be worked towards with effort, motivation and practice. Despite the differing theories of maturation speed and limitations there are also physical aspects to consider which certainly do limit the development of motor skills such as postural control. An infant is limited by factors such as the development of muscle strength and joint range, and the need to learn one’s own body morphology and proprioceptive capabilities. Furthermore there is the development of the system’s general adaptive ability to react to changes in the environment and modify the sensory and motor systems accordingly (Woollacott, et al., 1990). Parallels can certainly be seen between the motor skill development in infants and the deterioration that occurs in older adults due to limitations that are caused by physical factors relating to muscles and joints. The physical restrictions that are placed on children in development compared to the physical decline within the body of older adults are clear, as in the same way children may not have the strength and range to carry out certain activities, the same can apply to older adults through deterioration. For example muscle weakness can occur in older adults which is potentially caused by lack of use from activity avoidance. This activity avoidance often occurs due to the pain of moving certain joints or from arthritis and this can then lead to a reduced ability to carry out certain motor behaviours and result in diminished strength.

Over the course of a child's development the emergence of the ability to maintain a stable standing stance is marked by a gradual decline in the magnitude and frequency of postural sway (Hatzitaki, Zlsi, Kollias, & Kioumourtzoglou, 2002; Rival, Ceyte, & Olivier, 2005). This may be due in part to the level to which different cues are attended to by the central nervous system as we develop from infancy through to adulthood. The extent to which the central nervous system prioritises some sensory cues over others progresses as we mature and has been shown to lead to improvements in postural stability (Mallau, Vaugoyeau, & Assaiante; Rinaldi, Polastri, & Barela, 2009; Sparto, Redfern, Jasko, Casselbrant, Mandel, & Furman, 2006). Early in the development of static posture, infants and very young children rely heavily on visual information rather than the later developed and more refined proprioceptive information used by adults (Assaiante, 1998; David N Lee & Aronson, 1974; Wann, Mon-Williams, & Pascal, 1999). This proprioceptive information is provided through the vestibular system which offers sensory information concerning the orientation and positioning of the body in relation to its environment. The information provided by the vestibular system is particularly important in situations where visual information is not available. The fact that infants begin their development relying on visual cues for founding their standing balance has been well established (David N Lee, et al., 1974; D. N. Lee & Lishman, 1975), yet current research has not yet reached a clear consensus as to exactly what age a shift to reliance upon other cues can occur within this young population. Some research cites this shift occurs at as young as 6 years old (Rival, et al., 2005; Shumway-Cook & Woollacott, 1985), while others believe the importance of visual cues remains much longer for this age group, up until the age of 11 to 13 years (Hatzitaki, et al., 2002). Additionally, other research has found that although children aged 7 to 12 years may use visual cues in a similar way to adults, they do not have the same developed ability to use their somatosensory cues, and this can cause difficulty especially in situations where there is conflicting information presented from visual cues (Sparto, et al., 2006). However, more recent theories have suggested perhaps the sequence of developmental milestones are not as fixed as researchers may have previously assumed and instead of development happening at a set rate based on age, infants and children need to be motivated to use their motor skills to acquire a new behaviour, as postulated by the dynamic systems theory (Thelen, et al., 2006). Thus there may not be as clear of a difference in postural control abilities between the age groups of children used in this study as was previously thought, as some children may take longer to develop and fine tune their motor behaviours.

4.1.3 Objectives and rationale for undertaking the analysis

The age groups in the current study were designed to capture the ages when children have been documented to show changes in the development of their postural control and potentially shift priority from one system to another as they mature; the youngest age group will be 5 to 6 years, the middle aged group 8 to 9 years and the oldest 10 to 11 years. There will also be an adult age group of persons over 18 years to act as a control to compare levels of postural sway on the proposed tasks within a 'fully developed' group, as in Chapter 3. This study will use two visual conditions (eyes closed and eyes open fixating on a stationary target) to assess the proposed differences in the reliance on visual cues to maintain stable posture. In addition to the visual conditions, a visuomotor target tracking task will be used. Within this task it will be necessary for participants to first visually track a target and then using a hand held stylus manually track the same target. This means the attentional resources available for visual information that are relevant to maintaining postural stability will be limited.

Based on previous research and available evidence, it is expected that the youngest age group will show the highest levels of postural sway. Within this age group (aged 5 to 6 years) it has been documented by most sources that balance ability is still developing and visual cues are relied upon for maintaining stable stance. Therefore the highest levels of sway are expected in the conditions where visual information is deprived (eyes closed condition) or divided (during the completion of the visuomotor tasks). We predict that as children increase in age, sway will decrease compared to the youngest group for all of the tasks. Some research has shown that around the age of 10 to 12 years children have integrated their vestibular system sufficiently to reduce the reliance on basic visual cues (Sparto, et al., 2006), however this age of development is not unanimously agreed in the literature. Therefore it will be interesting to see whether there are changes in postural sway between the oldest aged school group (aged 10 to 11 years) in comparison to the control group of young adults who have a fully developed postural control system.

The condition where participants stand with eyes open fixating on a stationary target should offer a ‘baseline’ level of participants’ postural sway, within which no other testing factors are affecting their postural control. The other conditions are all in some way designed to purposefully destabilise participants to some extent through a range of devices; the eyes closed condition deprives participants of visual information which may be needed to maintain a stable standing stance; the visual tracking task may result in participants having to divide their attention between attending the visual cue on screen and using visual information from their surroundings to preserve balance; and the manual tracking task requires the movement of the hand and arm to track the moving target which can cause some destabilisation to balance. This manual tracking condition requires adaptation to overcome the displacement caused to the centre of pressure as the arm moves.

Within the visual tracking and the manual tracking tasks there are also differing levels of difficulty. The tracked target moves around the screen at three speeds; slow, medium and fast. It is predicted that at the slowest and least challenging speed participants will show the lowest levels of postural sway, with sway increasing as the target speed increases. This result is predicted, especially in the manual tracking task, as the destabilisation to centre of pressure caused by the physical action of manually following the target will be the greatest at the fastest speed.

Performance on the manual tracking condition will also be recorded to see how accurately participants are able to perform the task. It is predicted that tracking performance will be the best at the slowest target speed, with accuracy reducing as the speeds increase. It is expected that the youngest age group will show poorest tracking accuracy with the older groups performing increasingly well with increasing age. This is due to more refined motor skills development with age. The visuomotor task should also elicit some interesting results in the different age brackets of the under 11 year old population, to see if with increasing age there is a shift from reliance on visual cues to the somatosensory and proprioceptive systems to maintain postural stability. In the same way older adults show deterioration in postural stability resort to a compensatory strategy such as task prioritisation or 'posture first' (Lacour, et al., 2008) it is possible that young children who have not yet fully developed the automatic nature of their postural control system may find a dual tasking situation difficult through the increased demands on cognitive resources from both the visuomotor task and the need to maintain postural control. It is predicted that the youngest age groups will show the worst performance, but whether this will be on the visuomotor task, or be reflected in their postural stability or potentially both, is as yet unknown. As the children increase in age and their postural control systems develop, it is expected that levels of sway will reduce as the control within their system improves and thus performance on the visuomotor task may improve as well.

4.2 Methods

4.2.1 Participants

The study involved four groups of participants; three groups were primary school aged children recruited from a local school and the other was a group of young adults recruited from the University of Leeds to act as a control group to compare to each age group of children. The control group were volunteers recruited from the student population (n = 9, mean age = 21.67 ± 2.12). Testing of this group took place in a large, quiet room within the Institute of Psychological Sciences on the University campus. The three groups of children were accessed through contact with a local primary school. Prior to having any contact with the children, a letter was sent to home to the parents or guardians of all children involved in the study to provide information about the research and to obtain parental consent. The children who took part in the study were from three class age groups; Year 1 (n = 8, mean age = 5.86. ± 0.35), Year 4 (n = 10, mean age = 8.60 ± 0.52), Year 6 (n = 8, mean age = 10.75 ± 0.46). Testing took place in an empty class room at the school. Using age appropriate language all participants were informed of their right to withdraw from the experiment at any time. The study aims were explained in full to all participants after testing and there was plenty of time provided to ask questions.

4.2.2 Equipment and materials

A small, lightweight inertial sensor (Xsens Motion Technologies B.V., Netherlands) was used to record participants' head movements. The sensor was attached to a plastic headpiece placed at the level of the superior coronal suture, fitted securely but not restricting head movements and allowing easy head flexion. A Nintendo Wii balance board, connected to a laptop via Bluetooth connection, was used to capture postural stability through the path length of change in Centre of Pressure (CoP). The laptop had a foldable function so the screen could be used on the horizontal plane to write on. Task performance (manual tracking accuracy) was captured using a laptop running KineLab, a software programme for measuring human movement (Culmer et al, 2009), with use of a stylus for manual tracking tasks. During the manual tracking task, KineLab recorded root mean square error (RMS error) values which documented the positional distance between the participants stylus and the tracked target. KineLab automatically recorded head sensor and balance board data from the start of each task. A metal stand was used for the laptop as it could be adjusted for the different standing heights of participants.

Figure 4.1 A participant from the Year 1 age group shown in the testing set up

4.2.3 Procedure

Detailed and standardised instructions were given to participants prior to beginning the tasks. Participants were then asked to stand on the Wii balance board with their feet shoulder width apart. The height of the lectern was adjusted for each participant with the lectern being at approximately the same height as the participant's elbow. They were instructed to try and remain still and relaxed during testing, and not to speak once a trial had commenced.

The study consisted of four separate trials, taking a total testing time of four minutes to complete, however this could be longer if breaks were requested or needed between trials. Participants were asked to stand in the centre of the Wii balance board with their hands by their sides and to close their eyes for 30 seconds. Participants were then asked to concentrate on a static circular target on the laptop screen for 30 seconds. This was followed by a visual tracking task, which involved participants using their eyes to follow the movement of a circular target in a horizontal figure of eight motion at gradually increasing speeds; slow to medium to fast. Increasing the speeds instead of counterbalancing them helped to avoid lagging effects caused by hysteresis. The final trial consisted of the manual tracking task. This involved tracking the moving target using a handheld stylus device on the laptop screen. The stimulus increased in speed again from slow to medium to fast. Task order remained constant for all participants. The experimenter stayed close to the participant during the trials in case they should become unsteady and require assistance.

4.2.4 Data analysis

Three different measures were taken during each testing condition; total centre of pressure (CoP) data (mm) from the Wii balance board, cumulative head rotation data (°) from the Xsens inertial sensor, and manual tracking accuracy data (RMS error) from the KineLab tracking task (mm). The centre of pressure (CoP) data from the Wii balance board was obtained through measuring the degree of postural movement in the participants' centre of mass (CoM) in the X and Y position. The CoP can therefore be seen as the movement of the participants' CoM on the Wii balance board. The time-course CoP movement was measured as the distance subtended by the CoP over each testing period. CoP is used in this analysis to reflect participants' total postural sway. The cumulative head rotation data was recorded via the Xsens sensor attached to the top of the participant's head. The total head rotation was calculated through cumulative addition across the course of each trial of the angular rotation of the head over three axes (X, Y, Z). The summed angular rotation of the head, measured in degrees (°), was used to reflect participants' total head movement during a testing condition. The root mean square error (RMS error) was calculated to reflect the error experienced by the participants in tracking the moving target on the Kinelab visuomotor task. It provides an accurate measure of the distance (mm) between the desired reference position at the centre of the visuomotor task's moving target and participant's hand held stylus input position over all of the samples in a trial. All three recorded measures (CoP from the Wii board, head rotation from the Xsens, RMS error from Kinelab) were time stamped and synchronised to start and end at the exact same time to allow comparison across the trials.

The three recorded movement measures were the dependent variables and age group of participants was the independent variable which consisted of four levels; Year 1 (aged 5 to 6 years), Year 4 (aged 8 to 9 years), Year 6 (aged 10 to 11 years) and the young adult group aged 19 to 25 years. One participant from the aged 10 to 11 age group had to be excluded from analysis as their postural sway data from the Wii balance board did not record correctly. Within the analysis the Greenhouse-Geisser correction was used when there was a violation of sphericity within the data.

4.3 Results

4.3.1 Postural stability and head movement in eyes closed and eyes open fixating conditions

In the eyes closed condition and the eyes open fixating on a stationary target condition, the data recorded by the Wii balance board are presented in Figure 4.2 (a) and the data recorded by the head mounted Xsens inertial sensor are shown in Figure 4.2 (b). The figures show (a) the total CoP path length (mm) and (b) the head rotation data (°) recorded over a 30 second trial and averaged across each age group. A higher CoP path length equates to an increased postural sway and a higher rotation value equates to increased head movement.

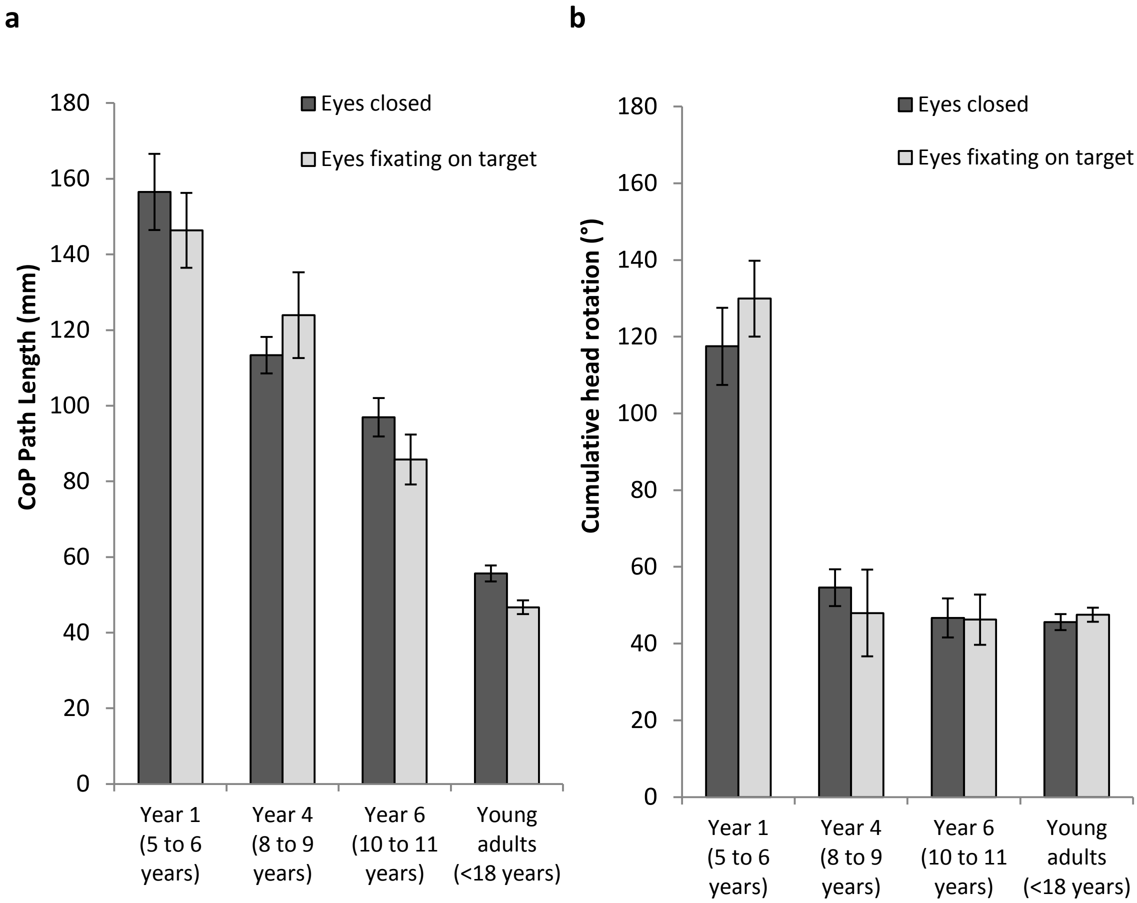


Figure 4.2 (a) Centre of pressure path length (mm) from the Wii balance board **(b)** Head rotation data (°) from the Xsens inertial sensor. Both measures were recorded during the eyes closed condition and the eyes open fixating on a stationary target condition for the four age groups. Bars = Standard error of the mean.

As shown in Figure 4.2 (a), there is a steady decrease in the CoP path length as the age of participant increases. The highest CoP path lengths were recorded in the youngest age group of Year 1 (age 5 to 6 years) with the CoP path length decreasing until reaching the lowest levels as recorded by the young adult group (aged 19 to 25 years). CoP path length is consistently higher in the eyes closed condition compared to the eyes open condition across all participant groups, except in the Year 4 age group (aged 8 to 9 years) where the opposite effect is seen. A 2 (eyes closed, eyes fixating) × 4 (Year 1, 4, 6, adult) repeated measures ANOVA found there was no main effect of the testing condition (eyes closed or eyes fixating) on the CoP path length, $F(1,30) = 1.41$, $p=0.24$, $\eta^2_p = 0.05$, and no significant interaction between condition and age group, $F(3,30) = 1.75$, $p = 0.18$, $\eta^2_p = 0.15$. There was a significant effect of age group, $F(3, 30) = 47.07$, $p<0.001$, $\eta^2_p = 0.83$.

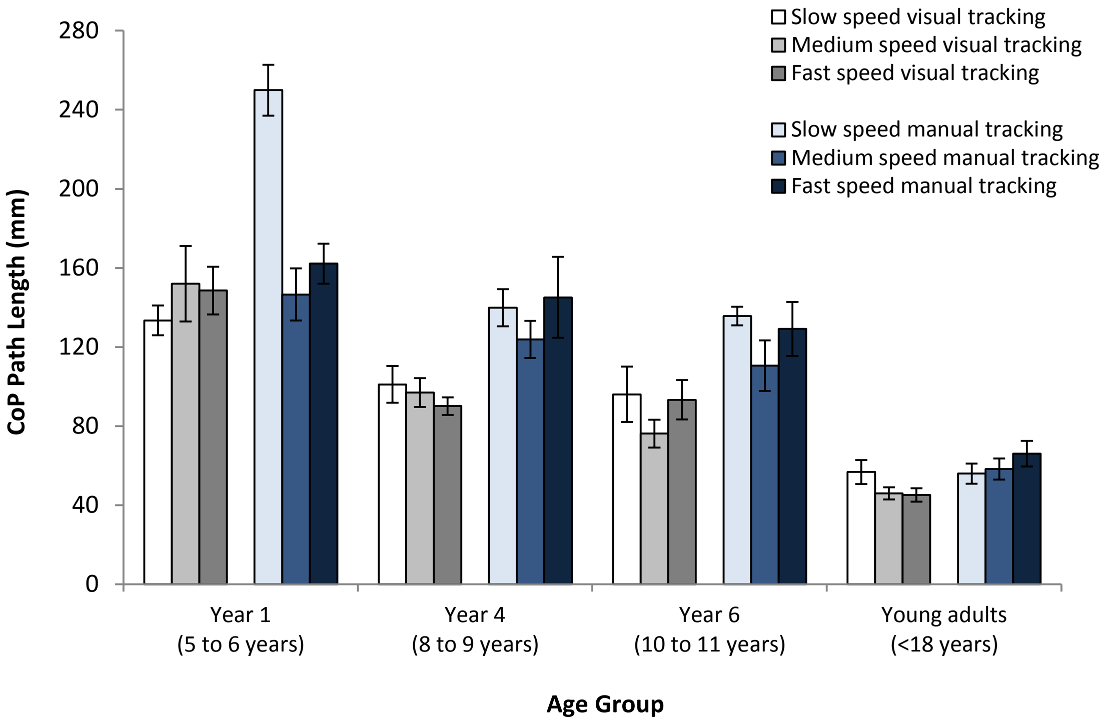
Bonferroni post hoc tests revealed that there were significant differences in postural sway between all age groups, as indexed by the CoP path length data.

The different age groups' head movements as displayed on Figure 4.2 (b) show a different pattern from the postural sway. The youngest age group of Year 1 pupils show considerably higher levels of head movements compared to all other age groups; the other 3 groups showing similarly low levels of head movement. A 2 (eyes closed, eyes fixating) × 4 (Year 1, 4, 6, adult) repeated measures ANOVA found there was no significant effect on head movements from the testing condition of eyes closed or eyes fixating, $F(3, 31) = 0.05$, $p = 0.83$, $\eta^2_p = 0.01$. There was a significant effect of participant age group, $F(3, 31) = 65.03$, $p < 0.01$, $\eta^2_p = 0.32$ but no interaction between testing condition and age, $F(3, 31) = 0.24$, $p = 0.87$, $\eta^2_p = 0.02$. Bonferroni post hoc tests showed that as expected the only significant differences in head rotation between age groups were between the Year 1 pupils and all other age groups at the $p<0.05$ level.

4.3.2 Postural stability and head movement during visual tracking and manual tracking conditions

Figure 4.3 shows the results from the visual tracking and manual tracking conditions for all age groups across the three tracking speeds. Figure 4.3 (a) shows the average CoP path length (mm) from the Wii balance board and Figure 4.3 (b) shows the average head rotation data (°) recorded by the Xsens head sensor.

a



b

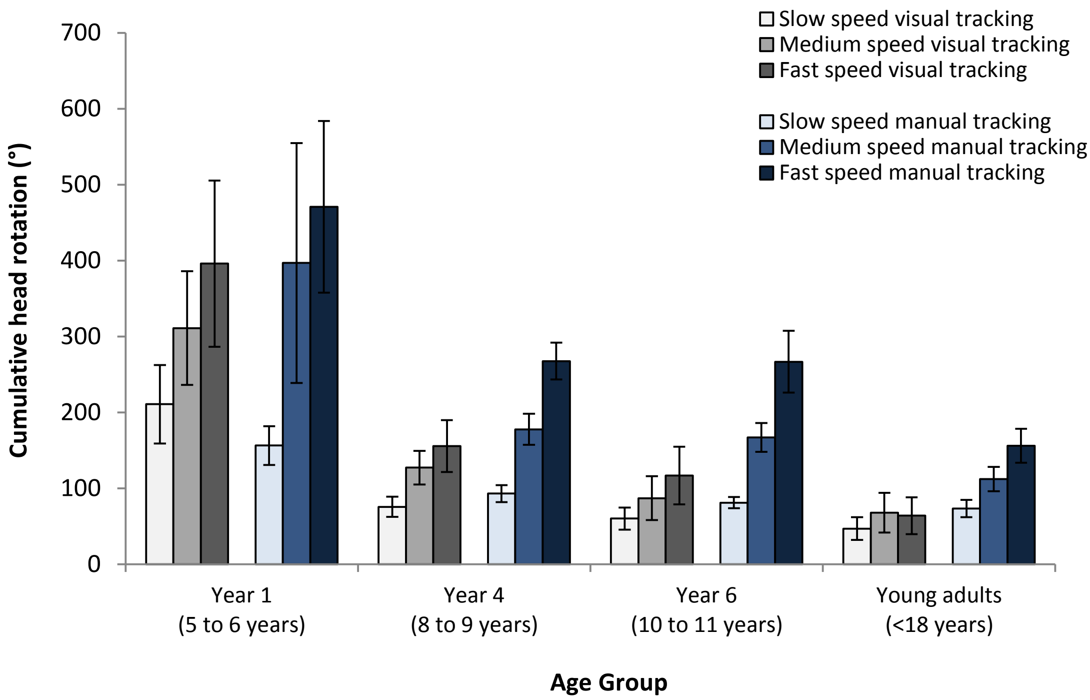


Figure 4.3 (a) Centre of pressure path length (mm) from the Wii balance board during the visual tracking and manual tracking conditions for the four age groups **(b)** Head rotation (°) from the Xsens head sensor during the visual tracking and manual tracking conditions for the four age groups. Bars = Standard error of the mean.

The general trend of the results displayed on Figure 4.3 shows that as the age of the participants increases, the total CoP path length and the total head rotation decreases. This reflects an increase in postural stability with age. Overall it appears that the manual tracking condition results in higher CoP path length than the visual tracking condition.

The CoP results were analysed using a 6 (testing condition) x 4 (age group) repeated measures ANOVA. A significant main effect of the testing condition was found, F (3.41, 98.91) = 21.41, p<0.001, $\eta^2 p$ = 0.43 showing there were noticeable differences in the recorded postural sway depending on the testing condition. Although there is a significant effect of the testing condition, from looking at Figure 4.3 (a) it can be seen that the predicted trend of a uniform increase in the levels of CoP path length with increasing speed of tracking task is not shown. This expected trend in results is only shown by the over 18 years of age adult group in the manual tracking condition. A main effect of age group was found, F (3, 29) = 47.74, p<0.001, $\eta^2 p$ =0.83, and the four age groups were shown to be affected by the testing conditions to differing levels, as reflected by a significant interaction between condition and age group, F (10.23, 98.91) = 4.96, p<0.001, $\eta^2 p$ =0.34. Bonferroni post hoc tests showed significant differences between all age groups at the p<0.001 level, except between Year 4 and Year 6 where there was no significant difference reported, p=0.96.

As shown on Figure 4.3 (a), there is a significantly higher CoP path length result for the Year 1 age group in the slow manual tracking condition compared to all the other age groups and conditions. The raw data from the Year 1 participants in this condition was inspected and this very high result was not caused by a few outliers; all Year 1 participants recorded very high levels of sway for this particular condition.

The head rotation data were also analysed using a 6 (testing condition) x 4 (age group) repeated measures ANOVA. A significant main effect of testing condition was found, F (1.81, 54.17) = 14.04, p<0.001, $\eta^2 p$ = 0.32, and from Figure 4.3 (b) there is a clearly observable pattern in the increase in tracking target speed and an increase in head rotation. This shows that head rotation on both the visual and the manual tracking tasks are closely linked with movement of the tracked target in the task. There is a main effect of age group, F (3, 30) = 8.01, p<0.001, $\eta^2 p$ = 0.45 again, but there is no significant interaction between testing condition and age group, F (5.42, 54.17) = 1.12, p=0.36, $\eta^2 p$ = 0.10.

Bonferroni post hoc tests reveal that for the head rotation data there are only significant differences between the youngest age group of Year 1 pupils and all other age groups; Year 4 ($p<0.01$), Year 6 ($p<0.01$) and young adults ($p<0.001$). There are no other significant differences in the head rotation data between any other groups.

4.3.3 Tracking accuracy during the manual tracking task

Performance on the manual tracking task was indexed by a measure of positional error between the centre of the moving target and the tip of the participant's handheld stylus. The root mean square positional error (mm) was calculated continuously across the 30 second trial to give a comparable score of accuracy between participants.

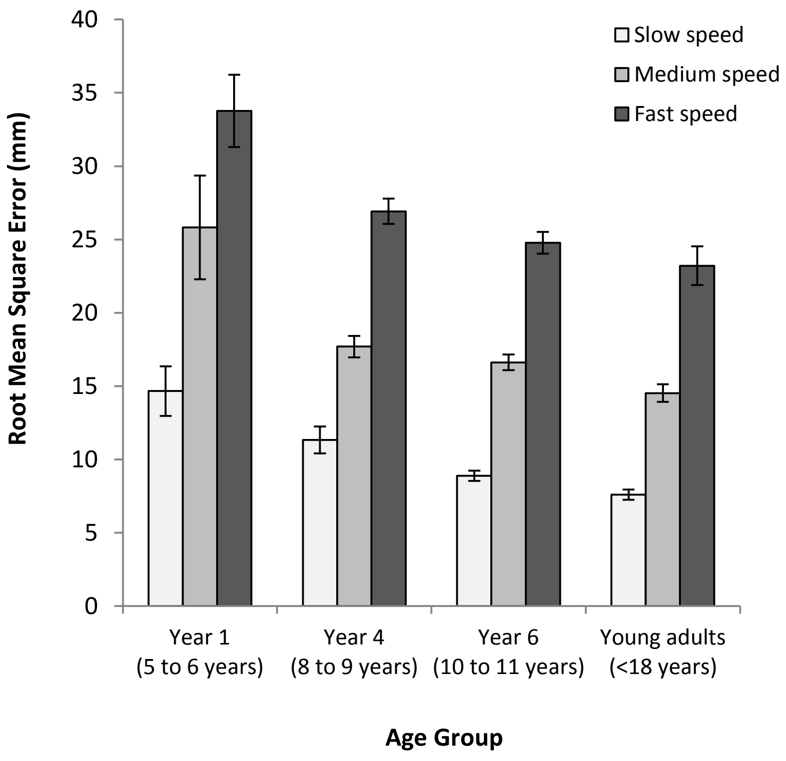


Figure 4.4 Manual tracking accuracy as indexed by the root mean square positional error (mm) over a 30 second trial of the manual tracking condition for the four age groups. Bars = Standard error of the mean.

The tracking accuracy results reflect the prediction made before testing; task performance will improve with increasing age. This is clearly shown in Figure 4.4 where the measure of performance, root mean square error, reduces as age of the participants increases.

A 3 (target speed) x 4 (age group) repeated measures ANOVA found a main effect of participant age group, F (3, 26) = 12.42, p <0.001, $\eta^2 p$ = .59, showing there was a significant difference in tracking performance between age groups, with worse performance in the youngest age group. There is also a clear trend in the results showing performance is best at the slowest target speeds with most errors shown at the highest speeds. The differences between target speeds was significant, F (2, 52) = 239.05, p < 0.001, $\eta^2 p$ = .90, however there was no interaction between age of participants and target speed showing that participants were affected to a similar level by the different tracking task speeds. As shown by the error bars on Figure 4.4, the greatest within group variability was shown in the youngest age group, with the levels of variability decreasing with age. Additionally, the variability between groups was higher in the fast tracking condition compared to the slower speeds.

4.4 Discussion

The findings across all four testing conditions show the same trend of results; as participant age increases, postural sway, as indexed by CoP from the Wii balance board, decreases. These results support previous research which helped develop the hypothesis for the current study that the youngest age group would display the highest levels of postural sway. This prediction was made as children of around 5 to 6 years are still developing their postural control and have been reported as using a more basic reflex led postural control system dependent upon input from visual cues to maintain a stable stance. These visual cues are relied upon for sustaining a stable stance, therefore in situations where these cues are removed (the eyes closed condition, or when the visual information is heavily involved in the completion of a task) this leads to situations of increased postural sway. The youngest age groups' postural sway was significantly higher than the other age groups in all conditions, with the lowest levels of sway being recorded in the condition where they simply had to focus on a stationary target, thus visual cues from the surrounding environment could still be attended to with their surrounding peripheral vision. The youngest age group also showed significantly higher levels of head rotation across all conditions when compared to the other age groups. This increased head rotation was especially pronounced in the eyes closed and eyes fixating conditions when the other three age groups showed very little head movement at all compared to the youngest group.

The results between the next two age groups; aged 8 to 9 years and age 10 to 11 years, were not significantly different in all conditions; no difference between their CoP path length or their head rotation in the visual and manual tracking conditions. This may be because these two groups are closer in age, being in adjacent school year groups unlike the youngest group who were significantly younger by three school years. However, the majority of the previous research states that it is around this age that the final stage of postural control development occurs, yet the exact age is disputed. This is why these two year groups were selected; to see if there were observable differences between the groups or if they were experiencing a similar level of postural sway. Although not all of the differences between these two groups were significant, it would appear that the postural control systems have become more refined during a further academic year as the oldest age group of school aged children do seem to display significantly less postural sway in some conditions (eyes closed and eyes fixating conditions).

Most existing research shows that at around the age of 10 to 12 years old children have developed their higher nervous centre postural control systems and their somatosensory and vestibular senses are used effectively to sufficiently reduce the reliance on the primitive reflex system based on visual cues (Sparto, et al., 2006; Woollacott, et al., 1990). Although the results show there were no significant differences in head rotation between the oldest age school group of Year 6 (aged 10 to 11 years) and the adult group, the CoP postural sway results show that there are still significant differences in the levels of postural sway observed between these age groups. Significant differences in postural sway were found in all testing conditions between the oldest age group of school children (aged 10 to 11 years) and the adult group. This shows that at the age of 10 to 11 years these children are not yet at the level of postural control expected in a fully developed adult. These findings support the previous results of Sparto et al (2006) who found that although children of around 12 years had developed to use visual cues in the same way as adults, their use of somatosensory information was still not as mature as adults.

With specific focus on the results from the visuomotor tasks, it was expected that as tracking task speed increased, postural sway would increase, as the task demands on vision increased. This pattern was found for the head rotation data with a clear pattern of increased speed of target reflected by increased head rotation. However for the CoP data, this expected pattern was only shown in the adult group during the manual tracking condition. In the other age groups there appeared to be no clear pattern of results reflecting this expected linear increase in postural sway with the slow, medium and fast conditions. The results show that in some conditions the slowest speed produced the highest path length and in others it was the medium or the fast speed. This difference in the outcomes of these recorded measures confirms the fact that head rotation and postural sway are separate measures. Therefore the Xsens sensor and the Wii balance board are recording different aspects of body movement.

All age groups recorded the highest levels of postural sway and head rotation in the manual tracking condition compared to the visual tracking condition, however the difference between the two tasks was less pronounced in the adult group with similar low levels recorded in both conditions. This may be a reflection of a compensation strategy that the adult group were able to utilise to adapt to the changes in centre of pressure caused by the arm movements. The higher levels of recorded sway across the school age groups was expected due to the increased task demands of interacting with the target and the mechanical process of manually tracking the moving target. Although there is little increase in the levels of postural sway experienced in the adult group between the two tasks, postural sway in the three school age groups increases dramatically from finishing the visual tracking task to beginning the manual tracking task. The three school age groups all show very high levels of sway in the slow manual tracking condition then show a drop in postural sway when moving onto the medium speed target before increasing again when beginning the fastest, most challenging tracking speed. In fact the youngest group, aged 5 to 6 years, show a dramatically higher level of postural sway when beginning the manual tracking task compared to any other results from any age group or task. These high values recorded for all of the school age children when first beginning the manual tracking task highlight their susceptibility to reduced postural control in certain challenging environments. None of the four groups involved were given a practice trial with the manual tracking task however the adult group’s postural stability does not appear to have been greatly affected by the introduction of this task into the testing. Yet all of the school age groups show this dramatic shift in levels of postural sway when the manual tracking task was introduced. It may be that when first presented with this new challenge, although it was in its slowest and easiest form first, the undertaking of this task has perturbed their postural control system as the task requires a great deal of their attention and places demands on their visual system. The school age participants need to adapt to this demand accordingly to undertake the task successfully and work to regain their postural control. By the time the school age participants begin the medium speed trial, they have adapted to the demands of the task and so their sway is much less than in the slow speed. On commencing the fastest speed manual tracking there is some increase in postural sway as this is the most challenging level to undertake, however for years 1 and 6, they do not reach the high levels they experienced in their first attempt at the task. The year 4 age group does have an increased level of sway at the fastest speed, which is higher than at the slowest speed.

The results from the visuomotor task are interesting as they show the effect that competing sensory information can have on the postural control system. As children shift from using visual cues to somatosensory cues, the body is better able to cope with situations where the visual system may be involved in a demanding task. This is because their proprioceptive and somatosensory cues will be given priority for stable stance maintenance. However in the groups of children tested in this study, it would appear there is still some reliance on the more basic systems of postural control, even in those older children of 10 to 11 years, especially when the results are compared to the levels of postural sway seen in the adult group who have a fully developed postural control system.

The tracking accuracy results from the manual tracking task also show an advantage with age. The results showed there was no trade off between prioritising the task performance in order to maintain a stable stance as the results simply showed the older the participant, the better the tracking performance and the better their postural control. Tracking performance was dramatically affected by tracking task speed, unlike postural sway; the faster the tracking speed, the higher the positional tracking errors.

This work was also undertaken to assess the capabilities of the new equipment, the Wii balance board. The Wii balance board proved itself to be extremely user friendly with data being recorded without issue via its Bluetooth capabilities. Additionally, the ability to detect the expected significant differences between the distinct age groups was substantiated and clear differences were found between the various conditions. The three measures functioned well together through the integration of incoming signals and the whole system was highly portable to enable the visit into the school environment.

The new measure of cumulative head rotation across the X, Y and Z axes was found to be a more appropriate measure of head rotation than simply using the SD of angular velocity across the X and Y axes. However, on comparing the recorded outcomes from the Wii balance board and the Xsens sensor it was found the two measures were producing different findings with one reflecting postural sway and one reflecting head rotation. In later thesis chapters, as the focus is primarily on postural sway and not head movements it is decided that it is appropriate to reduce the complexity of the testing and use only the CoP measures from the Wii balance board. The decision to stop using the Xsens sensor was made not only because it was measuring a different aspect of postural stability to the Wii balance board but also because all three groups of participants that had been tested thus far were not keen to wear the Xsens head sensor. The older adults from Chapter 3 were particularly concerned about wearing the plastic cap and head sensor so it was felt that if the results from the sensor were not required for the future testing needs, there was no benefit in continuing to use it. The Xsens sensor, although offering an interesting insight into head rotation, was deemed redundant to the postural sway investigation aims of the thesis.

There are some limitations with this current study in that there is a relatively small sample size of school age children. This was due to limited time within the school as all testing had to take place over one day for the school's convenience and to reduce disruption for the children. With increased time it would have been beneficial to test the entire year group to increase numbers, and also to test each class in the school to have more of an idea of the developmental trajectory from 5 years up to 11 years without any discontinuities in age. However time for testing and the school policy was a constraint in this and only three year groups were able to take part. It would also be interesting to use this equipment to continue testing year groups up until an age is found where they were consistently reaching similar levels of postural stability as an adult group. This could be done to see at what age one can deduce children have fully developed their postural control system in line with adults.

4.4.1 Objectives and implications for next phase of research

This phase of testing with a developmental population has revealed some interesting findings and has proved useful to the overall aims of further understanding postural control in an ageing population. This work has also demonstrated the flexibility of the assessment system for further use with a range of populations, showing there are multiple adaptations for this system in the future, for example with clinical populations.

The results from the primary school age groups of children substantiated previous research claims which described a developmental trajectory based on rate limited postural control development (Woollacott, et al., 1990). Despite the numerous similarities that have been described between early life balance development and later life deterioration, one of the most interesting findings from this work, which has strong implications for the next phase of research, is the most significant difference which exists between the *typical* development of balance and the *atypical* deterioration of balance. To explain, there exists in children a somewhat predictable developmental trajectory of postural control, however the deterioration experienced in older adults is much less defined in its potential onset and speed. Ageing is typically associated with a decline in function, yet for so many factors, including postural control, there is no defined age of typical onset. Some older adults may experience severe postural control and balance issues at an early stage of their later years, and this is often due to accompanying co-morbidities, yet others may not ever exhibit any difficulties. This is part of the exceedingly complex nature of the ageing process which can be dependent upon a multitude of individual factors. Thus part of the role of ageing researchers is to try and predict and assist those individuals who may be starting to suffer from a specific decline in function and to offer assistance before any serious adverse effects come to a head. In the case of a deterioration in postural control the end result of a loss of optimum function is often a fall, which can have sudden devastating effects for an individual leading to serious injury, loss of confidence and mobility and often social isolation. If those who are beginning to show problems with their balance and postural control can be identified there are strategies that could be put into place to firstly raise awareness of the risks the person may be facing, and secondly to highlight the situations of extreme external risk to exercise caution. Yet this needs to be done without causing a fear of falling disproportional to their actual risk. If problems are noticed early on a person can be advised to begin working on adaptive strategies such as focus on the musculoskeletal side of their postural control system and working on increasing muscle strength and mass to avoid the wasting that can cause so many problems in later life. Persons can also be warned about the risks of finding themselves in situations of reduced visual cues, such as environments with low lighting, or attempting to get out of bed in the night without first putting on a bright light and letting their eyes adjust. Simple strategies such as these could be put in place if individuals at risk were identifiable.

5 The effect of visuomotor task performance on postural stability: comparing performance in young and older adults

5.1 Introduction

Following on from the findings of work with a developmental population, this chapter will investigate the role of vision and dual tasking on postural stability in young adults and older adults. In Chapter 4 a dual task condition using a visuomotor manual tracking task was found to have a significant effect on postural sway in school aged participants. The effect of cognitive load on the postural stability of older adults has been reported in the literature (Huxhold, et al., 2006; Maylor, et al., 2001; Shumway-Cook, et al., 1997) with a general trend of increased cognitive load being associated with increased postural sway and decreased secondary task performance (Huxhold, et al., 2006). While this global impairment has been identified as a risk factor for falls (Tinetti, et al., 1988), the specific cognitive components are not as well understood (Liu-Ambrose, Katarynych, Ashe, Nagamatsu, & Hsu, 2009). More recent literature has explored the role of specific cognitive functions in falls for older adult populations, such as executive function (Mirelman, Herman, Brozgol, Dorfman, Sprecher, Schweiger, Giladi, & Hausdorff, 2012) and dual task performance (Liu-Ambrose, et al., 2009) and a review has outlined executive function and dual-task ability as the two distinct cognitive domains having received exploration (Hsu, et al., 2012).

Dual-task performance has been shown to be highly associated with falls and falls risk (Hsu, et al., 2012). The use of a dual-task paradigm would predict that during concurrent tasks such as visuomotor or spatial tasks, postural performance would be reduced, resulting in greater postural sway in older adults. Huxhold et al (2006) found that when performing more cognitively demanding tasks an older adult group showed increased centre of pressure displacements whereas young adults did not (Huxhold, et al., 2006). These results were supportive of the negative direction of the U-shaped postural control hypothesis, where the U-shaped hypothesis infers an inverse relationship between postural stability and the difficulty of a concurrent task (Riley, et al., 2003). It is hypothesised that a simultaneous cognitive task can benefit or attenuate balance performance; depending on low or high task difficulty respectively. Another theory proposes that older adults must actively prioritise their postural stability over the successful completion of a concurrent task. The “posture first” hypothesis suggests that in order to maintain a stable stance older adults neglect other tasks which are competing for resources to prevent a loss of postural control; this observation has been found to be a possible predictor for preventing older adult falls (Lundin-Olsson, et al., 1997).

Comparative research between younger and older adults has provided insight into age-related changes in postural control and cognitive capability. For older adults there is a greater demand for interdependence between sensorimotor and cognitive modalities (Pichora-Fuller, Schneider, & Daneman, 1995), leading to balance performance being affected by competition, but performance on concurrent tasks are also compromised. Age-related trends in dual-task postural effects are common; though there is mixed evidence as to these effects linked to the type of task used (see Yogev-Seligmann et al., 2009 for review) (Yogev-Seligmann, Hausdorff, & Giladi, 2008). Cognitive impairment in older adults has been found to increase the risk of falls (Rubenstein, 2006; Shaw, 2003; Van Dijk, et al., 1993; Van Doorn, et al., 2003) and research shows that even a mild cognitive impairment increases the risk factors for falls and leads to significantly higher levels of postural sway (Liu-Ambrose, et al., 2008b).

This chapter explores the relationship between postural sway and task performance in a group of community dwelling older adults using a dual task design. The purpose is to verify whether dual task interference occurs for older adults when performing a visuomotor task, alongside providing comparative data relating to postural stability in younger adults. The research will explore the dynamics of prioritisation relating to task in older adults through varying the visuomotor task difficulty, exploring the extent to which task difficulty impairs postural stability, and whether any compensatory trade-off behaviour occurs. Measures of cognitive function and attitude towards falls will also be examined to see if these offer explanations for any potential effects within the older adult group. If some of the older adult group are found to have mild cognitive impairments it is predicted they will show higher levels of postural sway. This prediction is made based on the findings of previous research but needs to be tested in a sample of community dwelling older adults. Attitudes towards falls will be assessed using a falls efficacy measure, the Falls

Efficacy Scale - International (FES-I) (Yardley, Beyer, Hauer, Kempen, Piot-Ziegler, & Todd, 2005) which evaluates an individual's fear of falling. Some older adults express a fear of falling which may be unfounded for their personal falls risk therefore in this study actual levels of recorded postural sway will be compared to attitude towards falls to see if the two measures are related.

5.2 Method

5.2.1 Participants

The study involved two groups of participants; young adults (between 18 to 35 years) and older adults (over 65 years). The young adults (n= 40, mean age 23 ± 3.23) were recruited from a University student population. The older adults (n=42, mean age 75.5 ± 8.55) were recruited through social groups at local community centres; all older adults were living independently. Both groups of participants were assessed for normal or corrected to normal vision using a Snellen eye chart, with a minimum score of 20/40 visual acuity required for participation in the study. A detailed medical history and activity questionnaire *(Appendix B)* was used with the older adult participants to establish the presence of any neurological conditions or diagnosed movement related disorders that could affect balance.

5.2.2 Equipment and materials

The Wii balance board, linked to a laptop via Bluetooth connection, was used to capture the total centre of pressure (CoP) across a timed trial, resulting in path length (mm). Task performance on a visuomotor task presented on a flat screen laptop was assessed using Kinelab software, which is specifically designed for measuring human movement in configurable visual-spatial tasks (Culmer et al, 2009), with use of a stylus for hand tracking tasks. Tasks used in this phase of testing included focussing on a stationary target, standing with eyes closed and the visuomotor task of following a moving target in a figure of 8 pattern. The target was represented by a green dot on screen. The moving target could be presented at three speeds (slow, medium and fast), requiring participants to use the stylus to trace the target in visuomotor condition. During hand tracking, KineLab recorded the root mean square positional (RMS) error which was the distance from the centre of the tracked target to the tip of the participant's hand held stylus. This value provided a measure of task accuracy. Kinelab automatically recorded data from the Wii balance board data from the start of each task.

Following the testing on the Wii balance board, the Addenbrooke's Cognitive Examination Revised (Mioshi, Dawson, Mitchell, Arnold, & Hodges, 2006) was administered to assess cognitive capabilities. The ACE-R was selected over the more frequently used Mini-Mental State Examination (MMSE) because the ACE-R has been shown to be more sensitive to mild cognitive impairments (Dudas, Berrios, & Hodges, 2005; Mioshi, et al., 2006; Pendlebury, Mariz, Bull, Mehta, & Rothwell, 2012). This was more suitable for this study where the older adult participants are not expected to have severe cognitive impairments. Also the MMSE has been found to show ceiling effects as it is not particularly challenging for many healthy older adults (Zadikoff, Fox, Tang-Wai, Thomsen, de Bie, Wadia, Miyasaki, Duff-Canning, Lang, & Marras, 2008). A detailed medical history (*Appendix B*) was obtained from participants in the older adult group, including falls history and current medication, to identify any potential impact on postural stability e.g. negative effects of polypharmacy (Hajjar et al., 2007). The Falls Efficacy Scale (FES-I) (Yardley, et al., 2005) was completed to assess self-confidence at avoiding falls during non-hazardous activities of daily living.

5.2.3 Procedure

Each participant was checked for appropriate footwear, which were preferably flat shoes with support provided around the foot with straps or laces. Detailed and standardised instructions were given prior to tasks. A height-adjustable metal lectern was used to support the tablet laptop so the participants could stand while completing tasks. The height of the lectern was adjusted for each participant; the lower side of the lectern being at approximately the same height as the participant's elbow. All participants were asked to stand up slowly when making their way to the testing lectern and were given time to prepare themselves before beginning the postural stability testing. This was to ensure there were no effects of postural hypotension which can result in dizziness when standing.

The study consisted of two trials of the three conditions, with each full trial taking approximately 3 minutes. To begin, participants were asked to stand with their hands by their sides and to close their eyes for 30 seconds. Participants were then asked to concentrate on a static circular target on the laptop screen for 30 seconds. This was followed by the visuomotor task, which involved participants tracking a circular moving target stimulus while using a handheld stylus device on the laptop screen. The stimulus moved in a horizontal figure of eight motion at gradually increasing speeds; slow to medium to fast. Increasing the speeds instead of counterbalancing them helped to avoid lagging effects caused by hysteresis. Task order remained constant and the testing procedure was completed two times for each participant.

For the older adults group, a chair was stationed behind each participant for safety during testing and to allow participants to rest if requested during testing. After the testing each participant was given a full debrief and given an opportunity to ask any questions regarding testing.

5.2.4 Data Analysis

The independent variable was age group, and the dependent variables were CoP path length (mm) from the balance board and Root Mean Square (RMS) error (mm) between the moving target and the handheld stylus position while tracking the moving target. These provided the values for postural sway and task accuracy respectively. The mean CoP path length and mean RMS error were calculated for each 30 second trial along with the standard deviation and standard error. Kinelab sampled the stylus position information at approximately 60Hz/s.

In both measures, a lower mean value equated to better overall performance; low postural sway from the balance board and low errors in tracking accuracy during the visuomotor task reflected a good performance. It was predicted that there would be greater path length and RMS error in the fast visuomotor task condition, and this would be more prominent amongst the older adults versus the younger adults. However, it was assumed that there would be greater variance amongst the older adult’s data set compared to the younger adults, as indexed by the standard deviations.

5.3 Results

Each testing condition was undertaken two times by the participants, to increase the testing accuracy. The results presented in this write up are the average of testing at time one and testing at time two.

5.3.1 Young and older participant group characteristics

All 82 participants completed the full testing procedure and no adverse events occurred during the testing. Two older adult participants did not wish to complete certain qualitative elements of the testing; one declined to complete the cognitive test (the ACE-R) and the other declined the medical history. Table 5.1 shows the young and older participant group characteristics and results from the medical history and activity questionnaire.

Table 5.1. Overview of young and older adult participant group characteristics

Characteristic	**Older Adults**	**Young Controls**
Age, mean ± SD	75.5 ± 8.55	23.4 ±4.14
Sex (women/men)	36/6	26/14
Number of co morbidities reported per participant, mean ± SD	1.98 ± 0.39	-
FES-I score, mean ± SD	24.12 ± 6.85	-
Participant experienced a fall in the last 2 years (yes/no)	12/30	-

Characteristic	Older Adults	Young Controls
Level of activity;		
Few to no activities per week	n = 9	-
At least one regular weekly activity	n = 24	
At least two regular weekly activities	n = 8	
ACE-R score mean ± SD	84.68 ± 9.23	-
Visual acuity (mean Snellen fraction ± SD)	20/20 ± 0.88	-

5.3.1.1 Health and activity levels in the older adult group

One participant declined to answer the medical history and activity questionnaire. Of the remaining 41 older adult participants, 3 had previously suffered a stroke but none of these participants reported it to affect their movement or balance in any way. No participants reported a diagnosis of Parkinson's disease or any other neurological disorders or movement related conditions affecting their balance. Nineteen participants reported having some form of arthritis and 13 reported issues with their blood pressure, for which they were taking medication. In total, 25 participants were taking daily medications.

As detailed on Table 5.1, 12 participants reported having experienced a fall within the last 2 years. Of these 12 persons, only 5 reported to have arthritis, 5 reported to be taking a daily medication, and 3 reported to have high blood pressure, thus there was no clear pattern within the fallers group of specific issues with health or medications. Therefore it was not necessarily the least healthy members of the older adult sample who had fallen previously. Additionally, the average age of the fallers was not dissimilar to non fallers; with fallers averaging 75.5 years (±7.84) compared to non fallers at 74.4 years (±8.54).

There was some variation in the activity levels amongst the older adult group, although all were reported to be living independently at the time of testing. As shown on Table 5.1, 8 older adults described very high daily activity levels, 24 were rated as quite active, while 9 persons carried out few to no daily activities. There appears to be no link with reported falls and lack of activity however as only 2 of the older adults who carried out few to no daily activities were in the group who reported a previous history of falls.

5.3.2 Postural sway in the conditions with no visuomotor task

A 2 (eyes closed, eyes fixating) × 2 (young adults, older adults) repeated measures ANOVA was carried out to assess if any significant differences exist in the postural sway between young and older adult groups in the no visuomotor task conditions; eyes closed and eyes fixating on a stationary target. This test was conducted using the centre of pressure (CoP) movement data (mm) from the Wii balance board. A significant difference was found in the CoP values recorded across the testing conditions of eyes closed and eyes fixating on a stationary target, $F (1.94, 155.38) = 35.19$, $p<0.001$, $\eta^2_p = 0.78$. There was a significant effect of age group; $F (1, 80) = 12.48$, $p<0.001$. $\eta^2_p = 0.53$, with the older adults displaying higher postural sway across all testing conditions compared to the young. However there was no condition × age group interaction, $F (1.94, 155.38) = 2.28$, $p = 0.11$, $\eta^2_p = 0.11$, showing that the pattern of changes in postural sway across conditions was similar for the young and older adult groups.

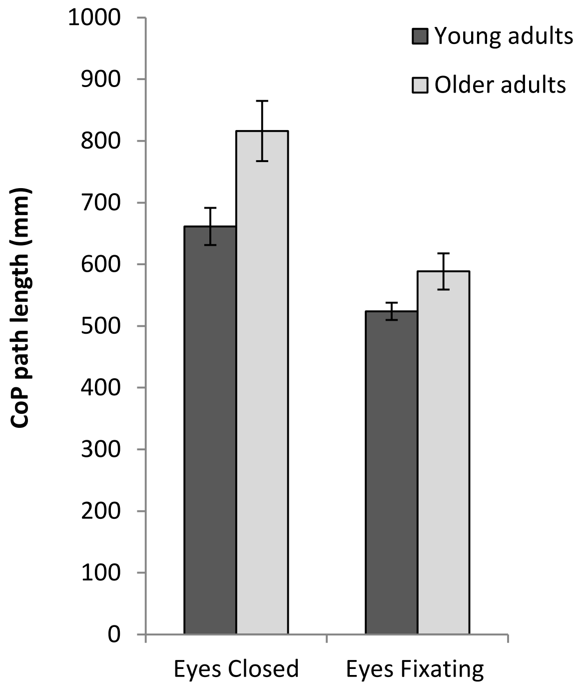


Figure 5.1 Postural sway results from the 'no visuomotor task' conditions. The figure shows the cumulative centre of pressure (CoP) path length (mm) as recorded by the balance board across a 30s trial duration for each of the conditions; eyes closed and eyes open fixating on a stationary target. Two separate trials of each condition were undertaken and the average results are shown. Bars = standard error of the mean.

5.3.3 Postural sway and visuomotor task performance

A clear pattern showing an increase in postural sway as task demands increased was found in the visuomotor task condition, with the highest levels of sway recorded during the fastest tracking task speed. Older adults showed consistently higher levels of recorded sway across all tracking task speeds when compared to the younger adult group. Significant differences were found through conducting a 3 (slow, medium, fast target speed) × 2 (young adults, older adults) repeated measures ANOVA for the effect of speed of tracked target, F (2.13, 159.45) = 294.16, p<0.001, η^2_p = 0.82, and age group, F (1, 75) = 37.76, p<0.001, η^2_p = 0.59, on postural sway. As shown on Figure 5.2(a) there was also a significant interaction found when undertaking the visuomotor task in the results for postural stability between the speed of tracked target and age group, F (2.13, 159.46) = 9.65, p< 0.001, η^2_p = 0.32, with older adults' postural stability being significantly more affected by the task demands than the young adults.

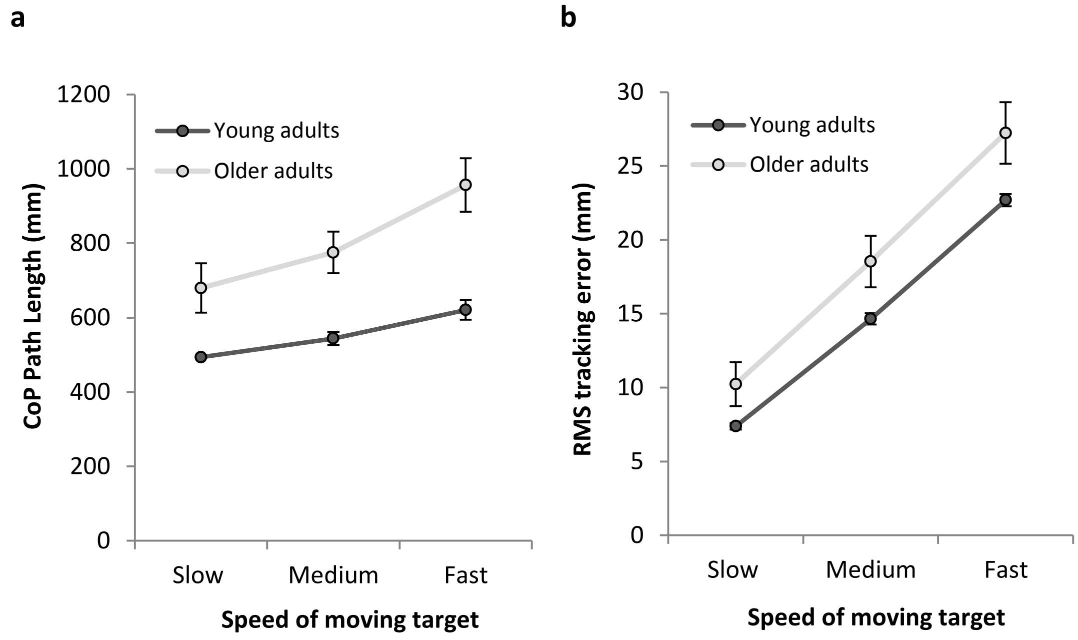


Figure 5.2 Visuomotor task results across the 30s trial duration for each of the three tracking speeds. Two separate trials of the visuomotor tracking task were undertaken and the average results are shown **(a)** the centre of pressure path length (mm) from the balance board **(b)** the root mean square (RMS) error between the position of the moving target and the position of the participant's hand held stylus during tracking. Bars = standard error of the mean.

A similar pattern of increasing results with task demands were found when looking at performance on the visuomotor task, as indexed by RMS error of distance of hand held stylus from the centre of the tracked target. A repeated measures ANOVA found there was a significant effect of target speed on participant performance error, F (1.82, 136.74) = 3003.59, p=<0.001, $\eta^2 p = 0.85$. There was a significant effect of age, F (1, 75) = 2190.80, p = <0.001, $\eta^2 p = 0.78$, with older adults having consistently poorer task performance than young adults across all speeds of target tracking. There was also a significant interaction of speed of tracked target and age; F (1.82, 136.74) =9.95, p<0.001, $\eta^2 p = 0.56$, showing that again older adults were significantly more affected than the young adult group by the increasing demands of the visuomotor task; as task demands increased, older adults performance on the task became markedly poorer than the young adults.

5.3.4 Focus on the results from the older adult group

5.3.4.1 Comparing cognitive function to falls history and baseline postural sway

In this study, self-report was used to ascertain whether older adults had experienced a fall within the last two years. Out of the 42 older adults who took part in this study, a total of 12 people (29%) self-reported as having experienced a fall within the last year. Cognitive function was assessed using the Addenbrooke's Cognitive Examination Revised (ACE-R). From comparing these two measures it was found that the ACE-R scores were on average lower in the group who had experienced a fall (mean 81.33 ±7.89) compared to those who had not fallen (mean 86.73 ±9.51). However, a one way ANOVA showed the difference between these two groups was not statistically significant, $F (1, 40) = 2.31$, $p=0.14$, $\eta^2 p = 0.04$.

To observe if there were any effects of cognitive functioning on postural stability, CoP path length was compared to ACE-R scores. The condition of eyes fixating on a stationary target was used to index the measure of general postural sway as in this condition there were no confounding variables potentially affecting baseline postural sway, such as concurrent task or deprivation of visual information. Using the established presence of dementia cut-off on the ACE-R of scores under 82 (Mioshi et al, 2006), the older adult group was split into two sub groups according to those who scored above 82 on the test (n=25) and those who scored 82 or under (n=16). From inspection of the means it was revealed that the lower scoring ACE-R group had a higher recorded average sway, 667.69 mm CoP path length, while the higher scoring ACE-R group recorded a lower average level of sway, 542.15 mm CoP path length over the 30 second trial. This difference in levels of sway was found to be significant by a one way ANOVA, $F (1, 39) = 7.58$, $p<0.01$, $\eta^2 p = 0.15$.

5.3.4.2 Focus on fall history and attitude towards falls

The Falls Efficacy Scale - International (FES-I) measures the level of concern an individual feels towards falling during social and physical activities inside and outside the home. The scale uses a four point rating system (with 1 representing no concern to 4 representing a high concern) over a series of 16 questions. In answering the full set of questions the scale produces a total score ranging from an absolute minimum score of 16, indicating no concern of falling, up to an absolute maximum score of 64 which equates to an extreme fear of falling.

The FES-I scores recorded by participants in this study ranged from the minimum score of 16 (no concern) up to the highest recorded score of 44 (SD of scores ±6.93). The highest recorded scores in this study, although not at the maximum level possible on the FES-I, still show a significant concern regarding falls amongst some members of the older adult group. The scores from the FES-I can be typically sub divided into three distinct categories (Yardley, et al., 2005); where 16–19 equates to a low concern, 20–27 represents a moderate concern and 28–64 is a high concern of falling. Using these recognised divisions the group was split into three sub groups according to those who scored 19 or under (n= 11) with very little concern of falling, those who scored between 20 - 27 (n = 22) reporting some concern of falling and those scoring 28 and over (n = 9) with a high concern of falling.

The recorded levels of postural sway were calculated for the low, moderate and high concern FES-I groups for the eyes closed and eyes fixating on stationary target tasks. The eyes fixating task was chosen again as there were the least confounding variables in this condition. The eyes closed task was selected additionally as the majority of older adult participants expressed the highest levels of concern at undertaking this task and felt it was disconcerting compared to the other tasks, therefore potentially a link could be found to the FES-I within the results.

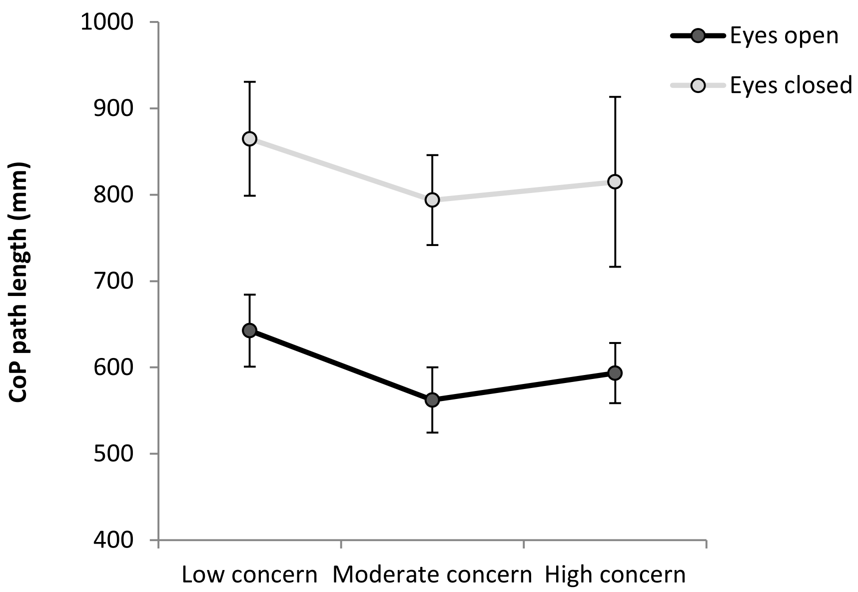


Figure 5.3 The level of concern regarding falls as indexed by categories of the FES-I and level of postural sway as indexed by CoP path length (mm) in the eyes fixating on a stationary target condition and the eyes closed condition. Bars = standard error of the mean.

The recorded CoP path length (mm) for the three groups showed that the low concern group exhibited the highest levels of recorded sway out of all of the groups split according to concern (Figure 5.3). However a one way ANOVA found the differences in average postural sway in eyes closed and eyes open conditions between the low, medium and high concern groups was not at a level that was significant, $F\ (2, 39) = 0.99$, $p=0.38$, $\eta^2 p = 0.12$.

5.4 Discussion

Significant differences were found to exist in postural sway between the young and older adult groups across all testing conditions. There were also significant differences between the three testing conditions with on average the lowest levels of postural sway recorded while stood with eyes fixating on a stationary target, then stood with eyes closed, with the highest levels recorded in the most challenging visuomotor condition; when the target object was moving at its fastest speed. However the two age groups were not affected by the visuomotor task to the same extent; the results showed that dual task interference occurred for the older adult group but not the young. This was shown by significant interactions with both increasingly higher levels of postural sway and significantly poorer task performance for the older adults as the visuomotor task difficulty increased.

It was hypothesised that during the fast tracking speed, which was the most demanding condition of the visuomotor task, there would be differential effects on performance in the young and older adult groups. This prediction was made as older adults have been shown to employ a compensatory 'trade-off' strategy between postural stability and task accuracy. This compromise between executing a task well and maintaining postural stability occurs due to the increasing demands made for restricted cognitive and motor control resources which can suffer from age related deterioration. A decline in the postural control systems with increasing age can mean that these systems may not function to their optimum level, putting older adults at risk especially in certain high demand situations such as undertaking a complex concurrent task.

In this study during the fast visuomotor tracking condition, the older adults are being pressured both spatially and temporarily in the task by the speed and movement of the target. The older adult group displayed significantly poorer tracking performance than the younger adults which was to be expected to some extent as ageing is known to reduce fine motor skills. However the fact that the older adults' performance becomes disproportionally worse than the young adults as the task becomes more demanding may add to the debate of the task prioritising or the balance stability theories that have been reviewed in this research. The results from the visuomotor task condition also showed a dramatic increase in postural sway in the older adult group with increasing task difficulty; this was very different to the slight increase shown by the young adult group.

From these results it would appear that the older adults in this experiment are not adopting a prioritisation strategy, instead their performance on the visuomotor task *and* their postural sway is being negatively affected by the undertaking of a demanding concurrent task, to the detriment of their stability and task accuracy. These findings support the dual-task paradigm which predicts that a concurrent task such as a visuomotor or spatial task will serve to reduce postural stability and result in greater postural sway in older adults (Huxhold et al., 2006) due to the compensatory trade off required in the competition for resources. The “posture first” hypothesis states that older adults may perform poorly on a task but will maintain good posture, yet in the current study no prioritisation effects were apparent as both task performance and postural stability appear to have been negatively affected. The fact that older adults do not appear to be prioritising the maintenance of their stability over the completion of a concurrent task highlights a potentially hazardous scenario which could lead to an increased risk of falls. It has been found that falls can be more likely if a combination of high risk environmental circumstances occur for a person with existing detriments to their postural control system. Consequently undertaking a spatially and temporarily demanding task could be potentially one of these high risk situations.

Due to the complex nature of ageing however, not all older adults will uniformly experience the same decline in postural control systems, or in cognitive or motor function. This variation was demonstrated within the older adult group involved in the current study as there were many within group differences found even in this similar age and living conditions group. More variation was found in the older adult group compared to the young adults for both postural sway and tracking performance. Some older adults were found to be functioning at comparable levels with the young age group, however others were showing serious detriments in their stability and motor skills. This demonstrates that certain older adults will be more at risk of deterioration in postural control and have a higher chance of suffering a fall than other older adults and it is important to be able to identify these individuals based on their personal risk. As shown by the FES-I results, those with the lowest concern about their personal risk of falls are not always the people who are experiencing the lowest levels of postural sway.

A limitation of this study is the self-reporting of falls history in the older adult group. Self-reporting of events, especially those with negative health connotations such as falls, are hard to get an accurate estimate of frequency therefore there may be issues of data validity (Cummings, et al., 1988; Means, et al., 1989). In this population of independent living older adults however there was no other way of gathering this falls history information other than through self-report.

Through this work the link between cognitive function and falls risk was also explored. The results showed that those older adults with mild cognitive impairment may be experiencing differential levels of postural sway from those without. Participants with a mild cognitive decline based on the scoring of the cognitive assessment were found to have higher average levels of postural sway than the group who showed no cognitive impairment on the ACE-R; these findings fit with previous work (Liu-Ambrose, et al., 2008b). Detection of the beginnings of mild cognitive impairment could prove an important early intervention point to begin prevention work to assist with balance deterioration.

5.4.1 Objectives and implications for next phase of research

The results from this chapter have revealed some important findings concerning dual tasking in older adults, and also the link between a mild cognitive impairment and increased postural sway. However the results concerning fear of falling were somewhat limited and also inconclusive as to their role in the deterioration of postural control and prevention of falls. Further research needs to be carried out to establish if older adults are aware of experiencing balance issues and if they are able to make accurate assessments of their personal falls risk.

6 Awareness of own abilities in relation to postural (in)stability in young and older adults

6.1 Introduction

6.1.1 The need for an accurate assessment of fall risk

This chapter is the culmination of experimental work within this thesis, serving to build upon earlier results and incorporate key findings from previous chapters. These findings are used to develop a final experiment to investigate not only the potential decline of postural stability in older adults but also the awareness of this reduced stability and the effects it may have on functioning. The previous chapters served to highlight the circumstances under which older adults' postural stability may be compromised, such as when undertaking a concurrent visuomotor task and when deprived of visual information. Through the work with children the systems which control balance were explored, and also the progressive change in function of these mechanisms to a fully developed postural control system. This was then related to the older adult population to show the shift to a return of reliance on the visual system to help maintain stability. In the previous chapter the role of perceived self-efficacy towards risk of falls was investigated using the Falls Efficacy Scale (FES-I). The results from this scale were then compared to assessments of actual postural stability to see if any relationship existed between perceived risk and physiological risk. The results were inconclusive, potentially due to the overly generalised measurement of fall concern used (the FES-I) but also possibly because the relationship between perceived risk and actual risk of falls is extremely complex. These inconclusive findings therefore justify the need to further explore the complicated relationship between postural sway (linked to declining postural control) and the awareness of this declining postural control.

The key findings from the earlier chapters, such as the conditions which lead to the highest levels of compromised stability, will be incorporated into this comprehensive final study. This study will serve to integrate these earlier findings and enhance the scope of this work through the inclusion of an investigation into the role of perceived postural stability and confidence in balance. The role of self-awareness of stability in older adults is a key factor to explore in the field of falls prevention because an accurate assessment of risk by this group is essential to reducing the likelihood of a fall. However, the existing literature shows that there may be ageing effects on how accurately people are able to assess ability and this can lead to unfounded concern or even overconfidence in ability (Delbaere, et al., 2010; Liu-Ambrose, Ahamed, Graf, Feldman, & Robinovitch, 2008a); this will be explored later in this section.

With regard to falls prevention, the accurate assessment of fall risk and postural stability could have dramatic effects on quality of life through maintaining high activity levels or conversely needing to reduce exposure to unnecessary risks. If older adults are aware of deficits in their postural control it may be possible to exercise caution in situations of increased risk of falls. Nevertheless, on occasion these high risk situations may not be easy to identify as potentially dangerous. The risks involved when walking along an icy pavement or descending steep steps are usually obvious to an individual so strategies for increased safety can be implemented, for example using a walking stick or holding a hand rail. In contrast, the potential risks of falling when stood still but with attention on a visuomotor concurrent task, for example concentrating to put a key in a lock are far less salient. Indeed research has shown that because of the attentional demands needed to simply maintain a stable posture, situations involving a concurrent and demanding task can represent a risk to vulnerable groups (Brauer, et al., 2001; L. A. Brown, Shumway-Cook, & Woollacott, 1999; Huxhold, et al., 2006; Lajoie, et al., 1993). This fact was also demonstrated in the previous chapter (Chapter 5) where the older adult group's stability was at its lowest during the most demanding speed of the visuomotor tracking task, with postural sway affected by this concurrent task to a far greater extent than the younger adult group. Additionally the findings from previous chapters have shown an increased reliance by older adults on visual input to maintain balance. Consequently, older adults need to be aware of their abilities and be able to accurately gauge when they may be at risk and compensate where necessary to avoid destabilisation of balance.

Psychological factors such as a fear of falling or decreased confidence in ability can have a marked effect on an individual's perception of their fall risk, and this can be independent of actual physical function (Delbaere, et al., 2010; Mann, Birks, Hall, Torgerson, & Watt, 2006; Tinetti, et al., 1988; Vellas, et al., 1997). An accurate awareness of postural stability can be distorted by a fear of falling and it has been found to be sufficient to drive avoidance behaviours that could actually increase fall risk through deconditioning and the increased development of physical frailty (Arfken, et al., 1994; Delbaere, et al., 2004). After experiencing a fall some older adults have been shown to alter their normal gait characteristics and lose the automatic corrective mechanisms involved in walking (Guimaraes & Isaacs, 1980); these changes then increase the threat of future falls. Interestingly the same changes in gait that occur after falling have been found in older adults who have a high reported fear of falling but have never actually experienced a fall, showing that being concerned is enough to cause significant detrimental changes to behaviour (Chamberlin, et al., 2005). As mentioned previously however, the relationship between physiological condition and perceived falls risk is a complex one and can depend greatly on the individual’s perception rather than their actual risk status. This is clearly demonstrated in a recent study by Delbaere, Close, Brodaty, Sachdev and Lord (2010) where the physiological risk of falling was assessed in 500 older adults and then compared to perceived risk. It was found that 69% of participants displayed an accurate awareness of their concern towards falls risk that was deemed appropriate for their physiological measures. But of most interest in this study were the remaining 31% of the older adult sample; of these participants, 11% were found to be much more fearful of falling than justified on the basis of their physiological risk, thus displaying poor risk awareness (Delbaere, et al., 2010). These older adults, although at low risk of falling from a physiological perspective, displayed a very high and unfounded concern of falling which was found to be closely linked to depressive symptoms and neurotic personality traits. The other 20% of participants making inaccurate judgments about their falls risk were named the ‘stoic’ group, as although they displayed a very high physiological risk of falling, their levels of concern were extremely low. This group showed an inaccurate assessment of their ability which could lead to placing themselves in potentially high risk fall situations due to lack of concern and lack of awareness of deficits. Yet this group’s inaccurate assessments leading to a high fall risk was reportedly mediated by high documented levels of community involvement and a positive outlook on life. Thus there may be a growing evidence base to show that personality factors (depressive/neurotic versus optimistic) and an active involvement in the community could help negate the risks of falls and potentially have a practical role in a falls reduction campaign.

6.1.2 Accurately assessing awareness of postural stability

In undertaking research into the complex relationship between actual physiological risk and perception of risk, it is important to understand how accurately people are able to judge their own potential deficits; in this case to have an awareness of postural stability and make an accurate assessment of fall risk. In studying this relationship a brief introduction should first be made into the research area of 'metacognition'; people's capacity to reflect on their own cognitive abilities. Metacognition is the self-awareness of ability and is defined as 'knowing about knowing' (Flavell, 1979). The study of this area was initially founded through work focussing on the disrupted self-awareness experienced in some clinical populations, and in the 'denial of deficit' or lack of concern which is prevalent in Alzheimer's disease and other dementias (Agnew & Morris, 1998; Green, Goldstein, Sirockman, & Green, 1993; Kotler-Cope & Camp, 1995; Lopez, Becker, Somsak, Dew, & DeKosky, 1994; McGlynn & Schacter, 1989; Vasterling, Seltzer, Foss, & Vanderbrook, 1995). However theoretical frameworks have since been developed to investigate normal patterns of self-awareness and reflective abilities in non-clinical populations (Nelson & Narens, 1990; Souchay, Isingrini, Clarys, Taconnat, & Eustache, 2004).

Within the study of non-clinical populations, differences have been found in the metacognitive abilities between certain populations. Even in groups of healthy older adults differences have been shown to exist between young adults and older adults in their metacognitive judgment abilities (Souchay, Isingrini, & Espagnet, 2000). With increasing age, the older adult population becomes more at risk of neurodegenerative diseases such as dementia. Types of dementia have been shown to cause a distorted assessment of one's own skills and lead to a reduced self-awareness and a potential loss of insight (Agnew, et al., 1998; McGlynn, et al., 1989). Recent research using clinical populations has helped inform the area of assessment of own skills, where those with frontotemporal dementia specifically often have a denial of deficit and overestimate their performance (Neary, Snowden, Gustafson, Passant, Stuss, Black, Freedman, Kertesz, Robert, & Albert, 1998).

In addition, research has suggested healthy older adults display a general inaccuracy when asked to reflect on their performance, but this was found to be a definite overestimation of abilities when looking at a sub group of older adults presenting with as yet undiagnosed cognitive decline (Barrett, Eslinger, Ballentine, & Heilman, 2005). In a real world situation, those older adults who may be in the early stages of experiencing some cognitive difficulties but have yet to receive any formal diagnosis or treatment could be at particular risk of falling. This is due to their potential denial of deficit and overestimation of abilities due to the cognitive decline, which if combined with deterioration in postural stability may lead to putting themselves in situations of increased risk. It is straightforward to see that if someone was suffering with early dementia symptoms their chances of experiencing a fall could be easily exacerbated through a denial of deficit of problems with postural stability. Neurodegenerative diseases such as dementia and Alzheimer's disease have also been shown to cause serious impairments to balance and mobility (Hauer, et al., 2003; Isaacs, 1992; Shaw, 2003; Shaw, et al., 2003; Tinetti, et al., 1995; Van Dijk, et al., 1993; Van Doorn, et al., 2003) thus leading to increased falls risk through multiple mechanisms.

Despite the serious consequences associated with a combination of cognitive decline and postural stability for older adults, rarely has previous research investigated the awareness of ability within the field of postural stability. As two of the most significant issues facing older adults in the UK today are cognitive deterioration and increased risk of falls (Age UK, 2010; World Health Organization, 2012) it is important to carry out this work into awareness of postural stability.

In this concluding study, both memory performance and postural stability will be investigated. Much of the existing metacognitive research thus far has involved older adult's awareness of their memory performance, especially in regards to memory control and monitoring (Nelson, et al., 1990). Older adult awareness of ability has been explored within studies of 'metamemory' which is described as one's own knowledge and control of memory (Flavell, 1979). It has been shown that differences in metamemory performance exist between young and old (Fernandez-Duque & Black, 2007; Souchay, et al., 2000) therefore this final study will involve a memory component as an effect is expected to be found through age differences. It is of interest to assess both memory and postural stability in the same study as differences in metamemory are expected between young and older populations and it is useful to compare if the inaccuracies that can exist in older adults' metacognition in memory may also apply to assessments of postural stability. Therefore we can see if there is a relationship between memory accuracy assessment and balance performance assessment. Additionally if a difference in metamemory can be confirmed between the two age groups it will help increase the validity of any findings that may be found in the perceived postural stability results. The memory conditions will include a learning section and a recalling section to assess participants' metamemory. Novel word lists will be presented on screen one word at a time over a set time period for participants to read and learn. Participants will then be asked to list as many words as they can during the recalling condition. Throughout these conditions, participants' postural stability will be assessed using the Wii balance board. As well as researching metamemory, these conditions are being used to assess a secondary theory; the effect of a concurrent *visual task* on postural sway. Thus far my thesis has focussed on visual tasks with moving targets or visual tasks with a motor element. Yet this learning condition is being specifically used as it involves a reading element. Various researchers have shown that there may actually be a stabilising effect on the postural control system from the subtle integration of visual information, for example undertaking an activity such as reading, and this stabilising effect remains even in an ageing population (Prado, et al., 2007). Therefore when someone is undertaking an activity such as reading, their postural sway may decrease to steady the body and focus on the task at hand. It will be interesting to see if the learning condition which involves reading a word list serves to decrease postural sway and lead to good stability or, if because the task is not simply reading but also involves encoding the words to memory, then the pressure for later recall will serve to increase sway through potential agitation from the increased cognitive demands of the task.

In this experimental design, participants' judgments of performance will be compared to actual performance. This will occur in the previously described word recall task through the number of words they judge they will be able to recall, and in the divided attention visuomotor tracking task where participants will be required to make judgments of the number of coloured cues they have observed on the periphery of a screen whilst tracking a separate set of coloured targets. Participants will also be asked to assess their predicted stability on a descriptive Likert type scale before undertaking a task and then make an assessment of their perceived stability after the tasks. It is of interest to see if an awareness of postural stability can be accurately linked to actual stability and how these judgments of postural stability will be affected by the various testing conditions, which should serve to provoke differing levels of balance confidence. Recent work by Hadjistavropoulos and colleagues (2012) looked into the relationship between fear of falling and confidence in balance when undertaking a dual task. In their study anxiety levels were manipulated during testing as it was argued that anxiety has a direct negative effect on balance rather than the previously proposed theory that anxiety of falling leads to activity avoidance and increased frailty. They found that simple manipulations of anxiety can affect balance negatively, and further negative effects are observed whilst undertaking a dual task (Hadjistavropoulos, Delbaere, Carleton, Barden, Zwakhalen, Fitzgerald, Ghandehari, & Hadjistavropoulos, 2012). These previous findings will be built upon by assessing participant anxiety towards each condition through making a prediction and assessment of their predicted postural stability on the descriptive scale at the time of testing. The novelty of this approach is that it will be taking a prediction measuring concern before testing and then an assessment of awareness of postural stability directly after testing, with each judgment made specifically to the task being undertaken, and at the exact time of testing. It is not simply using a general measure of postural stability in daily life but it is specific to each testing scenario. Through this an accurate measure of people's awareness of their stability at the time of testing and also their confidence in their balance can be assessed. This measure of postural stability awareness at the time of testing could be the key to reducing needless anxiety towards falling.

6.1.3 Predicted outcomes from testing

As there are several different elements being explored in this study, the predicted findings are divided into research areas for ease of interpretation.

6.1.3.1 Measured postural stability between age groups and under different testing conditions

It is expected that across all five testing conditions, older adults will show impaired postural stability when compared to the young adults. When deprived of visual information in the eyes closed condition it is expected that older adults will show significantly lower postural stability than the young age group. It is also predicted that older adults will be affected to a greater extent and show significantly decreased postural stability compared to young adults in those testing conditions which require dual task performance; recalling the word lists and the divided attention visuomotor tracking task. As the word list learning condition involves the integration of visual information through reading it may actually serve to increase postural stability (Prado, et al., 2007). However it will be interesting to see if this effect is present in the older adult age group or if the dual task nature of the learning condition due to the required encoding to memory while reading may actually cause a detriment to stability by causing competition for cognitive resources.

6.1.3.2 Judgements of perceived postural stability

It is predicted that older adults will be less accurate in their predictions of postural stability before tasks and less accurate in their assessments of perceived postural stability after tasks when compared to the young adults. It is expected that this inaccuracy will be greater in those conditions where there is a dual task element to the condition; learning word list, recalling word list and divided attention visuomotor tracking task. This prediction is made based on previous literature which shows older adults have poorer ability when making assessments of performance and in studies of metacognition where older adults show decreased accuracy in judging their capability (Delbaere, et al., 2010).

6.1.3.3 Memory task performance and perceived performance

It is predicted that older adults will recall fewer words than the young adult group when asked to recall from a novel word list. This result is expected due to the decline in memory capabilities shown in some older adults with increased age (Taylor, Miller, & Tinklenberg, 1992). According to previous literature it is thought that older adults will be less accurate in their predictions and assessments of performance compared to their actual performance, while young adults will make more accurate predictions.

6.1.3.4 Divided attention visuomotor tracking performance and perceived performance

The older adult group will observe fewer of the peripheral coloured cues available to observe during the divided attention visuomotor tracking task than the young age group due to the extremely demanding nature of this task. This poorer performance is expected by the older adult group as the divided attention visuomotor tracking task requires not only fine motor skills which have been shown to deteriorate with age (Barnett & Cobbold, 1968;

B. C. Clark & Taylor, 2011; Faulkner, Larkin, Claflin, & Brooks, 2007), but also good divided attention abilities as focus is required on the target being tracked but also on the periphery of the computer screen to observe all of the coloured cues. However there is some expectation that both age groups may be able to estimate their judgments quite accurately as participants undertake 6 trials of the task in total, so with practice they may be able to predict how many coloured cues they observed in previous trials. Also participants may be able to make accurate assessments after the task as the judgments are made directly following task completion so they may be able to recall exactly how many switches they saw out of the possible of five. However if the task proves to be challenging enough then it may interfere with the participants recall of the exact number of colour cues that were attended to.

6.2 Methods

6.2.1 Participants

A group of young adults, (n=15, 7 males, mean age 23 ± 7.42) and a group of older adults (n =11, 4 males, mean age 75 ± 4.54) completed the study. Group differences were able to be examined with relatively small numbers of participants because of the large time-course datasets which supply robust quantitative measures of postural sway; small participant numbers are appropriate as inter-individual variability is low (Harley, Wilkie, & Wann, 2009). All participants were unpaid volunteers recruited via the Institute of Psychological Sciences volunteer panel. The research was approved by the Institute of Psychological Sciences Ethics Committee. All participants in the older adult group attained scores on the Mini-Mental State Examination (Folstein, Folstein, & McHugh, 1975) above the cut off of 27 and were not receiving medication which would affect cognitive function. A detailed medical history and activity questionnaire *(Appendix B)* was completed by the older adult participants to establish the presence of any neurological conditions or movement disorders. All older adults were living independently at the time of testing and were able to travel to the Institute of Psychological Sciences to take part in the experiment. Participants were checked for colour blindness and all were found to have normal vision.

6.2.2 Equipment and materials

A Nintendo Wii balance board (Nintendo, Kyoto, Japan) was used to assess standing postural stability through changes in centre of pressure (CoP). Throughout each 30 second trial centre of pressure was recorded via a wireless blue tooth connection to a tablet laptop running KineLab (the software supporting the Kinematic Assessment Tool (KAT) as described in Culmer et al) (Culmer, Levesley, Mon-Williams, & Williams, 2009). The KineLab software presented the five testing conditions. The first two conditions involved participants firstly standing with their eyes closed, then standing with eyes open whilst fixating on a stationary target for 30 seconds. The third and fourth conditions involved memorising and then recalling a list of 10 words which varied for each of the 6 condition trials (further information provided below). The fifth condition was a complex divided attention visuomotor tracking task requiring participants to use a handheld stylus to track four smoothly moving coloured targets presented on a tablet laptop (further information provided below).

6.2.3 The descriptive scale used to make judgments of postural stability

To allow participants to assess their standing postural stability before and after each testing condition a descriptive Likert type scale was developed which was specifically designed for use with older adults. It consisted of a scale ranging from 0 to 100 with descriptive statements to define stability along the scale (*Appendix C*). The scale was fully explained to each participant before testing and standard examples with demonstrations were provided by the researchers. Participants were encouraged to ask questions before beginning testing to ensure they were clear on how to use the scale. Six descriptive statements were associated with the scores of 0, 20, 40, 60, 80 and 100 ranging from the lowest score of 0 reflecting a judgment of extreme instability to the highest score of 100 which reflected extremely good stability. For example, a relatively low rating of 20 was described by the statement "*I feel like I am swaying a little. I would be more comfortable if I had something to hold onto to steady myself*", whereas a rating of 80 was described on the scale as "*I feel steady and completely confident whilst standing. I can detect only tiny movements in my standing posture*". Participants were informed that if any of the ratings did not accurately describe their perceived stability they could choose any value on the scale between the numbers with corresponding statements. This scale was developed as previous research has shown that older adults cope well with Likert type descriptive scales (Zwakhalen, Hamers, Abu-Saad, & Berger, 2006). Additionally this type of scale is regularly used in metacognitive experimental work with very effective results.

6.2.4 The memory task

While standing on the balance board, participants were presented with a list of ten novel words on the tablet laptop; each word appeared one at a time for 2 seconds with a 1 second break in between words. Participants were asked to try to remember as many words as possible. Ten words were chosen for the memory task based on the average working memory capacity (Baddeley, 1992). Before commencing the learning conditions participants were asked to make predictions of how stable they felt they would be whilst learning the list of words and also how many of the ten words they felt they would be able to remember when asked to recall them a minute later. After seeing the words, participants were asked to make an assessment of how stable they felt during the learning condition. In the recalling condition participants had 30 seconds to recall as many words as possible. During this free recall they were asked to fixate on a green dot in the centre of the laptop screen. Again predictions of postural stability and number of words they felt they would recall were recorded before beginning the 30 second recall period and then assessments of stability and number of words remembered were made after the recall period. There were 6 different lists of 10 words each; they were presented according to the block randomisation for each participant. Three of the word lists contained high frequency words (mean = 200.47 ±21.63) and three lists were low frequency (mean = 2.73 ± .151). All the lists were matched for word imaginability (L mean = 479.10 ± 5.54, H mean = 488.00 ± 4.30) and word concreteness (L mean = 468.787 ± 5.75, H mean = 461.03 ± 5.74).

6.2.5 The divided attention visuomotor tracking task

The divided attention visuomotor tracking task involved tracking one of four coloured targets across a flat screen laptop using a hand held stylus. Participants were always instructed to begin tracking the red coloured target of the four possible targets. The four targets moved across the screen at 6 Hz following a combination of a ‘figure of 8’ and an ellipse trajectory (Figure 6.1 a). Whilst accurately tracking one of the four targets, participants had to divide their attention between the top two corners of the laptop screen where, at random intervals, different coloured target cues briefly appeared (0.5 second) signaling when they needed to switch between the four different coloured moving targets (Figure 6.1 b). Within the 30 second trial there were five different target change cues for participants to try and see. Participants were asked to track the four coloured target cues, one at a time, as accurately as possible, whilst attending to the corners of the screen to see the colour change cues. Participants were told to try and spot as many cues as possible and to switch between targets when the cues were seen. The order of the colour target cues were randomised for each trial and the location that the colour cues appeared on the screen was also randomized. In this task the number of colour change cues that were attended to was recorded and used a measure of task success. The hand tracking accuracy data was not used in this analysis as earlier chapters have previously shown that older adults exhibit poorer performance in manual tracking tasks.

a **b**

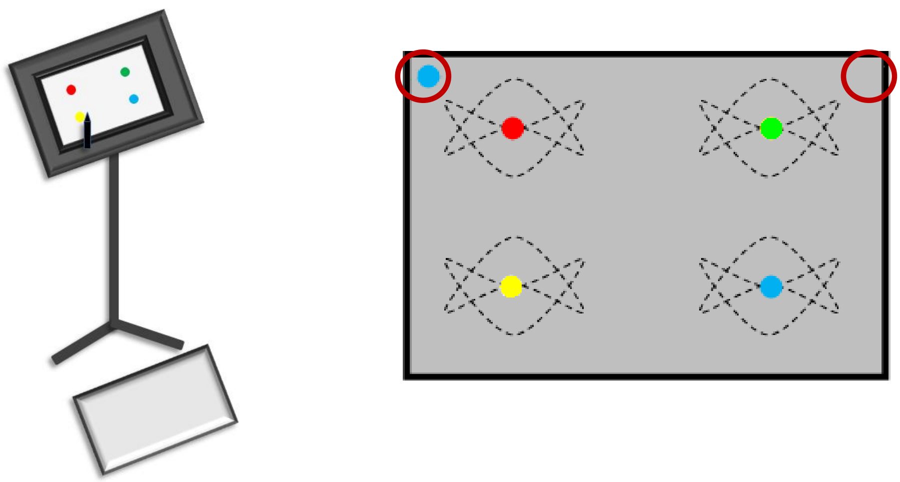


Figure 6.1 (a) Testing set up showing the balance board and the tablet laptop positioned on testing stand **(b)** The dotted lines show the movement patterns of the four targets in the divided attention visuomotor tracking task. The target cues are shown appearing in the top two corners of the screen

6.2.6 Procedure

Participants were asked to stand upright on the balance board under five conditions: (i) with their eyes closed; (ii) with their eyes open whilst fixating on a stationary target; (iii) whilst learning a list of ten novel words (iv) whilst recalling the list of ten words (v) whilst undertaking a divided attention visuomotor tracking task. Before and after each of the testing conditions participants were asked to rate their postural stability on a scale ranging from 0 (very unstable) to 100 (very good stability).

Each of the five conditions were tested in a randomized block and then participants were given a short break and refreshments if desired. Each block was completed six times, after which participants were given a full debrief. Testing took an average of 1.5 hours to complete. All participants were asked to stand up slowly a few minutes prior to beginning testing to allow them time to adjust to a standing position. This was to counteract any effects of postural hypotension which can result in dizziness and a potential loss of stability on standing.

6.2.7 Analysis of actual postural stability compared to perceived postural stability

The raw centre of pressure data from the balance board was recorded and converted into scaled scores of postural stability ranging from 0 to 100. To scale the data, z-scores were generated from previously collected postural stability data recorded from a separate set of young (n=30) and older adults (n=30) under similar visual conditions (but without making judgements of stability). Once converted, the scaled postural stability scores ranged from 0, which equated to exceptionally poor stability up to 100, which represented the highest possible score for stability. This allowed us to compare patterns across measures so the recorded postural stability scores could be directly compared to the descriptive scale of participants' perceived postural stability (also on a scale ranging from 0 to 100).

To measure accuracy of awareness, participants' judgments of their perceived stability were compared to their actual stability. These values were comparable as both scores, actual or judgments, were within a scale ranging from 0 to 100 with high scores equating to excellent postural stability. If a large discrepancy existed between perceived stability and actual stability then the participant's assessment was considered inaccurate. To illustrate, if a participant rated their perceived stability on the scale as 60, but their actual recorded scaled stability was 30, (in the bottom 5th percentile of postural stability) then there exists a large discrepancy in their accuracy of assessment equating to an overestimation of stability (considerable difference between actual (30) and perceived (60) stability). Depending on the direction of difference between perceived and actual stability, it relates to an underestimate (participants felt they were less stable than they actually were) or overestimate (participants felt they were more stable than they actually were). Even if participants did show a significant miscalibration between their actual postural stability and their perceived postural stability then these results were still of interest. In the metacognitive literature this is how the testing is undertaken and differences between perceived and actual performance can reveal a great deal about participant thinking and functioning.

6.3 Results

Firstly a brief overview of the older adults' medical history and activity levels will be provided before the results from the experimental work. This is to help characterise the older adult sample used for this final study before proceeding on to the main findings. Subsequently the postural stability results will be presented, followed by the judgments made (predictions/assessments) about perceived postural stability. The final section will show the results for performance on the memory task indexed by the number of words recalled and the performance on the divided attention task indexed by the number of coloured cues observed.

In these results the measure of participant postural stability presented is a scaled measure of postural **stability** not the actual postural **sway** derived directly from the balance board raw data (as in the earlier chapters). This scaled measure was used to allow direct comparison with the postural stability judgement scale that was used to assess confidence in postural stability.

6.3.1 Health and activity levels in the older adult group

Each person in the older adult participant group (n=11) completed the medical history and activity questionnaire. Of the 11 participants, none reported a diagnosis of Parkinson's disease or a stroke, or any other neurological disorders or movement related conditions that could affect their balance. Six of the 11 participants reported having some form of arthritis. Only 2 reported problems with their blood pressure, for which they were both taking medication. In total, 5 of the 11 participants were taking some form of daily medications but none were taking over 4 per day, which is the number reported to lead to an increased risk of falls of (Tinetti, et al., 1994). The older adult group were found to be extremely active, with all 11 participants undertaking some form of strenuous activity or sport each day. Three participants reported having experienced a fall within the last 2 years. Of these 3 persons, all reported to have some form of arthritis, 2 reported to be taking a daily medication, and 1 of these 2 reported to have blood pressure problems. The average age of the 3 participants who had a history of falls was slightly higher at 78.3 years (±7.74) than the 8 participants who had no falls history 72.6 years (±4.04).

6.3.2 Postural stability for young and older adults

6.3.2.1 Postural stability during the testing conditions

A 2 (age group) × 5 (testing condition) repeated measures ANOVA found that the testing conditions served to alter postural stability in both age groups, with the same pattern of postural stability found across conditions for young and older adults (Figure 6.2). Significant differences were found between the testing conditions, $F\ (2.8, 67.23) = 113.81$, $p<0.001$, $\eta^2_p = 0.83$, and age group had an effect on postural stability with the older adults shower significantly lower postural stability than the young, $F\ (1, 24) = 11.09$, $p<0.005$, $\eta^2_p = 0.32$. There was however no interaction between age and postural stability across the conditions, $F\ (2.8, 67.23) = 2.13$, $p = 0.11$, $\eta^2_p = 0.08$.

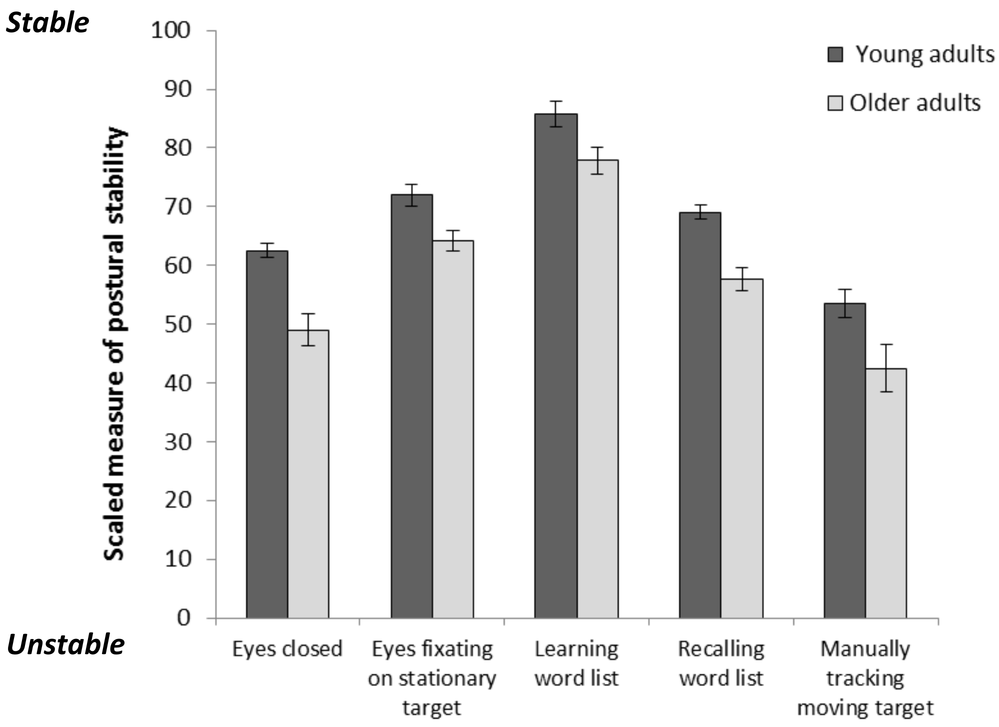


Figure 6.2 The average postural stability scores across the six trials of each of five different testing conditions for young and older adult groups. Bars = Standard error of the mean.

As predicted, the lowest levels of stability were recorded during the divided attention visuomotor tracking task and in the eyes closed condition. In these two conditions the older adults' postural stability was affected significantly more than the young adults; post hoc tests showed a significant difference between young and older adults for eyes closed ($p<0.001$) and divided attention visuomotor tracking task ($p<0.05$). The older adults' stability reached a particularly low level when undertaking the divided attention visuomotor task. This could have significant consequences for falls prevention as these findings show a complex concurrent visuomotor task can serve to destabilise older adults to a much greater extent than any other condition.

In both young and older adult age groups the greatest postural stability was recorded during the learning condition. The two age groups displayed extremely high levels of stability during this condition, far greater than when stood fixating on a stationary circular target. Despite the high levels of postural stability reached by the older adults in this testing condition, they still exhibited significantly lower postural stability when compared to the young adults ($p<0.05$).

6.3.2.2 Perceived postural stability during the testing conditions

Based on the participants' judgments of their stability (the average of the prediction and assessment) a 2 (age group) × 5 (testing condition) repeated measures ANOVA found that overall the young were significantly more accurate in their judgments of stability than the older adults, F (1,140) 12.52, p<0.001, η^2_p = 0.49. The accuracy of the participants' judgments was dependant on the condition, F (3,420) 26.44, p<0.001, η^2_p = 0.52, and there was a significant interaction of condition and age, F (3,420) 3.883, p<0.05, η^2_p = 0.22, showing that the two age groups were affected to differing levels by the various conditions.

The differences between perceived postural stability and actual postural stability are shown in Figure 6.3 and are split according to (a) the predictions made before testing and (b) the assessments made after testing, for the five conditions. Showing the results according to before or after task judgments (prediction or assessment) reveals the adjustments that were made to the judgments after the task. The results reveal some very interesting findings regarding the trends across the age groups for accuracy of assessments and the tendencies to over or underestimate stability.

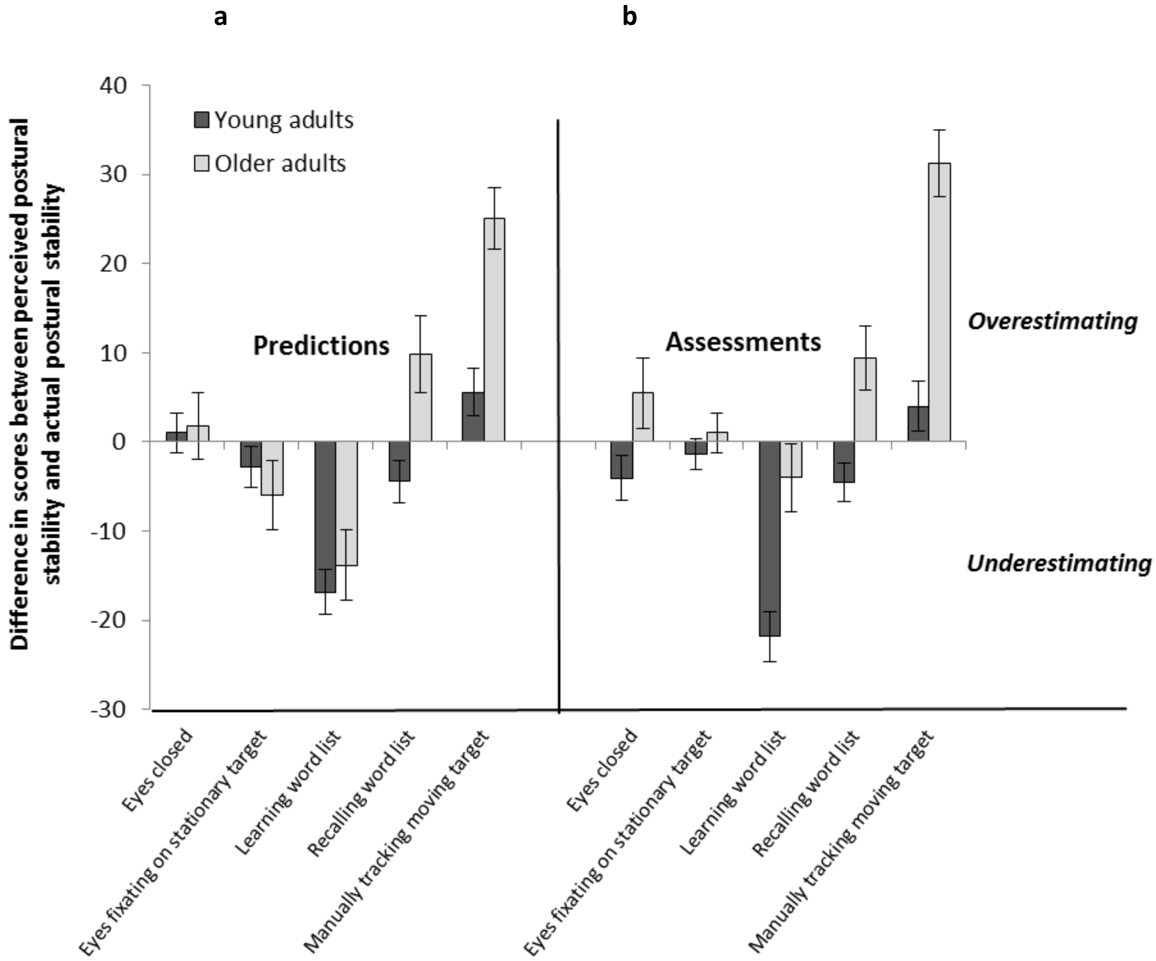


Figure 6.3 (a) the difference between prediction of postural stability before task compared to actual postural stability during task across the five testing conditions for young and older adults, **(b)** the difference between assessment of postural stability after task compared to actual postural stability during task across the five testing conditions for young and older adults. Bars = Standard error of the mean.

Young Adults' Perceived Postural Stability

A 2 (time of judgment) × 5 (testing condition) repeated measures ANOVA showed that the young age group tended to change their judgments significantly depending on which condition they were undertaking, $F\ (3, 480) = 44.45$, $p<0.001$, $\eta^2 p = 0.53$. This shows they understood their stability would be more affected by some conditions than others. However, there was no effect of whether the judgment was made before or after the task (prediction or assessment), $F\ (1,160) = 0.28$, $p=0.60$, $\eta^2 p = 0.20$. Also there was no interaction between the conditions and the time the judgments were made (prediction or assessment), F (3,480) = 64.15, p=0.57, η^2_p = 0.06. This shows that there was very little change from their prediction to their assessment, showing perhaps a confidence in their judgments through a stability of their self-scoring.

Older Adults' Perceived Postural Stability

In the older age group a 2 (time of judgment) × 5 (testing condition) repeated measures ANOVA also showed a significant effect of testing condition in their postural stability judgments, F (3, 360) = 7.36, p<0.001, η^2_p = 0.66. This showed the older adults gave considered judgments depending on each condition and predicted the various conditions would lead to differing levels of stability. However, unlike the young there is a significant effect of the time of judgment (prediction or assessment), F (1,120) = 4.34, p<0.05, η^2_p = 0.21, and a significant interaction of condition and time of judgments, F (3,360) = 9.38, p<0.001, η^2_p = 0.76. These results show that the older adult group made significant changes from their initial predictions to their later assessment of stability after completing the task. In all conditions, older adults made more positive assessments after completing the task. There was a significant interaction showing the older adults are varying the levels of change from their predictions to assessments by differing amounts depending on the condition they are undertaking.

6.3.3 Performance on the memory task

6.3.3.1 Actual performance on the memory task

As with all conditions, participants undertook the testing six times; a different list of ten novel words were used each time for the learning condition. On average young adults recalled significantly more words (6.06 words) compared to the older adults (4.23 words), as shown by an independent groups t-test; t (23) =3.46, p<0.005.

6.3.3.2 Accuracy of judgments for memory task performance

The predictions and assessments made by the participants before the learning condition and after the recalling condition were analysed. The results are shown on Figure

6.4 where the young appear to consistently underestimate their performance in both their predictions before testing and assessments after, while the older group consistently overestimated their performance again, in both predictions and assessments.

A significant effect of age group was found, F (1, 23) = 4.45, $p<0.05$, $\eta^2 p = 0.13$, but no significant difference was found between the actual number of words recalled and the judgments made before or after, F (1.25, 28.79) = 2.96, $p = 0.11$, $\eta^2 p = 0.22$. There was also no significant interaction between age and the judgments of words recalled/actual words recalled, F (1.25, 28.79) = 2.64, $p = 0.10$, $\eta^2 p = 0.23$.

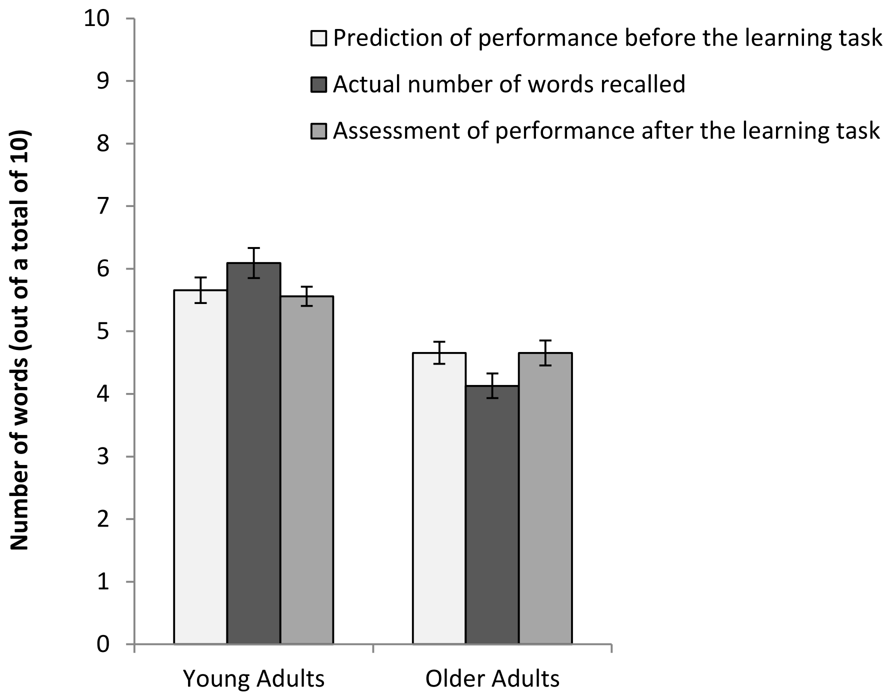


Figure 6.4 Number of words predicted before the learning task and assessed after the learning task compared to the actual number of words correctly recalled. Bars = Standard error of the mean.

Regardless of age group, there was no significant difference found between the predictions made before the word recall task and the assessments made after the task. To illustrate, even actually completing the word recall task does not appear to increase the accuracy of the assessments. This means that for each age group, their judgments were consistent across their predictions and assessments. It emerges that participants believed their judgments to be accurate and did not change them significantly according to the memory task, even immediately after the recall task when they could possibly accurately recall how many words they had correctly remembered. As predicted, older adults recalled fewer words than the young adults when asked to learn a novel word list of ten words. Despite recalling fewer words than the young group, the older adults consistently judged they would remember more, as shown by their higher predictions and their assessments of words recalled after the learning task. The young adults did not make accurate predictions and assessments either as to their performance, but their judgments were in the opposite direction and they consistently underestimated their performance.

6.3.4 Performance on the visuomotor divided attention tracking task

6.3.4.1 Actual performance on the visuomotor divided attention tracking task

An average score of the number of colour cues observed over the six trials of the visuomotor divided attention tracking task was calculated. On each trial participants began tracking one of the central four coloured targets and throughout the trial additional coloured target cues would appear on the periphery of the screen to signal when to change to tracking a different coloured target. Each of the six trials used a different order of colour cues appearing at randomised times in different locations on the screen so there were no practice effects from completing the six trials. Over each 30 second trial five coloured target cues appeared in total. If the colour cues were attended to then the participant switched and began tracking a new coloured target. On average the young adults attended to more coloured target cue switches (4.06 cues) compared to the older adults (2.84 cues), this difference was found to be significant by an independent groups t-test; $t(23)=3.65$, $p<0.001$.

6.3.4.2 Perceived performance on the visuomotor divided attention tracking task

The predictions and assessments made by participants before and after the visuomotor divided attention tracking task condition are shown on Figure 6.5. A significant difference was found between the young and older adults in the number of colour cue switches observed in the visuomotor divided attention tracking task. As occurred in the word learning condition, the young appeared to consistently underestimate their performance in both their predictions before testing and their assessments after. The older group consistently overestimated their performance again in both predictions and assessments. A repeated measures ANOVA showed a significant effect of age group on the judgments/actual number of colour cues observed, F (1, 23) = 5.01, $p<0.05$, $\eta^2_p = 0.22$. In the same pattern as previously shown for the memory task, there was no significant difference found between the actual number of colour cues observed and the judgements of how many were observed, made before or after testing, F (2, 46) = 0.45, $p = 0.64$, η^2_p = 0.19. There was however a significant interaction found between the age group of participants and the judgments of cues seen/actual cues seen, F (2, 46) = 7.09, $p <0.005$, $\eta^2_p = 0.24$, showing the two groups were affected differentially by the task. The young age group performed better than the older adults in the number of colour cues observed, but they consistently made underestimates about their performance. Meanwhile the older adults made far more positive judgments about their performance both in their predictions before testing and their assessment after testing.

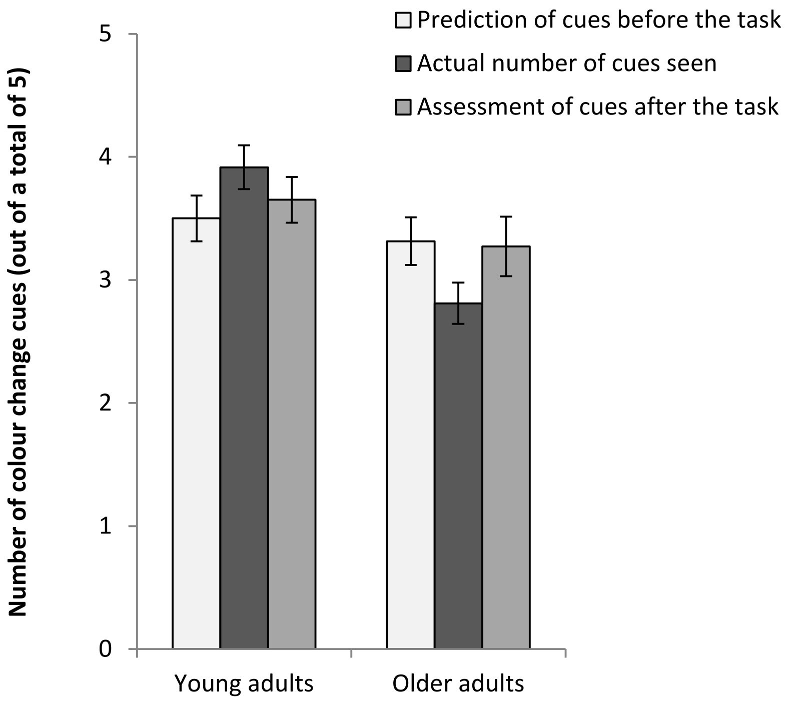


Figure 6.5 Number of colour cues attended to compared to the number predicted before the visuomotor task and the number assessed after the visuomotor task. Bars = Standard error of the mean.

As there were only a total of five colour cue switches during the 30 second trial it was somewhat unexpected that both groups of participants were consistently inaccurate in their judgments as five cues is a small number so it was expected that a more accurate recall of the number seen in testing may have occurred. This may be due to the demanding nature of the task which required high levels of concentration and focus, therefore participants were not able to monitor their actual performance during the task to recall numbers of cues seen.

6.4 Discussion

6.4.1 Summary of findings

In this concluding experimental chapter, the aim was to develop a final study to encompass the most significant issues involved in the decline of postural stability with age. Through researching older adults' deterioration of stability it became apparent that one of the most complex factors in falls prevention work is the inaccurate perceptions that some older adults can hold regarding their postural stability and their fall risk. These misconceptions can lead to negative outcomes from either developing a fear of falling, which then causes restriction of daily activities through avoidance, or conversely some older adults may hold a denial of deficit in balance ability and so place themselves in dangerous situations of increased falls risk. Either extreme can be detrimental to an individual's quality of life, hence further research into this area was deemed necessary in the culmination of this thesis investigating postural stability in older adults. This final study has integrated the most significant findings from previous chapters to develop an experimental set up to firstly assess the testing conditions which can cause decreased postural stability in older aged participants but also to incorporate an investigation of awareness of postural stability through making personal stability judgments. This final study has provided a range of very interesting findings which bring to light some key issues in the area of falls prevention.

Our postural stability measurement system showed that older adults exhibited lower postural stability than younger adults; this finding was consistent across all testing conditions and was also consistent with the findings from previous chapters of this thesis and research in this area (Era & Heikkinen, 1985; Maki, et al., 1994). The lowest levels of postural stability in both groups were recorded in two key conditions; when visual information was removed (through asking participants to close their eyes); this finding is in line with previous research (Black, et al., 2005; Lord, 2006), and in the divided attention visuomotor task where both groups of participants experienced their lowermost level of postural stability.

One of the major goals of this thesis was to explore the impact of a divided attention visuomotor task on postural stability. It was thought that capturing changes in sway under such conditions was likely to provide a deeper insight into an individual's risk of a fall when undertaking an attentionally demanding task, such as marking off a list of items whilst shopping or hurrying to find the right key to open a door. In this current study it has been established that a divided attention visuomotor tracking task significantly increased postural sway as indexed by changes in the centre of pressure on the balance board, indicating changes in the participants' centre of mass. The divided attention visuomotor tracking task had an impact on postural stability for both the young and older adults, as demonstrated by the lack of an interaction between condition and age group. Nonetheless, the lower starting baseline stability of the older adults meant that the potential consequence of increased postural sway was not equivalent. It is obviously possible for individuals to remain in an upright standing posture despite shifts in the centre of balance but there is a threshold beyond which a loss of stability makes an eventual fall unavoidable. The absolute level of sway was considerably higher in the older adults during the divided attention visuomotor task condition meaning that the task was pushing older adults towards a dangerous threshold. The actual threshold for falling depends upon the individual and the environment but our findings are consistent with the observation that falls often occur when individuals are undertaking a concurrent manual task (Brauer, et al., 2001; L. A. Brown, et al., 1999; Huxhold, et al., 2006; Lajoie, et al., 1993).

These findings do not isolate the mechanisms by which the divided attention visuomotor tracking task increased sway. There are two possible mechanisms and there is the potential for these factors to interact. Firstly, the movement of the arm causes a simple mechanical change in the centre of mass of the body. Thus, the increased sway may be caused by a failure to compensate for the arm movements. Secondly, the divided attention visuomotor tracking task was attentionally demanding. It required sustained attention (on the target that was being tracked) and divided attention (to monitor the peripheral cues being presented on the screen). Sustained attention uses cognitive resources that are consequently not available for monitoring balance. Divided attention requires shifts in visual attention (possibly by moving the eyes) which might degrade the visual information that can help the system maintain posture (Black, et al., 2005; Lord, 2006; Lord & Dayhew, 2001). Regardless of mechanism, the increased sway found when undertaking a divided attention visuomotor task has clear clinical significance.

Both age groups showed particularly high levels of postural stability whilst undertaking the learning condition, which involved the reading and then memorising of novel word lists. This finding was predicted to some extent as the integration of visual information has been shown to have a steadying effect on the postural control system (Prado, et al., 2007), however there were questions bought into consideration as to whether this condition was purely a visual task, as there were also cognitive elements involved through the need to encode the words to memory ready for the recall condition. However, when the levels of postural stability were compared to the eyes fixating condition which had similar properties to the learning task, it was found that stability in both age groups was considerably higher during the learning condition. This showed that postural stability was not affected by the extra cognitive load of having to learn a word list and in this instance the theories regarding visual information focussing the actions of the postural control system were supported. This positive effect from some visual tasks has been shown to be consistent in an older age group (Prado, et al., 2007) however in this study the findings still suggest that even in the learning condition with the benefit of integrated visual information, older adults' postural stability is markedly lower than young adults.

One additional aim of this study was to explore the awareness of postural stability. The results showed that judgments of postural stability were context specific in both young and older adults. The young adults showed this variation in judgment accuracy across the five testing conditions generally making both small under and overestimates of their postural stability depending on the condition. However, they were generally more accurate in their judgments when compared to the older adult group. This greater accuracy exists in all conditions except the eyes open condition and the prediction and assessments of the learning condition. In the learning condition the young adults are exceptionally stable and greatly underestimate their stability. Additionally after completing the testing they go on to underestimate their stability to an even greater extent becoming less accurate with their judgment. In the eyes closed condition the young show this tendency to underestimate performance again as although they begin with a very accurate prediction, after testing they decrease the assessment to an underestimation of stability. In the other conditions the young groups' predictions are very accurate and their judgments increase in accuracy after completing testing as shown through the improved accuracy of the assessments provided post testing.

Through looking at the actual postural stability during testing, the older adults' postural stability was particularly affected by the divided attention visuomotor task. In this condition they displayed very low stability, however due to the high levels of concentration demanded in this task, many of the older adult participants anecdotally reported that they did not attend to their postural stability, with their view being if they did not notice their stability they must have been very stable. This led to them giving even higher assessments of how stable they were. In the divided attention visuomotor tracking condition the overestimates given by the older adults were greatly higher than in any other condition and it is this condition which could potentially lead to an area of concern for real life scenarios. These findings do not necessarily fit with the findings of some previously published research in which older adults are shown to have significantly reduced confidence in relation to their postural stability; this is often reflected by a high level of fear of falling. This is especially so in those experiments which used the FES-I (Falls Efficacy Scale) to assess fear of falling. When using the FES-I participants are asked to reflect on their general feeling towards fear of falling during imagined daily activities, at a time when they were reflecting back on previous experience, and not at the time of testing. The overconfidence found in the current study's older adult sample is primarily due to the more direct testing set up. To clarify, the methods of testing mean that the older adults were asked to make judgments about their postural stability immediately before and immediately after undertaking a range of different tasks. In the divided attention task where they heavily overestimated their postural stability it was during a very demanding task in which the older adults were required to use sustained attention and were pressured both motorically and temporally in chasing and switching between fast moving targets. This meant the older adults were very involved in the task and were not necessarily paying attention to their postural stability. Therefore it was difficult for them to use extra cognitive resources in attending to their postural stability. Consequently, immediately after testing, participants reported honestly what they had felt during the testing in relation to their stability. In the case of the demanding divided attention task, they reported feeling very little concern as their attention was elsewhere. Therefore there was no fear towards this task as they were so involved in the task they did not consider their stability, and thus it led to extremely high overestimations. This scenario is more reflective of a real life situation as when one is fully immersed in carrying out a very demanding activity successfully you may not consider or reflect upon your postural stability. The results of this study are therefore of more use on a practical level rather than simply asking older adults to make a generalised judgment about their confidence in their stability. In terms of falls prevention those older adults at risk could be those who greatly overestimate their stability in conditions where a reduction in stability is actually occurring.

The findings from participants' perceived performance on the two interactive tasks (word recall and colour cues observed) provided a consistent pattern in the results. As predicted, the younger adults significantly outperformed the older adults both in number of words recalled and number of colour cues attended to during tracking. Yet consistently the younger adults underestimated and the older adults overestimated both their predictions and their assessments of performance.

6.4.2 Objectives and implications for next phase of research

Previous research has suggested that the ageing process can have a pronounced effect on the capacity to accurately assess one's own ability. In the case of postural stability this can lead to unfounded concern regarding falls or an overconfidence in ability. The findings from this study show that the effects of older adults' accuracy on assessing their ability can be context specific and dependent on testing condition. Older adults' inaccuracies in awareness of postural stability judgments were most apparent in the divided attention visuomotor task where stability was dramatically reduced. This task was designed to be complex and was demanding on both cognitive and motoric levels. In this task older adults estimated themselves to be much more stable than they actually were and they predicted that they would not experience very high postural instability in this task. However, as the results show, in this condition the older adults were most unstable yet their awareness of their stability did not reflect this finding.

These results highlight that older adults' judgments of postural stability are dramatically affected during a complex divided attention visuomotor task as they lead to reduced awareness of less stable posture, thus highlighting the need for increased awareness of these potentially high risk situations for falls. In terms of falls prevention it is of particular importance to potentially identify participants who greatly overestimate their stability and the conditions where this occurs; this could be an important aspect to target when attempting to prevent falls in older adults. Older adults need to be able to accurately assess their levels of risk so they do not undertake potentially unsafe activities in their daily lives, but equally importantly, so they do not restrict their activity levels unnecessarily. This study showed that under certain conditions older adults are able to make relatively accurate assessments of their ability. However, as shown by the results from the visuomotor task, once they are given a demanding task their assessments reduce in accuracy as their focus is no longer only on their postural stability. Previous research has shown that a certain level of cognitive processing is required for older adults to safely maintain their postural stability (Brauer, et al., 2001; L. A. Brown, et al., 1999; Huxhold, et al., 2006; Lajoie, et al., 1993; Teasdale, Bard, Larue, & Fleury, 1993); thus the mechanisms that increase an older adult's awareness of their postural stability could serve as a way to prevent falls in the future.

7 Discussion and recommendations resulting from work

7.1 Aims of the thesis and how these aims were achieved

This final chapter serves to summarise the key findings from experimental Chapters 2 to 6 and place them in the context of current published research in postural stability. The implications of these new findings and their original contributions to the field of falls prevention will be discussed. The limitations of the work and consequent methodological improvements will also be presented. This chapter will conclude with the future research consequences from these findings and practical recommendations leading from this work for improving falls prevention in an older adult population.

The main aim of this thesis was to investigate postural instability in persons over the age of 65 years with a wider view of improving risk assessment and fall prevention. As demonstrated in the introductory chapter (Chapter 1), recent studies in the field of falls prevention have investigated many different research strands, possibly due to the numerous factors which make the field of falls research extremely complex. These are multifaceted complications such as the current inaccuracy of reporting of fall frequency, the extremely varied and numerous medical and environmental reasons for falls and the complications in assessing fall risk in individuals. Due to these inherent difficulties in researching this area a range of research approaches were deemed necessary in this thesis to strive to reach a fuller understanding of the issue of falls in older adults. Using a diverse methodology the objectives of this thesis were to investigate several underexplored areas within older adult falls research.

Through reviewing the literature in Chapter 1, the key areas for further research were revealed. These were based upon high priority issues in falls prevention work which lacked research clarity and thus required additional, focussed investigation. This thesis therefore developed three main research aims based on the current literature; firstly to explore the scale of older adult falls in UK care homes, secondly to develop a flexible and user friendly system to accurately assess postural stability, and thirdly to evaluate under which dual tasking conditions older adults experience most instability and to assess their awareness of this instability.

To ensure these underexplored and complex issues were comprehensively investigated the following research methods were employed; epidemiological approaches (Chapter 2) to assess the scale of the problem of falls, pilot experimental work (from Chapter 3 onwards) to develop the postural stability assessment system, quantitative balance assessments during various testing conditions (Chapter 4-6) and qualitative methods (Chapter 5-6) to explore dual tasking's affect on stability and participants awareness of stability. These different methodological approaches enabled all of the main research aims to be further explored and comprehensively achieved within the work in this thesis.

7.2 Summary of key findings

7.2.1 Numbers of falls are significantly underreported in care homes

Chapter 2 of this thesis demonstrated the significant issue of falls in care homes and the serious injury consequences resulting from a considerable proportion of these total falls. The report analysis showed the probability that many falls are going unreported and are being wrongly categorized as other adverse events within the homes. An analysis within hospitals found that 60% of all adverse events were fall related (Healey, et al., 2006) which is roughly in line with the initial findings from the care home falls reports of 64%. However, after reviewing the other adverse events reported in the care homes it was found that a large proportion of these events (from those with sufficient information of the event details reported) were actually wrongly coded and should have been reported as falls, thus the total proportion of adverse events was around 71% falls. However, this was only based on the reports that had sufficient detail to draw conclusions so it cannot be taken as a final definitive figure. Despite the care homes being managed by the same group there were still significant differences found between the quality and detail of the reports being produced across the different care homes. A wide number of recommendations to improve the fall reporting system and to increase general safety within the care homes following the findings of this report have been passed on to the care home management team, such as the highest risk times and locations for falls. A large scale review of reporting of adverse events in care homes has never before been carried out in the UK, thus this work is highly novel and will be of interest to many within the health and safety research field.

7.2.2 Development of a user friendly system to assess postural stability

The development of the postural stability assessment system began in Chapter 3 where early exploratory work into the suitability of an Xsens sensor and a tablet laptop with kinematic software was first introduced. The aim of this system was to provide objective measures of motor skills and postural stability. Previous measures to assess balance have relied on tools such as the Berg Balance scale (Berg, Wood-Dauphinee, Williams, & Maki, 1991) which rely on the individual carrying out the assessment and thus are open to inter-rater variation. The balance assessments system in this thesis needed to be based on a quantitative measure of performance so there would be no susceptibility to variation or human error. Through the experimental chapters of this thesis improvements were made to the system to develop the initial set up of the Xsens sensor and the computer based kinematic software to the end stage where an automated testing system will run all of the pre set conditions including standard instructions for participants. The results from the balance board are then automatically fed directly into a data sheet via a blue tooth connection. Therefore the aims of developing a user friendly, quantitative assessment system were met and it is hoped this system can be developed further to use in falls prevention clinics to assess the improvements made in postural control by older adults. The review of the existing literature in Chapter 1 showed that targeted interventions could be very effective for falls prevention therefore this assessment system could be used to identify those persons most at risk to allow them to benefit from the available interventions or falls prevention advice, prior to a fall actually occurring.

7.2.3 Links exist between postural stability development and deterioration

A study was carried out with school aged children in Chapter 4 to explore the possible associations between postural control development in children and balance deterioration in older adults. This investigation was intuitively based as it appeared that both these age groups have been found to experience regular lapses in postural control, ultimately causing frequent falls. Consequently there may be common ground within these two groups at different ends of the life span where shared lessons in postural control could be learned. Obvious differences were found in postural stability between the age groups of children with the youngest children demonstrating a similar reliance on vision to maintain stability as was shown in older adult groups in Chapters 5 and 6. Therefore this work appears to show that the mechanisms that develop to assist balance as we mature are similar to the mechanisms that deteriorate as we age.

7.2.4 Older adults show impaired balance through increased sway across all testing conditions

Older adults display more postural sway than younger adults. This was found consistently in all of the thesis chapters with older adult participants in every testing condition (chapters 3, 5 and 6). These differences were especially pronounced whilst undertaking a concurrent visuomotor manual tracking task and whilst deprived of visual information (eyes closed condition). In these conditions the older adult groups experienced significantly impaired balance. These results also fit with the findings from the falls report analysis (chapter 2) where the highest risk situations for falls were when the older adults were deprived of visual information (frequent falls in the nighttime hours) or when dividing attention between the motor behavior of walking and navigating through the busy hallways (falls in the hallway led to highest proportion of serious injury falls). Each study within this thesis used a new sample of older adult participants and despite the vast disparity in ability that is known to exist in a group of similar aged older adults, the pattern of the findings for postural sway remained consistent throughout. This provides support for the theory that as older adults age their postural control system deteriorates resulting in increased levels of postural sway. This finding also adds to the validity of the postural stability assessment system in detecting these differences.

7.2.5 Older adults show significant detriments in postural stability when undertaking a concurrent task but task performance is variable

The effects of a concurrent task testing condition on postural stability and task performance were investigated in Chapters 3, 5 and 6. The results from these chapters were compared to the existing three models which aim to explain concurrent task effects on postural stability. Table 7.1 summarises how the findings from Chapters 3, 5 and 6 fit with the models’ predicted effects on task performance and postural stability.

Table 7.1. Summary of the key models concerning the effects of a concurrent task on postural stability related to the findings from the research chapters

Chapter results explained by model	**How the results from each chapter fit the model hypothesis**	**Actual effect on postural stability**	**Actual effect on concurrent task**
Chapter 3 results fit the Task prioritisation model	**Hypothesis**: Postural stability OR task performance will be negatively affected in the competition for attentional resources **Results:** Postural stability was found to decrease during completion of the concurrent task but performance on the task was not affected	The results show a negative effect on postural stability but no negative effect on task performance ↓ (posture first prioritisation strategy not supported)	—
Chapter 5 results fit the Cross domain competition model	**Hypothesis**: Postural stability and cognitive activity compete for attentional resources resulting in a negative effect on both **Results**: Both postural stability and task performance were negatively affected	The results show a negative effect on postural stability ↓	The results also show a negative effect on task performance ↓
Chapter 6 results fit the U-shaped nonlinear interaction model	**Hypothesis:** Postural stability can be reduced or improved depending on the task **Results:** Postural stability decreased under certain testing conditions (divided attention tracking) but improved in others (learning a word list)	The results show a positive or negative effect on postural stability depending on testing condition ↕	The results show no reported effect on task performance —

In Chapter 3 the older adults showed a significant detriment to their postural stability whilst undertaking the concurrent task. This is interesting as it was previously assumed that older adults would chose the posture first strategy for the sake of personal safety (Shumway-Cook, et al., 1997). Yet it appears they choose the accurate completion of a concurrent task and their postural stability suffered as the task became more challenging. These results supports the task prioritisation model (Lacour, et al., 2008). However, the results from Chapter 5 show that both postural sway and task performance were negatively affected from undertaking the concurrent task. As the same task was used in both Chapter 3 and Chapter 5 it is thought these differential effects were found simply due to the different postural sway assessment systems that were used. Significant developments occurred to the postural sway assessment system between Chapter 3 and Chapter 5, and it was found that the earlier system was not a true measure of postural sway but moreover was potentially an assessment of head movements. The findings from the different testing conditions used in Chapter 6 offers support for the U-shaped nonlinear interaction model. This model details the fact that postural stability may be reduced by a concurrent task, but it also may be improved, dependant on the cognitive demands of the task (Lacour, et al., 2008). In Chapter 6 a significant decrease in postural stability was found in the divided attention tracking task, however whilst undertaking the learning of a word list a significant improvement in postural stability was found from the baseline condition of eyes fixating on a stationary target, for both young and older adults. This was particularly interesting as the learning condition did not simply involve reading a word list but had a significant cognitive component as the words had to be committed to memory. Despite the pressure entailed in this condition from needing to recall the words in the learning task and the potential interference this may have caused with competition for cognitive resources, postural control was found to be extremely stable during this condition, thus showing support for the U-shaped nonlinear interaction model.

7.2.6 Older adults significantly overestimate their postural stability in certain situations

Chapter 6 investigated older adults' self-awareness of postural stability which is an important, yet relatively unexplored area in the field of falls prevention. Older adult confidence of ability is a complex area, especially in the specific domain of fear of falling.

An accurate assessment of personal falls risk is essential for reducing the probability of a fall but conversely, an accurate assessment is needed so as to not limit activities due to an unfounded fear of falling. In Chapter 6 a novel assessment scale was designed to measure how aware people are of their own stability. Older adults were able to make accurate judgments about their postural stability under certain testing conditions but they were found to make significant overestimates of their postural stability when undertaking a visuomotor dual task condition. In this testing condition postural stability was found to be significantly lower than in any other condition yet due to the significant task demands the older adults were unaware of these detriments and rated their stability as very good. This finding does not fit with previous work that has shown many older adults display greater concern towards falling. This may be because this work has gone further to specifically explore confidence in postural stability at the time of testing in relation to a specific and very demanding task. The specific task used in this study is cognitively, temporally and motorically demanding, requiring sustained divided attention throughout. Consequently the older adults were not able to focus on attending to their postural stability during testing. Immediately after testing they were asked to rate their confidence in their postural stability in relation to the specific task. As they had not been able to attend to their postural stability during testing due to the high demands of the task, they overwhelmingly rated their stability as very good. Additionally, this meant the results were not generalised to how they were feeling on an average day but were related specifically to the task at hand. This finding could reflect a possible real life application of a high risk of fall scenario when the person must undertake a task which is both cognitively and motorically demanding as well as being under significant time pressure. An example of this could be when someone is on the telephone, and they are being read out an important phone number very quickly; meanwhile they are in the process of looking for a pen and simultaneously trying to remember the phone number.

7.3 Limitations of the work

Despite achieving the overall research aims and furthering the existing knowledge in some key areas of older adult falls, due to the inherent complications that exist within the field of falls research, there are some limitations to be considered in the findings.

7.3.1 Accuracy of number of reported falls

Although conclusions were drawn regarding the inaccuracy of the falls reports, these inaccuracies meant an entirely accurate figure of number of falls per resident across the care homes was still difficult to calculate. Therefore the figures for falls frequency had to be based upon an average taken across all 40 care homes. This is because some homes were reporting over 50% of their residents falling per year whilst others were reporting less than 1%; this wide disparity is clearly indicative of the inaccuracies that exist within the reporting system.

7.3.2 Stability assessments based on static not dynamic balance

Many falls in older adults will occur whilst a person is walking; however all of the results from the postural stability assessments in this thesis are based upon the participants' standing postural stability, rather than their stability during walking. This factor limits the results to one specific area rather than allowing further study of the more complex process of walking and falls risk. However, the area of postural control in older adults is a vast research field thus it was necessary to focus on one specific niche and explore the area from there. Additionally, as other research studies have shown, standing postural sway can accurately reflect an overall balance deficit leading to potential falls risk, therefore it was deemed appropriate to keep the research focused on standing postural sway only.

7.3.3 Recruitment of older adult participants and the involvement of participants from care homes

Ideally, a wider range of older adults with a more diverse status in health and general functioning would have been recruited and tested, however one of the difficulties found in this research was trying to recruit more frail older adults from care homes. Firstly, even being allowed access to care homes was extremely problematic as most care home managers did not have the time to allow a researcher to enter their home to carry out research mainly due to health and safety concerns. Through persistent contact I was finally granted access by the care home management group used in Chapter 2 (fall reports), yet the residents of the care homes were not physically able to carry out the testing and stand unaided, thus preventing the involvement of a frailer participant group. After feeding back these findings to the care home management group it led on to my being granted full access to their incident reports which in itself resulted in some very interesting findings.

7.3.4 Generalisability of findings and external validity

One of the issues raised in this research is the difference that can exist within a similar aged group of older adults. A diverse range of ability can be found within a group of older adults therefore it can be difficult to generalise the findings from one population of older adults to another, as much depends on how ‘successfully’ they are ageing (Rowe & Kahn, 1997). The participants who took part in these studies were potentially more physically able than some other groups of older adults may have been as there was a baseline they had to achieve to even be able to stand unaided on the balance board. Thus the findings could reflect the results from a more physically able group than average. However even using more physically able participants, significant differences are still found between young and older adults.

In relation to external validity, the different testing conditions that were undertaken with the participants in the laboratory were designed to simulate real world situations that would place strain on the postural control system and serve to decrease stability. The KineLab testing system is beneficial as it enables real time assessment of participants under situations which can challenge postural control. These challenging situations, as originally suggested by the falls report data (chapter 2), are scenarios such as maintaining postural control whilst deprived of visual information and whilst undertaking divided attention tasks. The KineLab testing system offers many advantages in the assessment process in that exact quantitative measures of postural movements are accurately recorded and are time linked to the concurrent testing stimulus so the effects on postural stability can be compared. However, although the tasks attempt to recreate real world situations which are designed to challenge a person’s stability, in order to allow direct comparisons to be made between participants, the number of variables must be kept to a minimum, thus the tasks' simplicity is maintained. This could therefore also be a weakness of the system in that it is difficult to relate the motor tracking tasks and divided attention tracking tasks to real world situations. However, in theory the general principles behind the tasks are aimed to replicate the attention required to carry out a real world task. For example, there are many situations where one would need to stand while focusing attention on other tasks at hand, for example talking or texting on a phone whilst walking, or using motor skills whilst standing upright. A good example of this last challenging scenario is at the supermarket where persons must divide attention between looking down to read a shopping list, then looking up to search for items on the shelves and then looking down to cross the items off the list. There are of course however certain real world situations that can cause a significant compromise to stability which cannot be fully recreated in a testing condition. For example, a very high risk scenario for falls is in the bathroom environment as the combination of standing on a slippery, wet surface alongside closing of the eyes to avoid products or water from entering the eyes, as well as possibly overreaching for towels/products is significantly risky. However, due to the research that has been carried out, it may be that those types of situations can be identified through recognising the combination of high risk factors; therefore the actual scenario does not need to be reconstructed to assess risk.

7.4 Research implications, contributions and recommendations resulting from this work

It was found that achieving accurate figures to demonstrate the scale of older adult falls is problematic and may inherently suffer from issues of inaccurate reporting or problems in viewing falls as insignificant events, especially those with no injuries. This supported previous work which stated the complexity of the nature of recording numbers of falls (Robert G Cumming, et al., 1990; Cummings, et al., 1988; Means, et al., 1989). This meant determining an exact figure of how many falls occurred each month in a care home was problematic. For example when looking at the incident reports from the care homes, the actual number of reported falls was likely to have been far higher than the number reported due to the misclassification of falls as other adverse events, such as accidents or incidents. Also the number of reported falls resulting in serious injury requiring A & E was significantly higher after re-coding the described falls than was reported in the collated falls figures from the care homes.

Despite these reporting issues these findings still offer an excellent insight into the actual scale of falls in care homes in the UK and the serious consequences of these falls. Patterns in falls report data showed the highest risk times and locations for falls, especially those falls leading to the most serious injuries. The incident reports demonstrate the likelihood that in many of these homes a large proportion of falls go unreported. The findings show there are vast differences in standards of reporting across the homes and confirm the fact that the number of falls reported is not necessarily an appropriate measure to use to assess good standards of care. Homes with the highest numbers of falls may reflect excellent reporting practices rather than poor standards of care. Thus, the number of falls reported is not necessarily an appropriate measure on which to base an assessment of good or poor quality of care. Instead the management groups should be focussing on improving measures such as reducing injury from falls and reducing time resident was left on ground following a fall. Additionally care homes should record more thoroughly the extra input that was given to help a resident who has fallen multiple times to see which strategies work, as currently the management team are missing out on a significant opportunity for learning. Solely looking at the number of falls reported is not an accurate measure to assess the standards of care and to decide which homes should receive disciplinary measures. As has been demonstrated in reports of the existing literature in this area, falls in older adults are very common, and especially so in care home residents, therefore high numbers of reported falls in care homes are not a cause for alarm but instead show a level of transparency in reporting their falls so these events can be learned from and work can be done to prevent them in the future. Of course the high number of falls experienced by older adults in care homes needs reducing, but in not reporting these falls it only makes the situation worse.

The work carried out in this thesis has been disseminated to the care home management group to show the need to encourage reporting of falls by their staff. Through this work the management group have been shown that a home who reports a high volume of falls may simply be reflecting the reality of the number of falls which occur for older adults. More thorough reporting provides an excellent learning tool from which homes can adjust their shift patterns or increase bedroom checks at high risk times of day so older adults are not left on the floor for long periods following an incident. These research findings should lead to improvements in reporting practices and standards of care.

This review is novel in that it is the only current review of accident reports in UK care homes, thus it not only allows for an accurate estimate of the number of falls but also allows an analysis of reporting practices. In the analysis of the accident reports, every attempt was made to get the most accurate figure of the number of falls per month happening in care homes. Each accident report entry (over 7,000 individual reports) was checked against the event descriptions and ensured they were coded correctly for the type of event which had occurred. Through reviewing the raw data of the type of events it was found that a significant proportion of accident/incident events were actually falls, thus demonstrating many more falls were occurring than was previously thought.

The analysis of falls reports in Chapter 2 showed that falls most frequently occur in the bedroom in the hours of darkness, between midnight and 8am. To investigate further the factors that potentially make night time a high risk situation, the later experimental thesis chapters with older adults (Chapters 3, 5 and 6) went on to determine the effects of reduced lighting on postural control, through limiting visual information and looking at the effect on balance. Current research has suggested that older adults with deficits in their vestibular and somatosensory systems may rely on visual cues to maintain postural control to a far greater level than younger adults (Tinetti, et al., 1988), thus if they were to have this visual input reduced then it would lead to potential imbalance and increased likelihood of falling (Black, et al., 2005). An increased reliance upon vision was found throughout the experimental chapters, with older adults showing significantly greater postural sway than young adults when required to carry out testing with no visual information (Chapters 3, 5 and 6). This reliance on vision was also found amongst the young participants that were tested for the work looking into how balance development may link to balance deterioration (Chapter 4).

Children were used for this research as previous work has found some interesting parallels between the development of postural control in infants and children, and the deterioration that is experienced in older age. Fundamentally it is suggested that the developmental process of postural control can take many years to fully mature and in this time infant's move from using the more primitive reflex system involving visual cues, to late childhood when the higher nervous system somatosensory processes are developing and are given priority due to increased efficiency (Woollacott, et al., 1990). The findings in Chapter 4 showed that between age groups there were distinct levels of sway displayed representing increasing postural control. This demonstrates that with increasing age, postural sway reduces at a seemingly standard level as the postural control system develops in sophistication of functioning. In the same way these systems develop in children, they are believed to deteriorate in older adults. However unlike the rather predictable developmental trajectory observed in children roughly according to participant age (Woollacott, et al., 1990), the deterioration is much less defined in its potential onset and speed. Although one of the expected outcomes of ageing is a decline in function, there appears to be no defined age of typical onset. Some older adults may experience postural control and balance issues at an earlier stage of later life often due to accompanying co-morbidities, while others may not ever appear to exhibit any difficulties. This is due to the incredibly complex nature of ageing and can depend greatly on a multitude of individual factors. In older age there are a number of age typical conditions which directly affect balance and movement, for example Parkinson's Disease, stroke and arthritis, but there can also be a general deterioration in muscle strength and speed of muscular reactions, as well as a high level of muscle wasting. These changes in the musculoskeletal system cause a slowing down of responses and if an urgent corrector movement needs to be made rapidly to regain stability, it may not happen in time or there may not be the appropriate level of strength to make the corrective movement thus leading to an increased risk of falling. As well as changes to motor systems with age, there may also be changes in the availability of the sensory inputs that are used for postural control.

This thesis has considered ways to try and identify those older adults who may be at risk of falls. If an individual at risk of falling can be identified before they fall then it may extend their quality of life and years lived independently for an extensive period. This is of obvious benefit to the older adults themselves but also to society's benefit in reducing costs to the health service and social care. One way of identifying an individual at risk could be to use the findings in this thesis to look into the negative effects on postural stability from a visuomotor dual task (Chapters 5 and 6) but link this with awareness of postural stability (Chapter 6). The visuomotor dual task was found to significantly affect older adults' postural stability, causing dramatic increases in postural sway. If older adults who showed this strong susceptibility to dual tasking effects on postural sway could be identified and worked with to help them increase their awareness of this increased sway then it could potentially be a way to reduce falls through improving the recognition of the proprioceptive signals throughout the body.

7.5 Conclusions

Falls in older adults are a very serious and rapidly expanding problem for the health service in the UK and around the world. Due to their multifactorial causes they are highly complex to study and prevent but it would appear that early interventions and assessment of those at risk can help reduce frequency and thus alleviate the health service burden and increase quality of life for older adults. This thesis contributed to the area of falls research through several novel streams of research. Firstly the analysis on the reporting practices of UK care homes revealed the scale of number of falls per year in care homes. The development of a novel balance assessment system to ascertain quantitative measures of older adults' postural stability improves upon the previously used subjective measures of whether an individual is at risk of falling. The user friendly system that was developed throughout the thesis resulted in a fully integrated and highly portable postural assessment system linking a Wii balance board with a bluetooth communication to the KineLab software, on which the testing conditions were developed to automatically deliver complicated visuomotor stimuli. The work determining the circumstances under which older adults' postural control systems are most compromised and result in instability has added to previous existing research and has clarified exactly what effects are observed from placing older adults under these challenging circumstances. The experimental work has found both positive and negative postural sway effects from dual tasking in older adults, with further information being offered about the role of vision in maintaining postural control in older adults. The work into awareness of potential balance impairments is novel and has shown there is a tendency in older adults to overestimate their postural stability during a visuomotor dual task, as well as a general inclination to overestimate performance on other tasks unrelated to postural stability.

Through using different research methods including reviewing the existing literature, analysing a large data set of falls reports, and experimental work through several small pilot studies and larger scale research studies investigating balance development and deterioration, this thesis has explored and furthered the existing knowledge in the complex area of understanding postural instability in older adults. It is hoped the findings from this work can be further developed to enable significant improvements in fall assessment and prevention.

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Appendix A: The activity and medical history questionnaire used with older adult participants in the pilot testing (Chapter 3)

UNIVERSITY OF LEEDS

Participant ID ________________

Study title: Tracking performance **Ethics reference: 09329-07**

<u>Activity and Medical History Questionnaire</u>

As a participant in this study, you have the right to choose not to answer any of these questions or to stop at any point without needing to justify your decision.

1.) Could you tell me about your average level of activity per week
For example, any activities you do and how often you do them

2.) Medical history –

   a. Have you ever suffered a stroke?

   b. Have you been diagnosed with Parkinson's disease?

   c. Do you suffer from any lower limb problems?

   d. Do you suffer from any problems with your feet?

   e. Do you have arthritis?

   f. To your knowledge, do you have very high or very low blood pressure?

   g. Do you know of anything that may affect your balance?

   h. Do you know of anything that may affect your motor skills?

3.) Do you have a history of falls?

4.) Are you currently taking any medications?

Appendix B: The activity and medical history questionnaire used with older adult participants (Chapter 5)

Participant ID _______________

UNIVERSITY OF LEEDS

Study title: Balance and tracking performance **Ethics Reference: 11-0098**

<u>Activity and Medical History Questionnaire</u>

As a participant in this assessment, you have the right to choose not to answer any of the questions or the right to stop at any point without needing to justify your decision.

1.) Could you tell me about your average level of activity per week
For example, any activities you do and how often you do them

2.) Medical history –

   a. Have you ever suffered a stroke?

   b. Have you been diagnosed with Parkinson's disease?

   c. Do you suffer from any lower limb problems?

   d. Do you suffer from any problems with your feet?

   e. Do you have arthritis?

   f. To your knowledge, do you have very high or very low blood pressure?

   g. Do you know of anything that may affect your balance?

   h. Do you know of anything that may affect your motor skills?
   For example anything that may affect your movements to cause problems with things such as hand writing

Activity and Medical History Questionnaire continued

3.) Have you fallen within the last two years?
If yes, how many times? Were there any negative outcomes following the fall, ie. an injury?

4.) Are you currently taking any medications?

5.) Do you have a diagnosis of diabetes?

6.) Do you use a walking aid/have you been advised to use a walking aid?
eg. a walking stick or a frame

7.) Do you have problems with you hearing or trouble with your ears?

8.) Are you able to stand easily from a chair? With assistance or without assistance?

9.) Have you recently fractured or broken any bones? (within the last 5 years?)

10.) Are you currently a smoker or have you ever smoked (for a significant period, every day) in the past?

11.) Have you lost a significant amount of weight within the last 5 years? Do you find your clothes do not fit as well as they used to?

12.) Have you been prescribed any nutritional supplements from your GP?

13.) Do you need to wear glasses? If so are they bifocals/varifocals?

14.) Have you had any problems with your eyesight or issues with your vision in general?

Appendix C: The Likert type scale used to assess perceived postural stability with older adults (Chapter 6)

Postural Stability Assessment Scale

0 20 40 60 80 100

0	*20*	*40*	*60*	*80*	*100*
Very unstable	***Unstable***	***Fairly stable***	***Stable***	***Good stability***	***Very good stability***
I feel very unstable or I think I might fall. I can feel myself moving a great deal whilst standing	I feel like I am swaying a little. I would be more comfortable if I had something to hold onto to steady myself	I feel I am swaying slightly but I do not feel I need to hold onto anything to steady myself	I only notice myself sway a very small amount. I do not believe this amount would be observable to others	I feel steady and completely confident whilst standing. I can detect only tiny movements in my standing posture	I feel no sway at all. I am not making any movements in my standing posture