Eye and Body Movement Strategies during Turning Tasks in Older Adults at Risk of Falls

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> "Well - The good Lord, is such a good Lord
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Confidential Material

All confidential material generated during this project, including written consent forms, photographs and raw data stored on portable hard drive will be stored in a locked filing cabinet in the AUT University Health and Environmental Sciences Office for a period of six years, after which time it will be destroyed.

Attestation of Authorship

I hereby declare that this submission is my own work and that, to the best of my knowledge and belief, it contains no material previously published or written by another person (except where explicitly defined in the acknowledgements), nor material which to a substantial extent has been submitted for the award of any other degree or diploma or a university or other institution of higher learning.

Candidate: Date:

Abstract

Objective:

The aim of this study was to investigate eye and whole body movement strategies during a step turning task in older adults at risk of falls compared to healthy older adults. Specifically, this experiment investigates the sequence and latency of eye, head, trunk and foot movements; centre of pressure and anticipatory muscle activity while preparing for and initiating a turn from a static starting position. It is hoped that increasing the understanding of these complex movements will help with the development of rehabilitation strategies aimed at preventing falls during turning movements.

Study Design:

Laboratory based, experimental, repeated measures design.

Participants:

Twenty two participants volunteered for the study. Participants were allocated to either a healthy older adult (HOA) group (mean age 74 ± 7.6 years) or falls risk older adult (FROA) group (mean age 76 ± 7.8 years) based on a cut-off score of two on the Falls Risk Assessment Tool (FRAT).

Main Measures:

Three-dimensional motion analysis of head, trunk, pelvis and foot movement was used to determine onset and latency of body segmental movement. Onset of eye movement was determined by the use of electrooculography (EOG), while a force plate measured the onset of centre of pressure (COP). Muscle activity was determined using electromyography (EMG). Stepping strategies (ipsilateral or contralateral) were determined visually by reviewing data off-line.

Results:

An ipsilateral strategy was the most frequently used strategy when turning in both directions. Both older adult groups demonstrated an increased use of the contralateral strategy when turning to the right compared to the turning to the left ($t(438) = -2.32$, $p < .05$). FROAs were more likely to adopt the contralateral strategy ($t(438) = -3.58$, $p < .05$).

While there was no difference in the order of onset of movement when turning right (COP, eye, head, trunk, pelvis and foot), there were differences in order of onset when turning to left. FROAs demonstrated a significant increase in onset latency when compared to HOAs when turning to the left, though no differences were found when turning to the right. Compared to gait initiation studies, stereotypical anticipatory muscle activity was infrequently observed (<50% of trials).

Conclusions:

Older adults at risk of falls were about three times as likely to use a contralateral strategy compared to healthy older adults. While this may suggest more flexibility in the turning programme, it may also contribute to an increase in falls risk. Findings from the current study suggest that older adults may move more en-bloc compared to previous studies of young adults. Falls risk in older adults may contribute to differences in the onset order and latency of segmental movement, and may have some relationship to the direction of turn and preference of turning strategy. While tibialis anterior and gastrocnemius have been observed to activate consistently in the anticipatory period of gait initiation studies, a clear pattern of activity could not be established during step turning.

Abbreviations

APA- Anticipatory Postural Adjustment

BOS- Base of Support

CNS- Central Nervous System

COG- Centre of Gravity

COM- Centre of Mass

COP- Centre of Pressure

EMG- Electromyography

EOG- Electrooculography

FP- Force Plate

FROA- Falls Risk Older Adult

GRF- Ground Reaction Force

HA- Healthy Adult

HOA- Healthy Older Adult

HYA- Healthy Young Adult

LED- Light Emitting Diode

MA- Motion Analysis

ms- millisecond

PS- Pressure Sensor

1. INTRODUCTION

The ability to step and turn is essential for functional mobility and is a common occurrence in everyday life (Berg, Wood-Dauphinee, Williams, & Maki, 1992; Glaister, Bernatz, Klute, & Orendurff, 2007; A. E. Patla, Adkin, & Ballard, 1999). The risk of falling is greater when turning compared to straight line walking, especially in the older adult population (Chapman & Hollands, 2007; Cumming & Klineberg, 1994; Dite & Temple, 2002a). Currently, however, the majority of studies investigating visually guided mobility are of a young adult population while straight-line walking. It is suggested that the performance and control of turning tasks in older adults and those considered at risk of falls requires further investigation.

Visually guided turning involves transferring gaze to a target (Barnes, 1979; Freedman & Sparks, 2000; Land, 2004) which is coordinated with head reorientation and followed by whole body movements. In response to a peripheral stimulus, small shifts in eye position can be made towards the target with eye saccades alone. Larger shifts are made with both the eyes and the head, while very large shifts involve whole body movements inducing stepping and turning movements (Land, 2004). It is suggested that whole body reorientation is controlled in a top-down temporal order of segments: head rotation, trunk rotation, and foot movement (Grasso, Pre'vost, Ivanenko, & Berthoz, 1998; A. E. Patla, et al., 1999). It is known that eye movement precede head and foot movement in healthy younger adults during a step turning task, however it is uncertain whether the relative timing of eye, head, trunk and foot movements change with the addition of risk of falls and with increasing age. Turning requires the central nervous system (CNS) to coordinate eye and whole body reorientation in an anticipatory manner in order to attain a stable reference frame (Barnes, 1979; Freedman & Sparks, 2000; A. E. Patla, et al., 1999). However, little is published on the kinematics of gaze shifts that require movements of the whole body (Hollands, Ziavra, & Bronstein, 2004), or whether anticipatory postural adjustments (APAs) change with ageing, and whether the relationship among all these factors change with falls risk.

Anticipatory postural adjustments (APAs) involve changes in the activity of postural muscles and associated shifts in the centre of pressure (COP) prior to the initiation of dynamic task performance (Bouisset & Zattara, 1987b; Le Pellec & Maton, 1999). It is well established that APAs occur prior to tasks such as lifting the arms in a forwards direction (Belen'kii, Gurfinkel, & Pal'tsev, 1967; Bleuse, et al., 2006; Fujiwara, Kunita, Maeda, & Tomita, 2007; Fujiwara, Toyama, & Kunita, 2003; Maeda & Fujiwara, 2007; Woollacott & Manchester, 1993), there is less known about the behaviour of APA's during visually guided step turns. Much of the research investigating APAs uses measures of COP recorded from force platforms (Bent, Potvin, Brooke, & McIlroy, 2001; Fujiwara, et al., 2003; Hollands, et al., 2004; McIlroy, Bent, Potvin, Brooke, & Maki, 1999; Xu, Carlton, & Rosengren, 2004). Whilst this gives information about the timing of the onset of an APA it does not clarify which muscles are involved in APAs and the relative timings of these muscles.

1.1 Aim

This project aims to investigate whole body movements of healthy and falls risk older adults during a visually guided step turning task. This includes analysis of the onset of eye and body segmental movements as well as muscle activation strategies using kinematic, kinetic and electromyographic data collection. Findings will help determine whether there are differences that could explain functional performance of the two groups and may be incorporated into intervention strategies that can be further tested in a clinical trial of balance rehabilitation and falls prevention interventions.

1.2 Hypotheses

This project aims to examine the timing of saccadic eye and whole body movement in conjunction with the onset timing of muscle activation of healthy and falls risk older adults during a step turning task. This will help determine if there is a consistent relationship between whole body movement and anticipatory postural activity in this population. Given the evidence of age-related delay in the early “automatic” postural responses and age-related slowing of reaction times (McIlroy & Maki, 1996), it is reasonable to hypothesise that there will be further delays in the initiation of step turns in a falls risk older adult population.

The specific hypotheses are that during a step turning task:

1. There will be differences in the turning strategies when comparing healthy and falls risk older adults
2. There will be no difference in the performance of a step turn between healthy and falls risk older adult participants as measured by the order of movement onset of centre of pressure, eye, head, trunk, pelvis and foot onset.
3. There will be differences in the latency of movement onset of centre of pressure, eye, head, trunk, pelvis and foot movements between healthy and falls risk older adult participants.
4. There will be a consistent pattern of anticipatory postural muscle activity when comparing healthy and falls risk older adult participants.

1.3 Delimitations

The following delimitations apply to the study.

1. Only older adults who were aged between 65 and 85 who lived in their own home or a retirement village; could stand and step around without a walking aid; and did not have severe visual loss, neurological or physical conditions participated in this study.
2. This was a laboratory based study, with instrumental movement constraints. The reflective markers, EMG leads and waist belt and EOG leads may all have affected freedom of participant's movement.
3. The data collection was limited to surface electromyography (EMG), electrooculography (EOG), motion analysis and force plate data.
4. Reflective markers placed on bony landmarks are vulnerable to movement during activity as the skin and adipose tissue moves independently to bone. This can impede the accuracy of the kinematic data.
5. Surface electromyography data was limited to muscles of the lower limb based on an initial selection of two muscles, chosen from a literature review of studies on gait initiation and forward stepping.
6. Force plate data was limited to centre of pressure based on a literature review of studies on gait initiation and forward stepping.
7. The task under investigation was a step- turning task performed at a fast pace in response to a visual cue positioned 60 degrees to the right or left of the starting position.

1.4 Operational Definitions

Anticipatory period: period of time between the onset of the visual cue and the onset of COP movement in either the F_x (anteroposterior) or F_y (mediolateral) direction.

Anticipatory postural muscle activity: muscle activity which occurred between the time of the "Go" signal (time 0 sec) and the onset of COP movement.

Contralateral foot: the outside foot to the direction of the turn. For example, during step turns to the left, the contralateral foot is the right foot; during step turns to the right, the contralateral foot is the left foot.

Contralateral strategy: when movement of the contralateral foot precedes the onset movement of the ipsilateral foot during step turns.

Gait initiation: refers to tasks whereby participants are instructed to take an allocated number of steps or short distance from a quiet standing position. The period analysed is the duration from the quiet standing position until the beginning of heel off or toe off of the ipsilateral foot.

Ipsilateral foot: the inside foot to the direction of the turn. For example, during step turns to the left, the ipsilateral foot is the left foot; during step turns to the right, the ipsilateral foot is the right foot.

Ipsilateral strategy: when movement of the ipsilateral foot precedes the onset movement of the contralateral foot during step turns.

Onset of segmental movement: start of movement of the calculated segmental COM at the head, trunk, pelvis, left and right foot around the z axis. Onset of COP movement is calculated around the x, y and z axis.

Step turn: a turn in which the participant steps and turns in response to a visual cue from a position of quiet stance to realign the entire body to a pre-determined target.

Steering: turning to change the direction of walking without interruption to the ongoing locomotion.

2. REVIEW OF THE LITERATURE

2.1 Introduction

This chapter is divided into eight main sections and begins with a description of the search strategies used to identify the literature in this review. A discussion of key themes that are central to this experiment follows. These include: anticipatory postural adjustments in gait initiation and turning; role of eye saccades during step turn; the influence of ageing on visually guided movement; and laboratory measurements. The chapter concludes with a general summary.

2.2 Literature Review Search Process

A systematic search of the literature was undertaken between March and July 2008 to identify articles investigating early muscle activity during turning and stepping tasks. This was repeated in October 2009 to retrieve recent literature. Databases searched included: CINAHL (via EBSCOHost), MEDLINE (via EBSCOHost), SPORTDiscus (via EBSCOHost), and AMED (via OVID). Articles with citations of key articles and authors were also sourced using SCOPUS. A hand search through references of selected studies was then undertaken to identify any studies that had been overlooked.

Eligible studies published from 1967 through to the present day were included if they evaluated any kinetic, kinematic, electromyographic and/ or electrooculographic measurement; in studies of gait initiation, steering or step turning; in the healthy young or older adults, as well as falls risk older adult populations. Anticipatory postural adjustments were first referred to in the pioneering work of Belen'kii et al. (1967) who investigated electromyographic changes during arm movement (Woollacott & Manchester, 1993). The cut-off date of 1967 was based on this study.

Those that investigated pathological conditions, or included compensatory strategies after external perturbation (16) or obstacle avoidance (18) were excluded. Figure 2.1 provides a flow chart of the current search strategy. The body of the literature review draws on information from the 52 studies that refer to step turning, gait initiation and steering investigations.

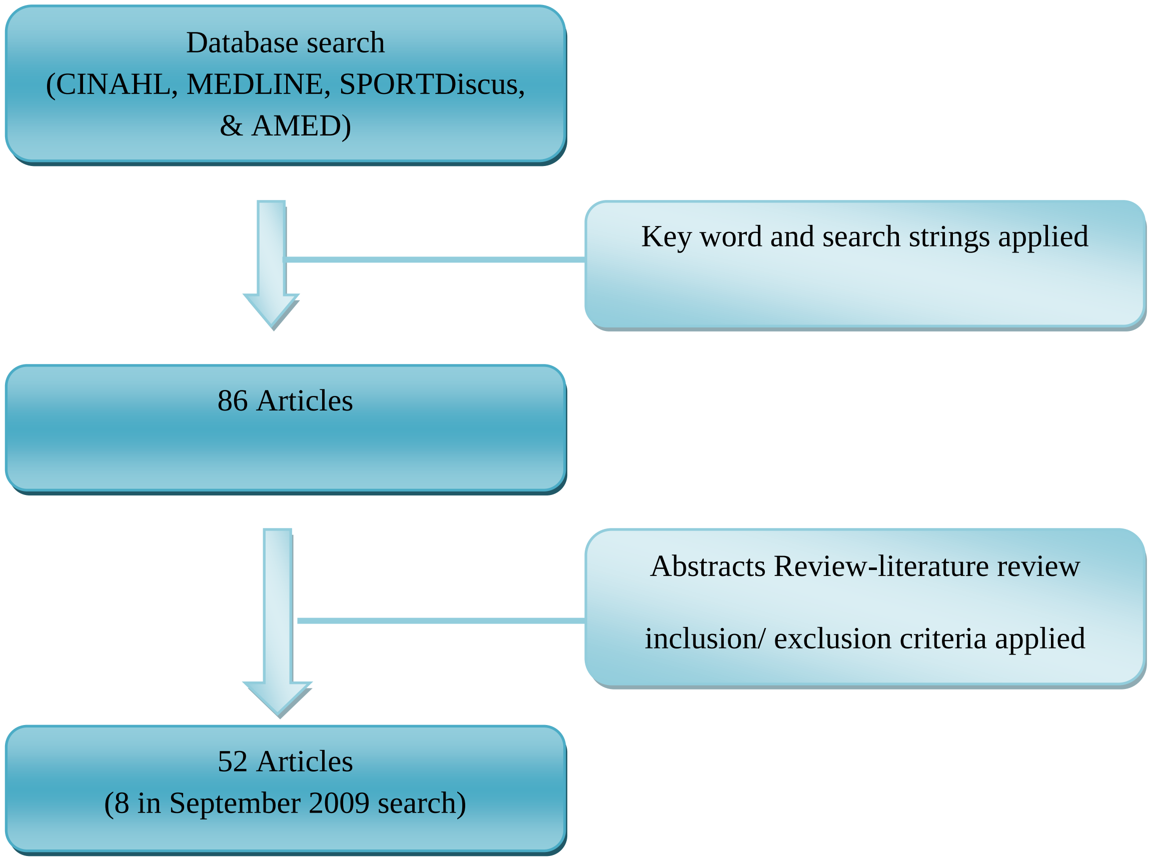

Figure 2.1. **Flow chart of search strategy process**

2.3 Anticipatory Postural Adjustments in Gait Initiation and Turning

Gait initiation may be considered a similar task to step turning as there is a stepping movement with one foot from a stationary position. It was therefore considered appropriate to review findings from studies that have examined anticipatory postural adjustments during gait initiation, prior to reviewing the limited work that refers to step turning.

2.3.1 Motor Programme

Gait initiation and turning are both complex multi-dimensional movements that are coordinated by the central nervous system (CNS) through a series of anticipatory and focal movements. While the theory of motor programmes remains contentious (Morris, Summers, Matyas, Iansek, & Gordon, 1994; Summers & Anson, 2009), the single-process control scheme is referred to in investigations of gait initiation and steering (Bouisset & Zattara, 1981; Cinelli, Patla, & Stuart, 2007; Haridas, Gordon, & Misiaszek, 2005; Henriksson & Hirschfeld, 2005; MacKinnon, et al., 2007; Massion, 1992; Massion, Alexandrov, & Frolov, 2004). This scheme suggests that one central controller initiates both the focal movement as well as the anticipatory postural adjustments (APAs) (Latash, 2008; Maki & McIlroy, 1999; Massion, 1992) (See Figure 2.2).

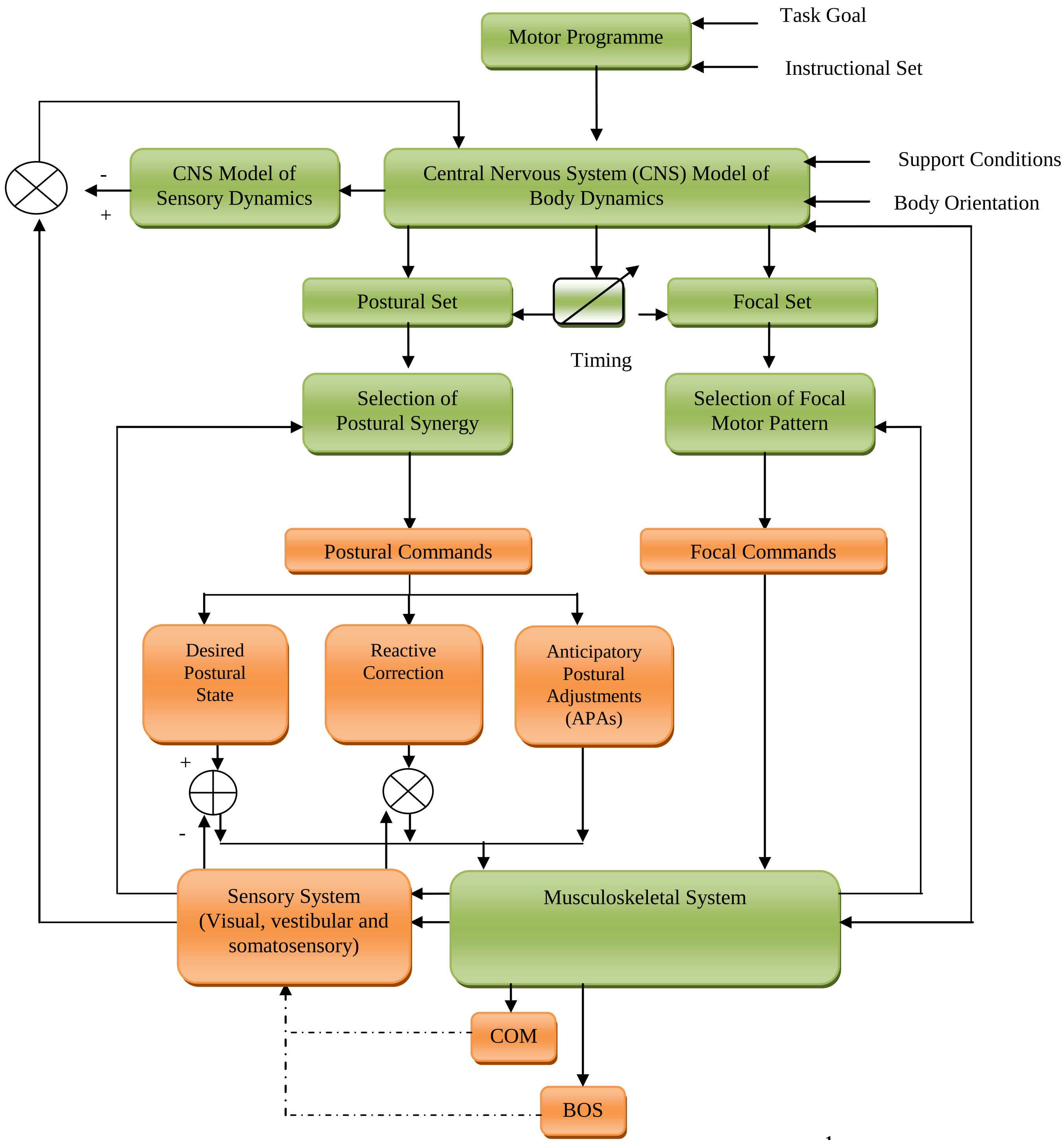

Figure 2.2. **Conceptual Model of the Single-process Control Scheme** [1]

Note: COM- Centre of Mass; BOS- Base of Support

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[1] Adapted From Frank & Earl (1990),Latash (2008), Maki & McIlroy (1999) and Massion (1992)

2.3.2 Conceptual Model of the Single-process Control Scheme

As figure 2.2 indicates, for a given motor task, a motor programme is activated depending on the goal of the task and/or the instructional set provided. This is compared to an internal model of body dynamics which has been developed through repeated movement experiences, thereby simplifying postural control by drawing upon a common set of synergies to maintain upright stance (Frank & Earl, 1990). Subsequently, the CNS initiates a postural motor programme while simultaneously activating a focal motor programme. The postural commands aim to regulate the centre of mass (COM) with respect to the base of support (BOS), and are divided into (1) anticipatory postural adjustments (2) reactive corrections, and; (3) the desired postural state (Maki & McIlroy, 1999). This division is based on both the pathway and timing of the activation from the controller (CNS). Although the programmes may be initiated simultaneously, the resultant anticipatory postural adjustments (APAs) are produced prior to that of the focal movement.

2.3.2.1 Focal/ Voluntary Movement

Two biomechanical requirements are required in order to initiate a step: (1) the generation of momentum; and (2) the maintenance of balance (Polcyn, Lipsitz, Kerrigan, & Collins, 1998). During gait initiation, momentum is generated by a shift of the centre of pressure (COP) backward and toward the stepping leg, prior to any movement of the body's centre of mass (COM) (Figure 2.3) (Y Breniere, Do, & Bouisset, 1987; Brunt, et al., 1991; Crenna & Frigo, 1991). This is assumed to be associated with a push downward with the foot that is about to step. The posterolateral shift of the COP increases the horizontal ground reaction force (GRF) that shifts the COM toward the stance limb, thereby generating momentum in those directions which enables unloading of the swing foot (Mickelborough, Van Der

Linden, Tallis, & Ennos, 2004; Polcyn, et al., 1998). This indicates that the initial momentum necessary for taking a step is achieved by shifting the COP rather than movement of the COM towards the stance leg (Bent, et al., 2001; McIlroy & Maki, 1999).

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***Figure 2.3*. Foot Centre of Pressure trajectory during gait initiation.**

Note: Adapted from Polcyn et al. (1998) page 1583. In this figure the initial trajectory of the COP backwards and towards the swinging foot is shown.

2.3.2.2 Anticipatory Postural Adjustments

Anticipatory postural adjustments (APAs) are thought to prevent or minimise postural disturbances associated with focal movement performance (Bouisset & Zattara, 1987b; Crenna & Frigo, 1991; Latash, 2008; Massion, 1992; Shumway-Cook & Woollacott, 2007). Pre-programmed muscle activity produces movement in the anticipatory period and is associated with the onset of COP changes (those above a threshold that would distinguish it from simple postural sway activity), simultaneously allowing for the appropriate focal muscle contraction for gait initiation (Crenna & Frigo, 1991). Whether similar anticipatory postural adjustments occur during step-turning has not been reported to date. Gait initiation and steering studies have referred to APAs as the electromyographic (EMG) events (Assaiante, Woollacott, & Amblard, 2000; Y. Breniere, Do, & Sanchez, 1981; Brunt, et al., 1991; Brunt, Liu, Trimble, Bauer, & Short, 1999; Brunt, Santos, Kim, Light, & Levy, 2005; Elble, Moody, Leffler, & Sinha, 1994; Fiolkowski, Brunt, Bishop, & Woo, 2002; Hase & Stein, 1999; Polcyn, et al., 1998); or the shift in the body's centre of pressure (COP) as a consequences of these muscle events (Crenna & Frigo, 1991; Fukushima, Asaka, & Fukushima, 2008; Latash, 2008). Investigation of muscle activity in gait initiation tasks has been limited to investigations of muscles acting in the sagittal plane (Crenna & Frigo, 1991; Fiolkowski, et al., 2002; Polcyn, et al., 1998), namely soleus/ gastrocnemius and tibialis anterior. It has been suggested that older adults may have difficulties in performing daily activities due to an inability to integrate APAs into on-going voluntary movements (Shumway-Cook & Woollacott, 2007).

2.3.5 Turning

Turning is a common occurrence in normal daily life with 8% to 50% of everyday activities involving turns (Glaister, et al., 2007). However, research is limited regarding normal turning biomechanics and behaviour (Dite & Temple, 2002b; Meinhart-Shibata, Kramer, Aston-Miller, & Persad, 2005). Turning strategies have been studied within a variety of contexts: navigating corners, changing walking direction, walking in a curved trajectory, avoiding obstacles, and turning on the spot (Anastasopoulos, Ziavra, Hollands, & Bronstein, 2009; Grasso, Glasauer, Takei, & Berthoz, 1996; Grasso, Ivanenko, McIntyre, Viaud-Delmon, & Berthoz, 2000; Grasso, et al., 1998; Hollands, Patla, & Vickers, 2002; Hollands, Sorensen, & Patla, 2001; Hollands, et al., 2004; Meinhart-Shibata, et al., 2005;

A. E. Patla, et al., 1999; Sklavos, Anastasopoulos, Ziavra, Hollands, & Bronstein, 2008; Solomon, Kumar, Jenkins, & Jewell, 2006; Vallis & McFadyen, 2003). Turning has been referred to as either ‘online steering’ whereby participants re-orientate to a new target while walking, without interruption (Berard, Fung, McFadyen, & Lamontagne, 2008; J. R. Fuller, Adkin, & Vallis, 2007; Hase & Stein, 1999; Hollands, et al., 2002; Hollands, et al., 2001; Paquette, Fuller, Adkin, & Vallis, 2008; A. E. Patla, et al., 1999; Reed- Jones, Hollands, Reed-Jones, & Vallis, 2009; Reed-Jones, Reed-Jones, Vallis, & Hollands, 2009; Vallis, Patla, & Adkin, 2001; Xu, et al., 2004); or as ‘on-the spot’ whereby re-orientation to the new target is made from a quiet standing position. This latter type of turn can be achieved by either a ‘pivot turn’- namely pivoting on unilateral or bilateral feet; or by a ‘step turn’ whereby both feet are lifted off the ground to re-orientate to the new direction (Hase & Stein, 1999). The step turn is preferential in terms of increased safety in that it provided a more stable base of support when changing direction, and may prove to be important in the older adult (Hase & Stein, 1999; A. E. Patla, et al., 1999; Taylor, Dabnichki, & Strike, 2005).

2.3.6 Identification of Turn Onset and APA- Online Steering compared to Step Turning

Although kinematic, kinetic and electromyographic measures have been included in online steering studies, none have included all three forms of analysis to enable a detailed biomechanical description of the step turn movement. As the turn occurs within a walking task during online steering, it is difficult to determine the onset of the turn, and therefore identify the anticipatory muscle activity and postural adjustments. On the other hand, identification of the onset of the turn is less complex during step turning (Stack, Jupp, &

Ashburn, 2004), thereby possibly aiding recognition of anticipatory muscle activity. Investigating the presence and consistency of anticipatory muscle activity during the step-turn may provide insights into the early balance responses and central organisation of movement that could ultimately be incorporated into rehabilitation programmes.

2.4 Role of Eye Saccades during Step Turn and Visually Guided Movement

Orientating the visual system to where you are going or to a target of interest is an important and necessary component of turning during daily activities (Cinelli, et al., 2007; Grasso, et al., 1996). Visually guided movements bring images of interest onto specialised regions of the retina by changing the direction of the line of sight (gaze). This can be achieved by rotating the eyes, head and trunk either in isolation or in combination (Land, 2004; A. E. Patla, et al., 1999). The human eye is capable of horizontal eye-in-orbit movements (saccades) as large as ±55 degrees in order to bring the image of a target to fall onto the fovea of the retina (Cinelli, et al., 2007; Freedman & Sparks, 2000; Guitton & Volle, 1987). However, eye-in-orbit movements are usually observed when less than 15 degrees of horizontal movement is required, after which involvement of the head (head-in-space movement) is dependent on the extent of reorientation (Anastasopoulos, et al., 2009; Hollands & Marple-Horvat, 2001). For example, during head-free gaze shifts larger than 45 degrees there is an initial eye-in-orbit movement, followed by a period whereby the head moves simultaneously with the eyes. In other words, the eyes remain relatively immobile in the orbit for this short period (Guitton & Volle, 1987; Solomon, et al., 2006). Once the saccade has brought to the target into view, gaze is then stabilised (despite continued head rotation) by the vestibular–ocular reflex (VOR) which compensates by counter rotation of the eyes at nearly the same velocity of the continued head movement so that eye position in space remains relatively constant (Latash, 2008; Laurutis & Robinson, 1986; Solomon, et al., 2006).

Saccades are not only dependent on the extent of movement required, but are also dependent on the starting position and the task required. Saccadic latencies (500ms) during standing step-turn trials (Anastasopoulos, et al., 2009; Hollands, et al., 2004) are larger than those reported for seated trials (150ms) (Dickov & Morrison, 2006; J. H. Fuller, 1996). This suggests that co-ordinated eye and body movements are initiated only after the appropriate APAs have taken place (Anastasopoulos, et al., 2009; Aruin & Latash, 1995). The influence of the visual system on the motor output of other body segments during turns requires further investigation, especially in the older adult population and those that are at risk of falls. During online steering, Hollands et al. (2002) identified a coordinated relationship between the eyes and the head whereby saccadic eye movements were followed by rotation of the head prior to turning to change direction. This was investigated further by Hollands, Ziavra and Bronstein (2004) during step-turning. In this study, the temporal order of onset among multiple body segments (including the eyes, head, trunk and feet), were examined during a step-turning task at a self-selected pace. Five healthy young adults turned 10 times towards randomly activated light emitting diodes (LEDs) positioned at 45, 90 and 135 degrees to the left and right of the starting position. A consistent temporal order of movement was found, whereby the eyes moved first (470ms), followed in order by the head (597ms), trunk (710ms) and then the stepping foot (1300ms). Correlation analyses of timing of movement onset between each body segment revealed significant correlations between the eyes and the head (r^2= 0.74), eyes and the trunk (r^2=0.59) and the eyes and the feet

(r^2=0.41). Consistent results are reported by Anastasopoulos, Ziavra, Hollands & Bronstein (2009) who used a similar set-up and population (healthy young adults) to that of Hollands et al. (2004), with an onset of eye movement first (500ms), followed by head (600ms), trunk (700ms) and foot (1100s).

2.5 The Influence of Ageing on Visually Guided Movement

Knowledge about the influences of ageing during visually guided movements is limited. This is somewhat surprising, in that falling while turning is 7.9 times more likely to result in hip fracture than falling while walking a straight (Cumming & Klineberg, 1994). With about 30% of community-dwelling adults over 65 years of age falling each year, understanding more about the control of eye, head and body segmental motion during turning may help to develop rehabilitation programmes that improve control of step turning and reduce turning related falls (Dargent-Molina, et al., 1996; Hayes, et al., 1996; Rubenstein & Josephson, 2002).

Functional deficits in daily activities have been reported as a result of ageing especially when required to move quickly during voluntary reaction time tasks (Horak, 2006). This may result in the degradation of physiological systems involved in postural stability (Lord, Clark, & Webster, 1991b; Paulus, Straube, & Brandt, 1984; Woollacott, Shumway-Cook, & Nashner, 1986). With ageing, there is a reduction of neurotransmitter production, cortical neurons and α-motoneurons which results in muscle fibre denervation and fewer, large and slower motor units (Latash, 2008; Lord, Clark, & Webster, 1991a; Lord & Fitzpatrick, 2001; Lord, Ward, Williams, & Anstey, 1994; Prince, Corriveau, Herbert, & Winter, 1997). This results in a 1- 1.5% reduction of muscle strength between the ages of 50 and 70 years of age, and 3% a year after the age of 70 (Spirduso, Francis, & MacRae, 2005). Also, the number of Type II muscle fibres declines more than Type I, which may lead to a slowing of quick voluntary responses. Although there are strong associations between reduced muscle strength and functional disability (Buchner & De Lateur, 1991) as well as strength and balance confidence, Binda, Culham & Brouwer (2003) found that strength, on its own, was not a significant factor when comparing healthy older adults and those who identified with a fear of falling. This suggests that fear of falling may be mulifactorial.

Joint stiffness increases in the older population. Crossbridges between adjacent tropocollegen molecules increase, thereby increasing the stiffness of the joints (Prince, et al., 1997). Joint stiffness may be observed as a more rigid movement, or requiring decoupling of adjacent joints in order to move effectively in complex movements. Along with ‘stiffness’ at the joints, older adults have greater co-activation of agonist and antagonist muscles (Woollacott, et al., 1986) which may contribute to both rigidity in movement as well as an increased risk of falls.

Older adults demonstrate an increase in reaction time during gait initiation and turning tasks (Brunt, et al., 2005; A. E. Patla, et al., 1993; Tucker, Kavanagh, Barrett, & Morrison, 2008). While comparing healthy and falls risk older adults, Brunt et al. (2005) found that falls risk older adults initiated swing toe-off later when asked to initiate gait from quiet standing (healthy older adults- 1297ms; falls risk older adults- 1459ms). This is supported by Lord and Fitzpatrick (2001) during a reaction stepping task (healthy older adults- 1322±331ms; falls risk older adults- 1168±203ms).

In the process of ageing, the quality of sensory information decreased making postural control increasingly difficult (Maki, 1997; Winter, Patla, Frank, & Walt, 1990; Woollacott & Tang, 1997). This is partially compensated for by a wider base of support (Bleuse, et al., 2006), an increased dependence on visual information (Chapman & Hollands, 2006b; Chapman & Hollands, 2007; Lord, et al., 1991a; Lord & Dayhew, 2001; Lord, et al., 1994) and a longer time to centrally process the information and produce a motor output (Chapman & Hollands, 2006a; Cinelli, Patla, & Stuart, 2008; Tang & Woollacott, 1998). Cinelli, Patla and Stuart (2007, 2008) compared healthy and falls risk older adults who were asked to reorientate eyes, head and trunk while standing and walking on a treadmill to 19 light-emitting diodes (LEDs) that were arranged from 0 to 90 degrees. While no whole body reorientation was required in this task, there was a larger delay between the onset of eye movements and body segment rotations in the older adults than in the young adults (HY 300ms; HOA 1000ms), indicating the older adults required more time in the anticipatory period to plan these movements.

2.5.1 Order of Onset of Movement and Ageing

The current body of evidence that describes onset of movement during a step turn is restricted to the healthy young population with no published literature investigating older adults, or those that are considered at risk of falls. When required to reorientate their whole body to LEDs placed horizontally at 45 degrees intervals, the temporal sequence of movements of young adults was reported as first eye (470ms), followed by head (600ms), trunk (710ms) and finally foot (1300ms) rotation (Hollands, et al., 2004). Consistent results are reported by Anastasopoulos, Ziavra, Hollands & Bronstein (2009) who used a similar set-up to that of Hollands et al. (2004), with an onset of eye movement first (500ms), followed by head (600ms), trunk (700ms) and foot (1100s). Interestingly, ‘return trials’ to the central LED resulted in a reduced latency of foot and trunk (but not eye and head) indicating that eye, head and trunk moved more en bloc with knowledge of target location. This may have implications of a learned effect of target location during repeated trials.

The majority of the literature investigating movement during gait initiation includes healthy young adults, however, the literature that includes a comparison with an older adult population report that older adults tended to move more en-bloc, or with increased ‘rigidity’ (Tucker, et al., 2008). Other age related differences include: an increased overall task time (Meinhart-Shibata, et al., 2005; Thigpen, Light, Creel, & Flynn, 2000); increased number of steps to complete a turning task (McIlroy & Maki, 1996; Meinhart-Shibata, et al., 2005; Thigpen, et al., 2000); altered stepping strategy (Meinhart-Shibata, et al., 2005; Thigpen, et al., 2000); an increased latency of muscle (tibialis anterior) onset time (Luchies, Wallace, Pazdur, Young, & DeYoung, 1999); and increased weight transfer time during gait initiation (A. E. Patla, et al., 1993).

The key literature referring to step turning is outlined in Table 2.1 below. It is pertinent to point out that the majority of these studies include only young adult populations, and none refer to a falls risk population.

Table 2.1. Summary of Key Step Turning Articles.

Author (s)	Year	Participant Details	Intervention	Main Outcome Measures	Key Findings
(Anastasopoulos, et al.)	2009	10 HA (52±2.6 years old)	From quiet standing, cued by LEDs to turn 45°, 90°, 135°, or 180° left or right of centre Trials: 4 trials to each LED target (Total Trials: 28)	EOG, MA	Sequence of Movement Eye (500ms)→ head (600ms)→ trunk (700ms)→ foot (1100ms)
(Hollands, et al.)	2004	5 HYA (20- 25 years old)	Cued by the extinction of a central light, participants were required to locate and align their whole bodies to a visual target at 45°, 90° or 135° to the left or right of centre Trials: Randomised for 10 to each LED (Total Trials: 60)	EOG, MA	Sequence of Movement Eye (470ms)→ head (497ms)→ trunk (710ms)→ foot (1300)

Author (s)	Year	Participant Details	Intervention	Main Outcome Measures	Key Findings
(Meinhart-Shibata, et al.)	2005	10 HYA (22 years old) 10 HOA (73 years old)	From a quiet standing position, participants were asked to pick up a bowl, turn 180° and place on a table behind the starting position Trials: 48 trials consisting of turns left or right; 14 turns with sudden direction change Total- 62 Trials	MA, FP, PS	Stepping Strategy Ipsilateral: HYA- 76%; HOA- 35% Contralateral: HYA- 24%; HOA- 65%

Note. HYA- healthy young adults; HOA- healthy older adults; HA- healthy adults; LED- light emitting diode; FP- force plate; EOG- electrooculography; EMG- electromyography; MA- motion analysis; PS- pressure sensor (in-sole); APA- anticipatory postural adjustments; ms- milliseconds

2.6 Laboratory Measurements

The following section will evaluate the literature regarding laboratory measurements used to identify the presence of anticipatory postural muscle activity. Rationale for the methods used will include reliability and validity studies where available and will comment on methods used in similar studies.

2.6.1 Surface Electromyography

Muscle activity has been measured using electromyography for many decades, despite contention as to how the signal is collected, processed and interpreted. Surface electromyography (EMG) involves placing electrodes over muscle motor points, while providing a safe and reliable signal collection. The following four issues relating to EMG will be discussed: (1) choice of muscles to monitor; (2) quality of EMG signals; (3) management of EMG data; and (4) identification of the onset of muscle activity.

Choice of muscles to monitor

There is evidence of a stereotypical pattern of muscle activity early in gait initiation. Crenna & Frigo (1991) reported key components of gait initiation include inhibition of soleus (SOL) followed by activation of tibialis anterior (TA) after approximately 100ms in both the swing and stance limbs. It is unclear in the findings of this study if activity was unilateral or bilateral or if data from both limbs were pooled, as graphic representation is provided only for the stance limb. This apparent lack of identifying which side the EMG activated is evident in other studies of gait initiation muscle activity (Brunt, et al., 1999; Brunt, et al., 2005; Fiolkowski, et al., 2002; Polcyn, et al., 1998).

Mickelborough, Van Der Linden, Tallis & Ennos (2004) aimed to provide a baseline of gait initiation muscle activity of healthy older adults by recording EMG of tibialis anterior, medial gastrocnemius and gluteus medius. The authors found that gait was initiated by the contralateral TA, followed by the ipsilateral TA, ipsilateral medial gastrocnemius, contralateral gluteus medius, contralateral medial gastrocnemius, and finally ipsilateral gluteus medius (Mickelborough, et al., 2004). It has been suggested that activity of the medial gastrocnemius is considered more consistent than soleus in elderly people for both swing and stance legs (Mickelborough, et al., 2004; Polcyn, et al., 1998).

The quality of surface electromyography signals

Surface electrodes measure electrical activity of muscles by recording the summated compound potential of many units (Cram, Kasman, & Holtz, 1998; Echternach, 2003). In order to best identify the onset of muscle activity, a desirable high signal to noise ratio can be achieved by reducing the level of skin impedance as well as sources of potential noise and movement artifact (Cram, et al., 1998; De Luca, 2002; Winter, 2005). Skin impedance can be reduced by preparing the electrode site by shaving; skin exfoliating using an abrasive gel; and wiping with alcohol swabs (Cram, et al., 1998; Winter, 2005). Skin impedance levels of less than 10kΩ are generally considered acceptable (Hermens, Freriks, Disselhorst-Klug, & Rau, 2000). Ambient noise as a result of electromagnetic equipment can be absorbed by the EMG leads. It is therefore recommended that the leads themselves are kept short, and that the testing equipment is kept away from computer monitors (Cram, et al., 1998; Kamen & Caldwell, 1996). Ambient noise can also be reduced by incorporating pre-amplifiers close to the collecting electrode, thereby increasing the desired signal. Inherent noise from the power supply can be filtered out (De Luca, 2002; Winter, 2005). Shortened leads and fixating on the body also reduce the amount of movement artefacts. Alternatively, artefacts at frequencies between 10 and 20Hz can be filtered out (De Luca, 2002; Kamen & Caldwell, 1996; Winter, 2005).

Baseline muscle activity can be reduced by encouraging participants to relax in between trials (Tomberg, Levarlet-Joye, & Desmedt, 1991) thereby limiting inaccuracies when identifying the onset of muscle activity (Hodges & Bui, 1996). Cross talk can be reduced by using small electrodes and minimising the distance between paired electrodes to one centimetre (Kamen & Caldwell, 1996).

The site of the EMG electrode placement affects the quality of the EMG signal. In order to detect sequential action potentials, the electrode should be placed between a motor point and the tendon insertion or between two motor points, and along the longitudinal midline of the muscle (De Luca, 2002; Kamen & Caldwell, 1996). Guidelines to the optimal sites for electrode placement have been developed by a European collaborative project- Surface ElectroMyoGraphy for the Non-Invasive Assessment of Muscles, or SENIAM (Hermens, et al., 2000) and were used in this study.

Management of surface electromyography data

In order to interpret the signal, the raw EMG must be converted from an analogue to a digital signal. It is recommended that the EMG signals are then full wave rectified (Cram, et al., 1998; Kamen & Caldwell, 1996) thereby providing numerical quantification of the signal (Kamen & Caldwell, 1996; Winter, 2005). Although filtering the full wave rectified signal assists with the identification of muscle onset (Hodges & Bui, 1996), it does result in a loss of fine detail, therefore its use should be considered carefully (De Luca, 2002; Soderberg & Knutson, 2000). It is recommended that EMG signals between 20 and 350Hz are retained while signals outside of this are considered unstable and should be filtered out (De Luca, 2002; Solomonow, 1997).

Identification of onset of muscle activity

Two methods are commonly used to identify the onset of muscle activity from a EMG trace- visual detection or computer algorithms (Hodges & Bui, 1996; Soderberg & Knutson, 2000). Although computer algorithm techniques have good reliability (Di Fabio, 1987), the identified onset of muscle activity may not always represent a physiologically meaningful event (Staude & Wolf, 1999). Visual estimation, has been found to have high intra-rater reliability when determining EMG onset (Hodges & Bui, 1996), though this is dependent on the experience of the researcher (Di Fabio, 1987; Hodges & Bui, 1996). It is suggested that a combination of both observer detection of onset along with the use of computer recognition programming should be used in order to optimise the accuracy of the parameter or event location (Staude & Wolf, 1999), as well as to best determine its relation to a physiological event (Di Fabio, 1987; Hodges & Bui, 1996).

EMG activity of gastrocnemius and tibialis anterior are consistently referred to in gait initiation literature (Mickelborough, et al., 2004; Polcyn, et al., 1998), and therefore considered likely to be active during the similar task of step turning. The medial gastrocnemius is considered more consistent than soleus in older adult muscle activity (Mickelborough, et al., 2004; Polcyn, et al., 1998). The period of time chosen to investigate the activity of anticipatory muscle activity was 200ms prior to the onset of the first movement (namely centre of pressure movement). Other studies of anticipatory activity have indicated that anticipatory muscle activity occurs between 60ms to 200ms prior to the focal movement (Belen'kii, et al., 1967; Schmidt & Lee, 2005) and so the 200ms timeframe was used to ensure capture of anticipatory activity. Key articles that have identified anticipatory muscle activity during gait initiation and steering are outlined in Table 2.2 below.

Table 2.2. Summary of Studies reporting Onset of Anticipatory Muscle Activity during Gait Initiation and Steering Tasks

Author (s)	Year	Participants	Intervention	Measurements (EMG)	Focal ONSET Event	Key Findings
(Assaiante, et al.)	2000	6 infants 5 children 8 HYA	Gait initiation at self-selected pace (no cue)	Ipsilateral TA, Gast, Hams, Quads, PS; Abdo; contralateral) TA and GMed 10 Trials	Hoff	Adults: Contralateral TA→ ipsilateral TA ('almost simultaneously')→ contralateral GMed→ ONSET
(Y. Breniere, et al.)	1981	7 HYA	Gait initiated at self-selected pace (no cue)	Bilateral TA and Sol 40 Trials	HOff	↓ Sol→ TA (63-106ms)→ ONSET
(Brunt, et al.)	1991	9 HYA (18- 40 years old)	Gait initiation at "slightly more than normal speed" pace (visual cue)	Bilateral MGast and IA Foot switch 10 Trials	TO	Contralateral TA→ Ipsilateral TA→ → ONSET→ GRF→ Gast→ focal ipsilateral TA
(Brunt, et al.)	1999	10 HYA (21-34 years old)	Gait initiation at (1) self-selected pace and (2) fast pace to (A) initiate walking (B) step over ruler; (C) step over obstacle	Contralateral TA and Sol 10 Trials per condition. (The last five were used in data analysis)	TO	Self Selected Gait Initiation: ↓Sol (0ms)→ ↑TA (46±3ms)→ ↑Sol (21±15ms) → ONSET Fast Gait Initiation ↓Sol (0ms)→ ↑TA (51±3ms)→ ↑Sol→ ONSET (-58±11ms- co-contraction)
(Brunt, et al.)	2005	9 HOA 9 FROA	Gait initiation to (1) self-selected pace; (2) step up onto curb; (3) step over obstacle (no cue)	Bilateral TA, Sol, GMed 10 Trials per condition	TO	Ipsilateral GMed→ ONSET→ TA and Sol→

Author (s)	Year	Participants	Intervention	Measurements (EMG)	Focal ONSET Event	Key Findings
(Crenna & Frigo)	1991	6 HYA (22.5 ± 1.5 years old)	Gait initiation to (a) take single step forward; (b) initiate walking (c) rise on tip-toe (d) fast forward bend head and trunk (e) throw a ball (f) sit to stand (visual cue)	Bilateral Sol and TA; ipsilateral BF and VM). BF and VM not reported on 30 Trials	HOff	↓ bilateral Sol (0)→ ↑ bilateral TA (100ms)→ ↑ bilateral Sol→ ONSET→ COP (100- 200ms after)
(Elble, et al.)	1994	5 HYA (22-47 years old) 6 HOA (64- 82 years old)	Gait initiated at 'brisk pace' (light cue)	Bilateral TA, MGast, RF, BF 20 Trials	TO	↓ bilateral MGast/ Sol→ ↑ bilateral TA→ RF (160ms)→ ↑ contralateral MGast/ Sol (326ms)→ Hams (506ms)
(Fiolkowski, et al.)	2002	10 HYA	Gait initiation at fast pace (1) before (pre-test), and (2) after a tibial nerve block (no cue)	Bilateral TA and Sol 1 Trial of each pre and post condition	TO	Bilateral Sol→ ipsilateral TA→ contralateral TA (both pre and post-test)→ ONSET
(Hase & Stein)	1999	10 HYA (26- 57 years old)	Right or left turn steering while walking comfortable pace (noxious cue- electrical stimulus to the superficial peroneal nerve)	Right TA, Sol, BF, ES, GMed, VL 80 Trials	Heel contact	Step Turn ↓ bilateral Sol→↑ipsilateral BF→ ipsilateral ES→ ipsilateral Sol→ GMed→ ONSET
(Mercer & Sahrmann)	1999	20 Children (8- 12 years old) 20 HY (25- 25	Step initiation at a self-selected pace to either 'place' one foot onto a step or to	Contralateral TA, Gast, Sol, Hams, GlutMed; ipsilateral RF and GlutMed	RF onset	TA (229- 272s) (contralateral→ ipsilateral right)→ GM→ ONSET

Author (s)	Year	Participants	Intervention	Measurements (EMG)	Focal ONSET Event	Key Findings
		year sold) 20 HOA (65-73)	‘step’ up onto the step	20 Trials		
(Mickelborough, et al.)	2004	21 HOA (over 65 years old)	Gait initiated at normal, self-selected speed (light cue)	Bilateral TA, GMed, MGast 10 Trials	500ms after TA activation	Contralateral TA→ ONSET→ ipsilateral TA→ ipsilateral GMed→ contralateral GMed→ contralateral MGast→ ipsilateral MGast
(Polcyn, et al.)	1998	20 HYA 20 HOA	Gait initiation at slow, normal and fast speed (no cue)	Biliateral TA, Sol and Gast 10 Trials	TO	Bilateral ↓ Sol→ ONSET→ bilateral ↑ TA in both HYA and HOA adults

Note: EMG- electromyography; HYA- healthy young; HOA- healthy older; TA- tibialis anterior; Gast- gastrocnemius; MGast- medial gastrocnemius; ES- erector spinae; Hams- hamstrings; Quads- quadriceps; PS- paraspinals; Abdo- abdominals; GMed- gluteus medius; BF- biceps femoris; VM- vastus medialis; VL- vastus lateralis; RF- rectus femoris; GRF- ground reaction forces; COP- centre of pressure; HOff- heel off; TO- toe off; ONSET- onset of focal movement (i.e. initiation of swing)

2.6.2 Surface Electrooculography

Studies that have investigated the role of vision or eye movements during gait initiation and step-turning tasks have used a variety of methods which result in caution when comparing findings. Eye movements have been measured using infra-red reflectometry (Crowdy, Hollands, Ferguson, & Marple-Horvat, 2000; Hollands & Marple-Horvat, 1996, 2001; Hollands, Marple-Horvat, Henkes, & Rowan, 1995), electrooculography (Anastasopoulos, et al., 2009; Hollands, et al., 2004; Petrofsky, et al., 2004; Sklavos, et al., 2008) as well as head mounted eye or gaze trackers (Chapman & Hollands, 2006b; Cinelli, et al., 2007, 2008; Hollands, et al., 2002; Imai, Moore, Raphan, & Cohen, 2001; Reed- Jones, et al., 2009; Reed-Jones, et al., 2009).

Electrooculography is the most frequently used technique in the small body of evidence that investigates eye movement during step turning tasks (Anastasopoulos, et al., 2009; Hollands, et al., 2004; Sklavos, et al., 2008). Hence, electrooculography will be used in the current study, and further discussion in this review will be limited to the use of this measurement of eye movement onset.

In 1948, Du Bois Reymond reported that in the normal eye there is a flow of electrical current that is oriented so the retina is relatively more positive than the posterior pole of the eye. This potential difference is referred to as the resting potential of the eye (Miyake, 2006). Electrooculography (EOG) provides an indirect measure of this resting potential during eye movements. In most cases, pairs of electrodes are placed at the outer canthi of both eyes and a ground electrode is position on the forehead (Brown, et al., 2006). If the eye is moved from the centre position towards one electrode, this electrode "sees" the positive side of the retina and the opposite electrode "sees" the negative side of the retina (Miyake, 2006). Consequently, a potential difference occurs between the electrodes (Figure 2.4).

Assuming that the resting potential is constant, the recorded potential is a measure for the eye position (Brown, et al., 2006).

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Figure 2.4. **Electrooculography.** As the eye moves, one electrode will 'see; the positive side of the retina, while the opposite electrode will 'see' the negative side, representing a change in potential, therefore eye movement during electrooculography measurements. Adapted from Miyake (2006).

The disadvantages of electrooculography include variability in retinal health and metabolic changes in the eye which may alter the movement of the eye (Miyake, 2006). This can be limited by screening participants for eye disease; maintaining a constant source of light in the laboratory; and calibrating eye movements prior to data collection (Hollands, et al., 2004). Adequate contact between the electrodes and the skin is another source of variability, though is limited by the application and drying of an alcohol swab prior to electrode placement and testing for acceptable levels of impedance (10kΩ). Electrooculography provides a cheap, easy and non-invasive method of recording eye movements.

Hollands et al. (2004) were the first to publish step turning findings that accounted for eye movements. The authors placed electromyographic (EMG) skin surface electrodes at the outer canthi of each eye and an earth electrode at middle of the forehead. This method of electrode placement will be used in the current study.

2.6.3 Motion Analysis

Investigation of anticipatory muscle activity is related to onset of body segment movements. Three-dimensional motion analysis systems provide identification of both linear and angular kinematics. Data from three or more cameras has been shown to limit the problems associated with missing markers as well as improve the accuracy of the calculations (Rowe, 1999). Automatic tracking software identifies the movement of a set of markers and combines the tracking of available cameras to enable the three-dimensional model (Calvert & Brunderlin, 1997). This does not eliminate the requirement for visual verification of the data, as missing data can result in trajectory conflicts within the automation (Allard, Blanchi, & Aissaoui, 1997; Rowe, 1999).

The location of the markers is dependent on both the body segment of interest (Greaves, 1997) as well as the type of motion analysis system used (Rowe, 1999). As the system used in the current experiment is optoelectronic, retro-reflective markers will be discussed. Advantages of retro-reflective markers are that they are easy to attach to the body. The disadvantage of this type of marker is that convergence of adjacent markers is problematic when placed close together. This can be corrected in part by tracking software, though additional manual editing may be required (Allard, et al., 1997; Pedotti & Ferrigno, 1997).

In other words, the onset of segmental body movement can be identified using three-dimensional motion analysis by incorporating both automatic marker tracking and visual identification. As a result of automated calculations based on three-dimensional reconstruction, it is important that the above recommendations for the collection of motion analysis data are followed (Pedotti & Ferrigno, 1997).

2.6.4 Force Platform

Although force plates have been frequently used during investigation of step initiation (Brunt, et al., 2005; Clarac, 2008; Degani, Danna-Dos-Santos, & Latash, 2007; Fiolkowski, et al., 2002; Ito, Azuma, & Yamashita, 2003; Jian, Winter, Ishac, & Gilchrist, 1993; Kukulka, et al., 2009; Lyon & Day, 1997; A. E. Patla, et al., 1993; Polcyn, et al., 1998) and steering (Hase & Stein, 1999; A. E. Patla, Prentice, Robinson, & Neufeld, 1991; Taylor, et al., 2005; Xu, Chow, & Wang, 2006), there is an apparent absence of inclusion in step turning studies. Measurements of ground reaction forces as well as calculations of COP provide insight into foot contact and movement during the task. Centre of pressure has been described as the location of the vertical ground force vector representing an average of the total pressures that are in contact with the ground. It has been suggested that APAs are generated to minimise the displacement of the COP (Bouisset & Zattara, 1987a). While the magnitude or timing of muscle activity is indicative of the neural output, the excursion of the COP reflects the biomechanical output of the postural control system (Winter, 2005).

In a recent study that required standing participants to turn their head to known targets positioned at 90 degrees to their left and right, Fukushima, Asaka & Fukushima (2008) reported on the ground reaction force and calculation of COP in relation to eye, head and trunk movements and EMG of lower limb muscles. The authors found that each participant demonstrated a consistent change in COP that was associated with head movements (Fukushima, et al., 2008). Although force changes preceded head movement (along with anticipatory muscle activity in the biceps femoris), the mean latency in the other movements lagged behind the head movement onset. They conclude that the COP and muscle activity (biceps femoris) preceding head movement may be pre-programmed in relation to anticipatory postural movements (Fukushima, et al., 2008).

In an investigation of age-related changes in the gait initiation motor programme, Polcyn, et al. (1998) found that the momentum-generating capacity of the COP shift mechanism was significantly diminished in older adults. Specifically, the relationship between the time of backward COP shift and the amount of forward momentum generated was significantly lower in older adults, indicating that less momentum is generated during changes in COP displacement and could be attributed to the increased levels of soleus and gastrocnemius activity (Polcyn, et al., 1998). The authors go on to suggest the benefit of rehabilitation interventions aimed at improving COP shift mechanisms in older adults at risk of falls. This may include the use of biofeedback or relaxation techniques to learn appropriate inhibition of soleus and gastrocnemius during gait initiation (Polcyn, et al., 1998).

Summary

Surface electromyography provides a safe and reliable signal collection. Tibialis anterior and biceps femoris have demonstrated stereotypical anticipatory muscle activity that precedes centre of pressure movement in gait initiation and steering studies. Anticipatory muscle activity can be related to both changes in kinetic measures, as well as body segmental movements. Ideally, a combination of the measures mentioned above would provide a more detailed analysis of step turning movements in future studies, and in the development of rehabilitation programmes.

2.7 Chapter Summary

Few studies have addressed the key questions of this literature review; namely: to identify the key anticipatory muscles responsible for postural adjustments during turning; to identify the onset and latency of these muscles; and to identify differences in step turning strategies depending on direction of turn.

Anticipatory postural adjustments (APAs) occur in either postural muscles prior to focal movement or in reference to associated changes of COP movement. Muscles that are consistently active across participants and repeated trials are likely to have a central role to the task. In gait initiation and steering studies, tibialis anterior, gastrocnemius and soleus have been reported to activate in the anticipatory period (Assaiante, et al., 2000; Y. Breniere, et al., 1981; Brunt, et al., 1991; Brunt, et al., 1999; Crenna & Frigo, 1991; Fiolkowski, et al., 2002; Hase & Stein, 1999; Mercer & Sahrmann, 1999; Mickelborough, et al., 2004). It has also been identified that activity of the gastrocnemius is considered more reliable than soleus when investigating EMG activity in older adult populations (Mickelborough, et al., 2004; Polcyn, et al., 1998). Currently there is no reported study that has investigated whether anticipatory muscle activity is present during turning.

Visually-guided movements can be achieved by the eye, head and trunk movements in isolation or in combination. However, the role of saccadic eye movements during turning tasks requires further investigation to aid understanding of its involvement in falls risk older adults. Previous literature in step turning studies has provided some insight into the temporal onset of muscle activity and segmental body movements (Anastasopoulos, et al., 2009; Hollands, et al., 2004). However, it is recommended that a combination of kinematic, kinetic, electromyographic and electrooculographic measures would provide a more detailed representation of the anticipatory and focal movements. Older adults have a tendency to demonstrate a longer reaction time, be slower in overall task movement; alter the latency between segmental movements, and alter anticipatory muscle activation when compared to healthy young adults. It is unclear as to if these differences are exaggerated in the falls risk older adult population, and therefore clarification is required.

While turning has been identified both essential to daily movement, it has also been reported to increase the potential risk. This gives reason to investigate the ageing population, especially those that are considered at risk of falls while completing a step turning task and to compare to effective strategies observed in previous studies of healthy young and older adult populations (Meinhart-Shibata, et al., 2005). Differences identified could be incorporated into development of balance assessment and rehabilitation.

It is therefore suggested that investigation of eye and whole body movements during turning tasks in falls risk older adults should include reference to the anticipatory period of muscle activity. This should include a combination of kinematic, kinetic, electromyographic and electrooculographic measures to best represent postural responses in this population. Knowledge of these responses can be implemented into assessment and rehabilitation interventions that monitor and enhance postural control.

3. METHOD

3.1 Introduction

The purpose of this study was to assess the effects of falls risk during a step turning task, in terms of onset of segmental movement and anticipatory muscle activity. This chapter will set out the study design, participant details, methods, data management and statistical analyses applied in order to address this objective.

From a position of quiet standing, participants completed multiple trials of a step-turning task. Following a visual cue, participants stepped and turned towards visual targets positioned 60 degrees the left and right from the midline. There were four objectives: Firstly, to evaluate which foot predominately moved first. Secondly, to identify whether there was a consistent order in the onset of movement between the eyes, head, trunk, pelvis and feet. Thirdly, to identify if there was a consistency in the latency of movement onset. Finally, to identify if a consistent pattern of anticipatory lower limb muscles activation existed.

3.2 Sample Size

A sample size calculation was undertaken assuming a statistical significance level of α=0.05 and a power of 0.8. The calculation was based on the latency of movement onset between the head and the foot segments as published by Hollands et al. (2004). Using a student's *t*-test, a sample size of seven in each group achieved the significance level and power requirement to detect a clinically important difference in the latency of movement onset 0.7s (±0.5s). As there are limited studies including muscle activation, the sample size was increased to eleven in each group to prevent a potentially underpowered study.

3.3 Study Setting and Design

All testing took place in the Health and Rehabilitation Research Institute, AUT University, Auckland. A convenience sample was recruited by means of poster advertisement (Appendix B). The study was an experimental, laboratory based, repeated measures design. The study was unblinded as the researcher was involved in recruitment and data collection, however this was considered to have a minimal effect as all data recording was automated and not under the control of the researcher. All participants were informed of the purpose and methods of the study verbally and in writing (Appendix C) and gave written informed consent to take part in the study (Appendix D). The potential participants were given a week to consider whether they would like to take part, prior to a follow-up phone call. Participants attended the laboratory once for all data collection. The order of stepping direction was randomised using a spreadsheet application prior to the enrolment of each participant.

3.4 Ethical and Cultural Considerations

Ethical approval was obtained from the AUT University Ethics Committee (AUTEC), approval number 08/154 (Appendix A). The principles of the Treaty of Waitangi of partnership, participation and protection were applied in the study design and delivery of the study. All volunteers meeting the inclusion criteria had an equal opportunity to take part in the study regardless of ethnicity.

3.5 Study Participants

Inclusion Criteria

Participants were included in the study if they had volunteered to participate; were over the age of 64 years; lived in their own home or a retirement village (community dwelling); could stand and take a step to turn 90 degrees without a walking aid; did not have a known allergy to taping materials; had no neurological or musculoskeletal disorders, and did not have severe visual loss. A pragmatic assessment of visual acuity was applied. To be included, volunteers had to be able to indicate when a light-emitting diode (LED) at eye level was extinguished from a distance of one and a half metres- with or without corrective eyewear.

Volunteers were required to have the cognitive ability to follow instructions and to provide informed consent. This was evaluated by the Telephone Mini-Mental State Examination (T-MMSE) (Newkirk, et al., 2004) which has been validated for screening cognitive function in community dwelling adults over the age of 55 years. The T-MMSE correlates strongly with the Folstein MMSE to indicate intact cognitive status with a score of 20 or more out of a possible 26 (Newkirk, et al., 2004). Hence, attaining a score of 20 or more was required for inclusion in the study. A copy of the T-MMSE is appended as Appendix E.

The final requirement for inclusion was that volunteers had to be willing to attend AUT University and consent to take part in the study. Vouchers were provided for travel costs to and from the laboratory. The ability to withdrawal from the study at any time was emphasised verbally.

To determine if the participant would be allocated to the “Healthy Older Adult” (HOA) or the “Falls Risk” (FROA) group, allocation was determined using the Falls Risk Assessment Tool (FRAT) developed by Nandy et al. (2004) (Appendix F). This has been validated for screening falls risk in a community dwelling older adult population. Although a score of three or more indicates a potential risk, a score of two or more in Part One of the FRAT was used in this study to clearly differentiate the two groups.

Exclusion Criteria

Exclusion criteria were applied to limit any potential risk of harm to participants, and limit confounding factors of step turning performance to falls risk. This project excluded people who had a known allergy to adhesive taping materials; had a neurological or musculoskeletal condition; or had severe vision loss.

3.6 Instrumentation

3.6.1 Kinematic Data Collection

A motion analysis system (Qualisys Medical AB, Gothenburg, Sweden) with nine ProReflex Motion Capture Unit (MCU) 240 cameras was used to record 3-Dimensional displacement data. The cameras were placed at different heights and distances from the participant in order to optimise accurate the field of view of the experimental area and retroreflective markers (Figure 3.1). The sampling rate for the motion analysis system was set at 240Hz and synchronised with the kinetic, EMG and EOG signals using a motion analysis system (Qualisys Medical AB, Gothenburg, Sweden). This was subsequently stored for off-line analysis.

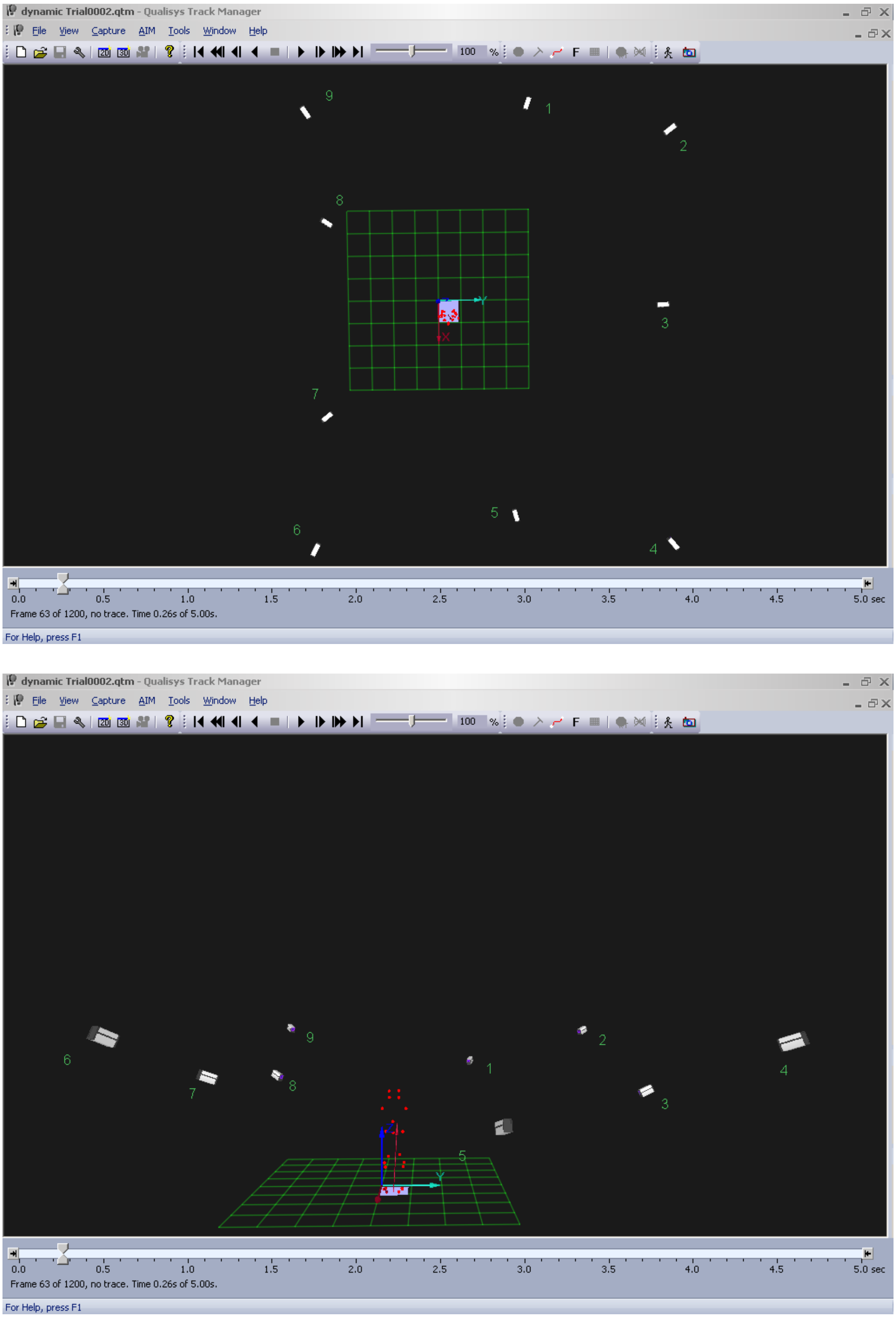

Figure 3.1. **Laboratory layout.** Nine cameras (offset rectangles), force vectors and force plate (grey square) with reflective marker (red dots) located on participant represented.

3.6.2 Kinetic Data Collection

An AMTI force plate (Model OR6-7-2000, Advanced Mechanical Technology Inc. USA) was used to measure the three force components along Fx, Fy, and Fz axes. The force platform, sampling at a rate of 1200 Hz, recorded the displacement of COP during each trial. The force plate consisted of a top plate connected to a base plate by four sensing force gauges allowing collection of six degrees of freedom. To ensure stability and to minimise vibration, the force plate was bolted to a concrete base. When a load was applied to the force plate, a six-component transducer measured the three force components. The signals were amplified using a dedicated six-channel strain gauge amplifier (AMTI MiniAmp, MSA-6, Advanced Mechanical Technology Inc. USA) before being synchronised by the motion analysis system (Qualysis Track Manager, version 2.3, Medical AB, Gothenburg, Sweden).

3.6.3 Electromyography Data Collection

Electromyography (EMG) signals were collected using an eight channel analogue multiplex telemetry system (AMT-8 EMG Wire Telemetry System, Bortec Biomedical Ltd, Canada). This unit is recommended due to its design for functional collection of EMG signals, as well as its low noise and high signal fidelity (Bortec Biomedical Ltd, 2010). Additionally, the Bortec AMT-8 provides complete subject isolation, ensuring subject safety. Nortrode 20 silver/ silver chloride 20mm bi-polar self-adhesive surface electrodes (Norotrode 20™, Myotronics-Noromed, Inc, WA, USA) were applied over the muscle bellies identified by palpation during active resistance as recommended in the SENIAM guidelines for electrode placement (Hermens, et al., 2004). EMG signals were pre-amplified close to the electrode placement to minimise potential noise.

The electrode leads were collected to a portable unit which was secured to the participant's waist. Signals from the unit were transmitted via a single fixed cable to the main amplifier (Bortec Biomedical Ltd, 2010). Data was collected in real time using a bandpass filter of 10- 1000Hz and synchronised using a motion analysis system (Qualisys Medical AB, Gothenburg, Sweden). This was subsequently stored for off-line analysis.

3.6.4 Electrooculography Data Collection

Eye movement signals were collected from electrodes applied to the outer canthi of each eye and the middle of the forehead (ground). Signals were collected at 1000Hz and transmitted to an AC amplifier (Model P511, Grass instruments Company, Warwick, RI, USA) prior to integration with the motion analysis system (Qualysis Track Manager, version 2.3, Medical AB, Gothenburg, Sweden).

3.6.5 Digital Camcorder Data Collection

Two digital camcorders (Panasonic, USA) captured real-time sagittal and frontal images of the step turn, sampling at a rate of 60Hz. The camcorder data were synchronised using the motion analysis software (Qualisys Medical AB, Gothenburg, Sweden). Real-time images could be used to verify the collected motion data.

3.7 Procedures

3.7.1 System Calibration

Prior to each testing session, the motion analysis system was calibrated using the Wand calibration method in order to provide information about the orientation and position of each camera (Qualisys Medical AB, Gothenburg, Sweden). Once cameras were calibrated, the location of the force plate was specified so that force vectors could be processed in the same coordinate system as the motion capture. Calibration was carried out in accordance to manufacturer recommendations (Qualysis Track Manager, version 2.3, Medical AB, Gothenburg, Sweden). The force plate was zeroed by using a bridge balancing switch on the strain gauge amplifier.

3.7.2 Participant Preparation

On arrival, each participant was re-familiarised with the information sheet (Appendix C) that was sent out prior to appointment. Additionally, a verbal explanation was provided prior to signing the consent form (Appendix D). The Activity-specific Balance Confidence (ABC) Scale (Powell & Myers, 1995; Tinetti, Richman, & Powell, 1990) was administered at the time of laboratory appointment (Appendix F). The ABC Scale is a self-report measure of falls efficacy or ‘fear of falling’ that has been used in similar research (Chapman & Hollands, 2007).

All participants were barefoot during the static and dynamic trials and wore singlet and shorts to enable positioning of retroreflective markers. Height and weight measurements were taken for computer modelling data. Leg dominance was determined by asking participants which leg they would preferentially kick a ball (Solomon, et al., 2006). The length of the sessions varied between one and a half to two hours. All testing occurred in the same laboratory.

3.7.3 Tracking Markers and EMG Preparation

Passive retroreflective markers (*n*= 24) were applied to bony landmarks identified by palpation. All markers were spherical with a 19mm diameter. Single markers were placed at the centre of posterior superior iliac crests (PSIS) as well as one offset from spinal level T8. Markers were positioned bilaterally at the tregus (ear), acromion process, anterior superior iliac crest (ASIS), unaligned on thigh, medial epicondyles of the knee joint, lateral epicondyles of the knee joint, unaligned on mid shank, calcaneous, and centre of the 2^{nd} and 3^{rd} metatarsal. Participants wore a cap with two reflective markers positioned in the frontal plane.

Surface electromyography (EMG) activity was collected bilaterally from tibialis anterior and medial gastrocnemius muscles sites of each leg. All electrode sites were prepared by shaving and use of a skin exfoliate (Omni Prep® paste, D.O. Weaver & Co, USA) followed by an alcohol wipe.

The EMG electrodes contained two circular 1.5cm diameter recording areas spaced 1cm apart. Half a Nortode 20™ electrode was applied to the head of fibular as a reference electrode. Skin resistance levels of less than 10kΩ were accepted. Each electrode cable had a small pre-amplifier attached close to the electrode. The pre-amplifier was attached to the participant's leg using hypoallergenic tape to reduce the incidence of movement artefacts. The electrode leads were attached to a central collection port which was attached to a belt, placed around the subjects' waist. This was attached to an analogue multiplex telemetry system (AMT-8 EMG Wire Telemetry System, Bortec Biomedical Ltd, Canada) via a long, lightweight lead to enable unimpeded movement. Participants stood approximately 2.5 metres from the computer system. Functional contractions of the four muscles were completed so that the quality of the signal at baseline and during the early contraction period could be assessed. If the signal was poor, the source of this was identified and resolved until the signal was of sufficient quality.

The electrode sites for electroogulography (EOG)- namely the outer canthi of each eye and centre of forehead (ground) enabled collection of horizontal eye movement. Electrode sites were prepared by alcohol rub and dried prior to application of half a Nortrode 20 silver/ silver chloride 20mm bi-polar self-adhesive surface electrodes (Norotrode 20™, Myotronics-Noromed, Inc, WA, USA). Skin resistance levels of less than 10kΩ were accepted. Lighting within the laboratory was consistent to prevent the possibility of variability of dark adaptation (Knox, 2000).

Participants positioned themselves in the tape-marked starting position with both feet on the force plate, facing a custom made lighting rig (two metres by three centimetres) which consisted of light emitting diodes (LEDs) targets inserted at 60 degrees to the left and right of a central LED. The rig was positioned at the eye level of each participant with each of the LEDs 1.5 metres from the participant's starting position (Figure 3.2). At the beginning of the laboratory session the participant confirmed that they were able to see the centre LED from the starting position clearly. Electrooculography signals were calibrated and zero position checked (Grasso, et al., 1998) by asking the participant to look from the central starting position to a 60 degrees target LED while keeping their head and body stationery. This was conducted after the participant was acclimatised to the illumination within the room, and prior to the collection of the static trial (Laurutis & Robinson, 1986). If signal was poor, the source of this was identified and resolved until the signal was of sufficient quality. Further calibration was deemed redundant as the aim of experiment was to determine the onset of eye movement, rather than measures of amplitude.

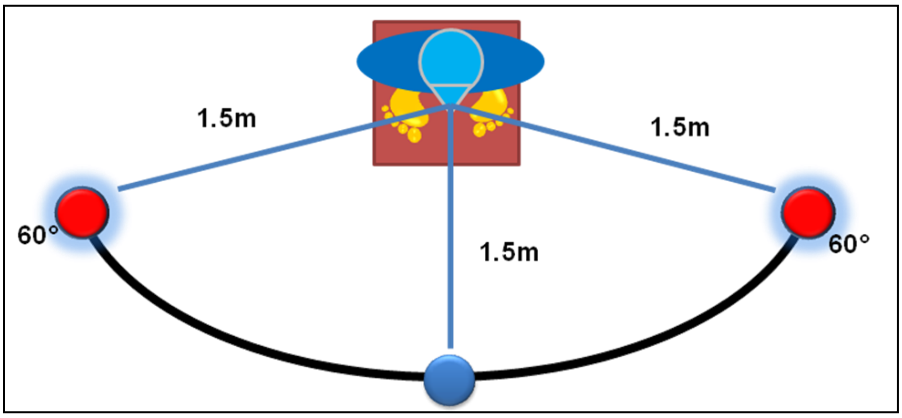

***Figure 3.2*. Bird's eye view of experimental set-up.** A lighting rig was positioned so that the 60 degrees LED targets and central LED (circles) were 1.5m from the participant's starting position on a force plate (square).

A static trial of three seconds was collected to ensure capture of all reflective markers, and for later analysis. The medial knee and medial malleoli reflective markers were then removed to allow unimpeded movement for the step-turning (dynamic) trials. The remaining 22 markers were used to track body segments and define the six-degrees of freedom of each body segment under investigation.

3.8 Experimental Task

The testing procedures were based on the work of Hollands et al. (2004). Participants were asked to stand quietly over the concealed force plate, and to fix their gaze at the centrally positioned green light emitting diode (LED). Participants were instructed to place their feet in the same position relative to taped markings on the force platform at the beginning of each trial; put weight through both legs evenly; focus their gaze on the central green LED; and stand at a relaxed manner. Instructions to the participant were to “step and turn to align your whole body with the red light when you see it as quickly and as safely as you can”.

Once participants indicated that they were ready, a random duration of time was given (one to five seconds) whereby one of the red 60 degrees LEDs was activated. Participants stepped and turned to align their entire body to that LED. There was a 20 second break between trials. This was carried out in light of the older adult population, for data fetching, and for returning to the starting position. Participants were informed that they could request an additional rest break at any point in the procedure. As an additional safety precaution, a helper was closely available during data collection to provide physical support and minimise participants from falling if they become unsteady. This is consistent with research in this area (Chapman & Hollands, 2006a).

One test trial towards one LED was provided to familiarise the participant with the experimental protocol. This trial was then discarded. Ten turns towards each peripheral red LED were completed in a random order (total of 20 trials collected). The onset of the peripheral light was be recorded by the data collection system (Qualysis Track Manager, version 2.3, Medical AB, Gothenburg, Sweden). Figure 3.3 shows the frontal and sagittal view of one participant with reflective markers, surface electromyography electrodes respectively.

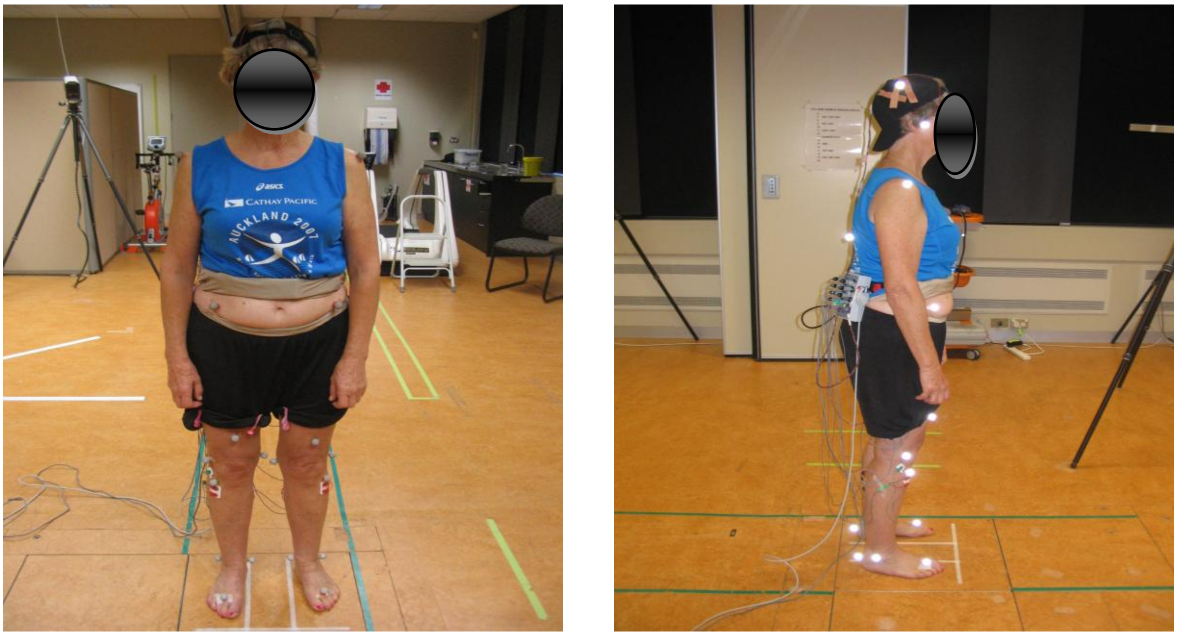

***Figure 3.3*. Frontal and sagittal view of a participant with reflective markers, surface electromyography electrodes.**

3.9 Data Management and Processing

Written data were stored in a locked cabinet in the researcher's office. Computer data were collected simultaneously and subsequently stored on the laboratory computer. On completion of each individual's laboratory session, a backup copy of the computer date was kept on a portable data device and stored with the written data. Confidentiality of all participant information and results were ensured by identifying each participant's demographic details and results by a numerical unique identifier. Only the researcher had access to the database which matched each unique identifier with the corresponding participant.

3.9.1 Motion Analysis Data

A predetermined marker set was used for all participants in order to generate a model for each individual in data analysis. Once calibration markers had been identified from one of the dynamic trials, an Automatic Identification of Markers (AIM) model was generated using motion analysis software (Qualysis Track Manager, version 2.3, Medical AB, Gothenburg, Sweden) for each participant, with the location of each marker verified by the researcher. This was applied to respective participant's static and dynamic trials using batch processing. Captured static and dynamic trials were converted to C3D files and transferred to modelling software (Visual 3D^{TM}, Version 4.0.0.20, C-Motion Inc, Gaithersburg, USA). Using the modelling approach by Hanavan (1964), the anatomical placement of the markers (see Figure 3.4) were used to develop an eight-segment rigid link biomechanical model of the trunk, pelvis, bilateral thigh, bilateral shank, and bilateral feet. The biomechanical model of the participants' static trial and was applied to the step-turning (dynamic) files.

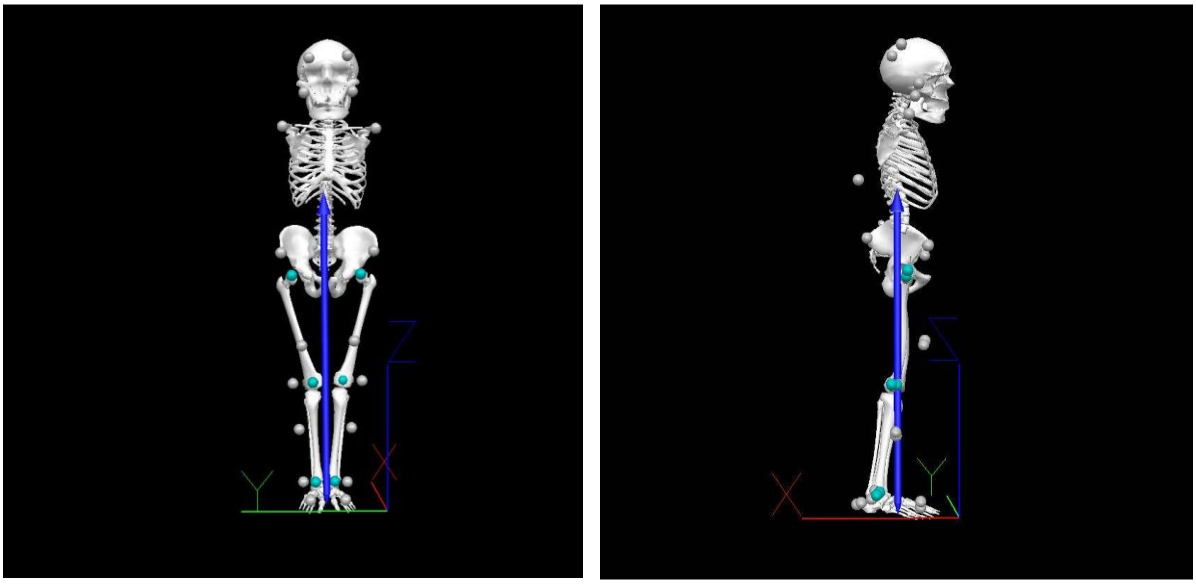

Figure 3.4. **Frontal and sagittal view of a participant modelled in Visual3D**

Kinematic marker traces were smoothed using a 4th order Butterworth bidirectional low pass filter with a frequency cut off of 6Hz in order to eliminate noise such as movement artefacts (Winter, 2005).

3.9.2 Surface Electromyography Data

The raw data were inspected visually for signs of external interference, crosstalk and low frequency motion artefacts. When more than one onset time was identified by the system, the first onset time after the light cue was chosen. How frequently each muscle was active prior to the onset of movement in the predominantly first moving foot (in the z direction) was calculated for each direction and extent. All raw EMG data for each leg and muscle was processed using Visual3D (Visual 3D™, Version 4.0.0. 20, C-Motion Inc, Gaithersburg, USA). For all participants, the onset time from the 20 step turns for each leg and each muscle was calculated from the rectified signal during the entire five seconds of data collection. The rectified signal was smoothed off line using a fourth order Butterworth filter with a cut-off of 6Hz. All EMG files were converted into C3D files and stored for subsequent processing in Visual3D (Visual 3D™, Version 4.0.0. 20, C-Motion Inc, Gaithersburg, USA).

Onset of segmental movement and anticipatory EMG activity were first determined using a programme within Visual3D. As the onset of anticipatory muscle activity may be less accurate in the presence of background activity (for example, postural sway while quiet standing), identification of the APA onset can be unreliable if based solely on automated means (Hodges & Bui, 1996). Onset event markers (COP, body movement and muscle activity) were verified visually by the investigator. Reliability of the visual estimation was assessed by completing two separate ratings of 10 trials on different days, by the same rater. The majority (87%) of segmental movement onset differences were less than 20ms, the limit of temporal accuracy of the kinematic data (Mickelborough, Van Der Linden, Richards, & Ennos, 2000). Identification of anticipatory muscle activity had high agreement of 93%.

3.9.3 Surface Electrooculography Data

The raw EOG data in collected in Qualysis Track Manager was processed using (Visual 3D™, Version 4.0.0. 20, C-Motion Inc, Gaithersburg, USA) to identify the onset of eye movement. The filtering parameters used were a 4th order Butterworth filter with a bandpass of 20 to 450Hz, and a 4th order Butterworth bandstop filter between 49 and 51Hz.

3.9.4 Force Plate

Force plate data was smoothed using a (4th order) Butterworth low pass filter with a cut off of 70 Hz to eliminate high frequency noise. The kinematic, EOG, and kinetic data were exported as American Standard Code for Information Interchange (ASCII) files; and imported into Microsoft Excel prior to statistical analysis in SPSS (Version 17.0.0, SPSS Inc, Chicago, USA).

4. RESULTS

4.1 Introduction

The purpose of this study was to investigate the effect of falls risk on segmental movement and muscle activity while preparing for and performing a visually guided step turning task. Onset and latency of movement parameters were determined using motion analysis, force plate, electrooculography (EOG) and electromyography (EMG); while lower limb muscle activation was determined by electromyography (EMG) recordings.

This chapter will report the main findings of the study and as such will be divided into six sections; section 4.2: Statistical Approach; 4.3: the participants; section 4.4: hypothesis one- order of onset of movement 4.5: hypothesis two- latency of onset of movement; section 4.6: hypothesis three- step turning strategies; and section 4.7: hypothesis four- anticipatory postural muscle activity.

4.2 Statistical Approach

This section describes the process in which data was checked for normality, and subsequently the statistics used based on the distribution of the data.

4.2.1 Normality

Data entered in SPSS were checked against the raw data to ensure data entry was accurate. Raw data were explored for normal distribution by generating a *z* score for both skewness and kutosis. A critical cut off score of 1.96 is usually acceptable for these measures, however, as a small sample size was used, the cut off score of 3.29 was used to indicate normal distribution (Field, 2009). Data skewness and kurtosis were also visually confirmed by plotting data on probability- probability plots (P-P plot) and histograms. Skewness and kurtosis were confirmed with *Z* scores ranging between 4.98 and 10.72 for $Z_{skewness}$, indicating that data was positively skewed; and $Z_{kurtosis}$ between 5.56 and 27.90 indicating that data was not significantly kurtosis. The z scores for skewness and kurtosis for all the dependent variables were above 3.29, therefore the data was considered to have non-normal distribution. As a result of positive skewness, data was transformed (square root transformation) for further exploratory analyses of normality. A Kolmogorov-Smirnov test with a significance of < .05 indicates non-normal distribution (Field, 2009). Onset of segmental movements in healthy older adults turning to the left, $D(51) = 0.001$ to 0.20, $p < .05$, while onset of segmental movements in healthy older adults turning to the right, $D(50) = 0.001$ to 0.20, $p < .05$. Onset of segmental movements in falls risk older adults turning to the left, $D(48) = 0.001$ to 0.20, $p < .05$, while onset of segmental movements in falls risk older adults turning to the right, $D(36) = 0.001$ to 0.033, $p < .05$. Although there were some non-significant values in eye movement, onset of segmental movements in both healthy and falls risk older adults while turning to either direction were non-normal in their distribution overall (Table 4.1). Nonparametric statistics were therefore used to analyse onset and latency of segmental movements (hypotheses two and three) as well as anticipatory muscle activity (hypothesis four).

Table 4.1. Kolmogorov-Smirnov test for Healthy and Falls Risk Older adults during step turn task

Step Turn Direction	Group	Statistic	Degrees of Freedom	Significance
Left	HOA	.06- .22	51	< .05*
	FROA	.11- .22	48	< .05*
Right	HOA	.13- .28	50	< .05*
	FROA	.20- 32	36	< .05

Note. *- non-significant value of Kolmogorov-Smirnov in eye movement

If the data was found to have a normal distribution a general linear model 2 x 2 repeated measures design was to be applied to the individual scores for each trial for each dependent variables under investigation. If the data was found to have not to have normal distribution, then suitable nonparametric alternatives will be explored.

4.2.2 Deference of Bonferroni Adjustment

In order to account for multiple variables, post hoc tests which consist of pairwise comparisons have been suggested in order to control the probability of making a Type I error in any group of tests by correcting the level of significance for each test so that the overall type I error-wise rate (α) across all comparisons remains at .05 (Field, 2009). The disadvantage of the Bonferroni adjustment is a loss of statistical power. By being more conservative in the Type I error, Bonferroni comparison increases the chance of rejecting an effect that does actually exist, resulting in a Type II error (Field, 2009; Perneger, 1998). Instead of applying a Bonferroni adjustment, Perneger (1998) suggests that describing what tests of significance have been performed, and why, is generally the best way of dealing with multiple comparisons.

Statistical tests used within this project are now described in relation to respective hypotheses.

4.2.3 Hypothesis One: Step Turning Strategy

An independent samples *t* test was used to establish that the two groups were comparable for the demographic characteristics, as well for the analysis of step turning strategy. This test is used to determine whether two means collected from independent samples significantly differ (Field, 2009).

4.2.4 Hypothesis Two: Order of Onset of Segmental Body Movements between Groups

The Kendall's coefficient of concordance (*W*) non-parametric statistical test is used to determine sequences of onset of segmental body movements as indicated by temporal data. It measures the relation among several rankings of variables, providing an indication of the extent of agreement between the rankings (Siegel & Castellan, 1988). A high or significant value of *W* is indicative that the group of participants being investigated are applying the same variable rankings. If there is no agreement amount the rankings $W = 0$ and if there is full agreement $W = 1.0$ (Siegel & Castellan, 1988). In the current study, a Kendall's coefficient of concordance will be conducted on the two groups separately (healthy and falls risk older adult), and will also be conducted separately based on the direction of the step turn (left and right). Comparisons of order of onset will be then made by evaluating the data based on the turn direction while comparing the healthy and falls risk older adults. Interpretation of difference of onset of movement between healthy older adult will be made based on the turn direction.

Identification of any relatively homogeneous groups of variables (body segments) will be represented by hierarchical cluster analysis. This statistic measures the association of variables using an algorithm that starts with each case (or variable) in a separate cluster and combines clusters until only one is left (Siegel & Castellan, 1988). The clusters are displayed in dendograms with distances between individual body segments and other clusters being indicative of the similarities between onset of body segments and centre of pressure movements, with closer distances indicating greater similarity.

4.2.5 Hypothesis Three: Onset Latency of Segmental Body Movements

The Kruskal- Wallis test is a nonparametric test that is used with an independent groups design employing *k* samples. It is considered as a good alternative to the parametric one-way ANOVA when the assumptions of that test are violated (Field, 2009; Pagano, 2007). The Kruskal- Wallis test does not assume population normality nor homogeneity of variance, and requires only ordinal scaling of the dependent variable (Pagano, 2007). Similar to the Wilcoxon rank-sum test, the Kruskal-Wallis is based on ranked data, whereby segmental onset values were ordered from lowest to highest (irrespective of group) and assigned the lowest value a score of one. Once the data were ranked, the onset values were re-allocated to their respective group and the ranks for each group added up. The sum of ranks for each group is identified by R_i.

4.2.6 Hypothesis Four: Order of Onset of Anticipatory Muscle Activity

The described Kendall's coefficient of concordance will be used to determine the sequence of anticipatory gastrocnemius and tibialis anterior muscle activity as measured by electromyographic data. A hierarchical cluster analysis will be conducted to identify any homogeneous groups of variables. One limitation with the Kendall's coefficient of concordance test with regards to the surface electromyography data is that trials in which a muscle has not activated cannot be included for analysis. Hence, only muscles that were active in an anticipatory manner in at least 50% of trials will be included in tests to identify a sequence in the order of onset (Mercer & Sahrmann, 1999). This ensures that sufficiently large numbers of trials are tested. SPSS software will be used to run the statistical tests (Version 17.0.0, SPSS Inc, Chicago, USA).

4.3 Participant Descriptive Analysis

A total of 22 community dwelling adults volunteered to participate in the study. Participants were screened using the Falls Risk Assessment Tool (FRAT) and allocated to healthy and falls risk older adult groups respective of their score (section 3.5). The healthy older adult (HOA) group (65 to 85 years) consisted 5 males and six females; as did the falls risk older adult (FROA) group (67 to 90 years). All volunteers met the inclusion criteria with none having any physical impairment that might lead to ineligibility to join the study. Intact cognitive status was determined using the T-MMSE (section 3.5). There were no withdrawals from the trials.

In order to establish that the two groups were comparable for the demographic characteristics, an independent samples *t* test was undertaken to compare the means of age, weight, height, and Telephone Mini Mental State Examination (t-MMSE) between the two groups. There were no statistically significant differences in age ($t(20) = -.89$, $p = 0.9$); weight ($t(20) = .37$, $p = 0.57$), height ($t(20) = .70$, $p = .9$); or T-MMSE ($t(20) = .28$, $p = 0.36$) or ABC Scale ($t(20) = -.19$, $p = 0.5$). See Table 4.2.

Table 4.2: Participant Characteristics

	Healthy Older Adult (HOA)	Falls Risk Older Adult (FROA)
Age (years)	74 (SD±7.6)	76 (SD±7.8)
Weight (Kg)	70.7 (SD±14.5)	68.4 (SD±14.8)
Height (m)	1.68 (SD±0.07)	1.65 (SD±0.08)
T-MMSE score	25 (SD±1.2)	25 (SD±1.8)
ABC Scale score	84 (SD±12.9)	85 (SD±16.5)

Note. T-MMSE- Telephone Mini Mental State Examination; ABC Scale- Activity-specific Balance Confidence Questionnaire

Participants were also asked to indicate their leg dominance, based on which leg would they preferentially kick a ball with. This question is consistent with other studies for determining leg dominance during step initiation and whole body turns (Mercer & Sahrmann, 1999; Solomon, et al., 2006). All except for one participant (participant D) indicated that they were right leg dominant.

4.2.1 Number of Successful Trials

Each of the eleven healthy (HOA) and falls risk older adults (FROA) completed ten trials towards each direction (left and right 60°). During turns towards the left, the left foot was considered the ipsilateral foot while the right foot was considered the contralateral foot. When the ipsilateral foot moved first, this was called the ipsilateral strategy. When the contralateral foot moved first, this was referred to as the contralateral strategy (see Operational definitions section 1.3). All 220 trials were included for the analysis of hypothesis one (step turn strategy). In order to ascertain trial inclusion for analyses of hypothesis two (onset); three (latency) and four (anticipatory muscle activity), only trials that included an ipsilateral strategy were included.

In order to analyse hypotheses two (onset); three (latency); and four (anticipatory muscle activity) the last five trials of each condition were used in the data analysis to provide the best representative trials of the step turning task. This is consistent with studies investigating gait initiation (Brunt, et al., 1991; Brunt, et al., 1999; Brunt, et al., 2005). Trials were excluded in analysis of these three hypotheses if postural sway or anticipation prevented the reliable detection of the onset of movement, or a contralateral strategy was used. If this occurred then earlier trials were included in the analysis. A total of 185 trials were available for analysis as 35 trials (16%)- 101 trials (51 to left; 50 to right) were available for the HOA group; while 84 trials (48 to left; 36 to right) were available for the FROA group. Figure 4.1 outlines the recruitment and trials available based on group allocation.

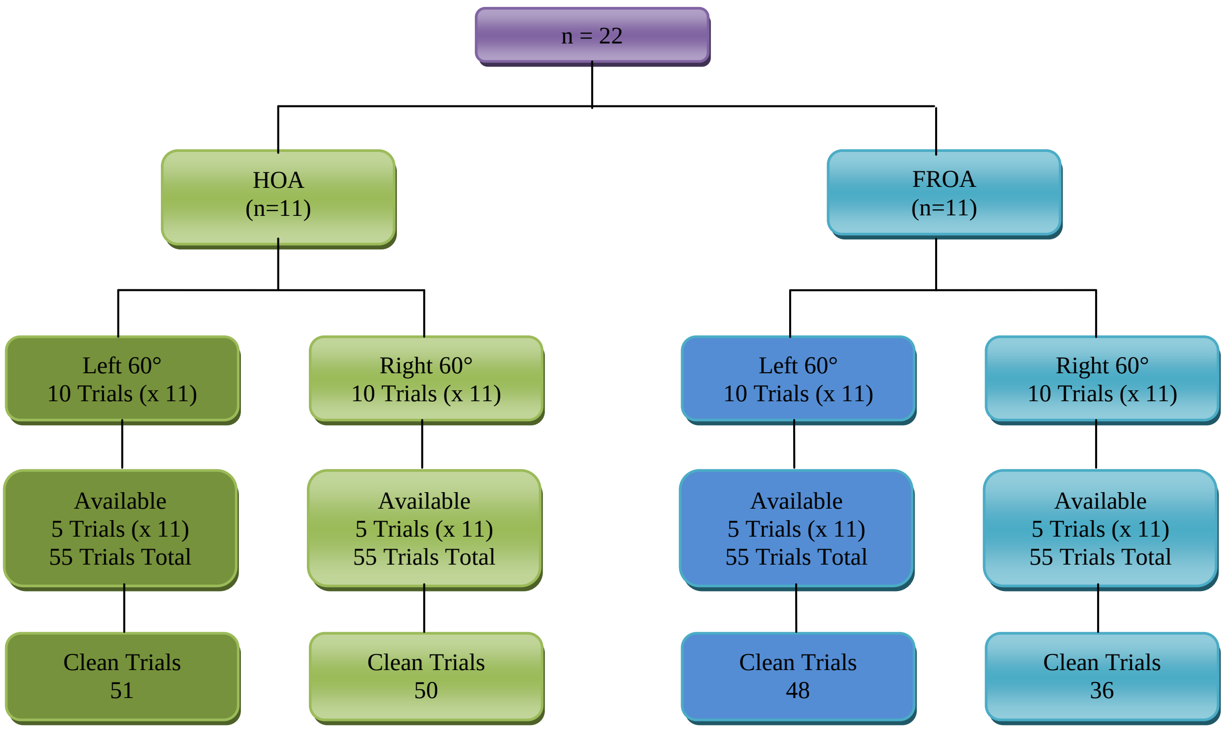

Figure 4.1. **Flow Chart of Data Collection**

In order to determine if data could be pooled from left step turn and right step turn data, a Wilcoxon rank-sum test (W_s) was conducted. Onset of movement of the centre of pressure (W_s= 2400.50, *ns*), head (W_s= 2445.00, *ns*), trunk (W_s= 2579.50, *ns*,) and onset of pelvic movement (W_s= 2507.00, *ns*) when turning to the left did not significantly differ from onset of movement when turning to the right in the healthy older adult (Table 4.3). However, onset of eye movement when turning to the left was significantly different compared to when turning to the right in the healthy older adult group (W_s= 2141.00, p <.001).

Table 4.3. Healthy Older Adult: Step Turn to Left compared to Step Turn to Right (Wilcoxon W_s Test)[a]

	Centre of Pressure	Onset of Eye Movement	Onset of Head Movement	Onset of Trunk Movement	Onset of Pelvis Movement
Wilcoxon W	2400.50	2141.00	2445.00	2579.50	2507.00
Asymp. Sig. (2-tailed)	.310	.005	.476	.884	.523

Onset of centre of pressure (W_s= 1442.50, *ns*), head (W_s= 1300.00, *ns*), trunk (W_s= 1345.50, *ns*) and pelvic movement (W_s= 1443.00, *ns*) when turning to the left did not significantly differ from onset of movement when turning to the right in the falls risk older adult group (Table 4.4). However, onset of eye movement when turning to the left was significantly different compared to when turning to the right in the falls risk older adult group (W_s= 1186.00, p <.001).

Table 4.4. Falls Risk Older Adult: Step Turn to Left compared to Step Turn to Right (Wilcoxon W_s Test)[a]

	Centre of Pressure	Onset of Eye Movement	Onset of Head Movement	Onset of Trunk Movement	Onset of Pelvis Movement
Wilcoxon W	1442.50	1186.00	1300.00	1345.50	1443.00
Asymp. Sig. (2-tailed)	.429	.002	.038	.095	.432

Due to the statistically significant difference in onset of eye movement when comparing left and right step turn direction in both groups, data from the two directions were not pooled for each group. Hence, step turn direction data were analysed separately.

4.4 Hypothesis One

There will be differences in the turning strategies when comparing healthy and falls risk older adults

4.3.1 Frequency of Foot Strategies Used During Step Turns

How frequently the ipsilateral and contralateral strategies occurred during 220 step turns in each direction (total 440 trials) are outlined in Table 4.5. Overall, the ipsilateral strategy is predominately used towards both directions.

Table 4.5. Frequency of foot strategies used during step turns

Turn Direction	Ipsilateral Strategy (%)	Contralateral Strategy (%)
Left	78 (71)	32 (29)
Right	59 (54)	51(46)
	137 (62)	83 (38)

4.3.2 Movement of the Contralateral Foot First

An analysis was undertaken to examine how many participants moved their contralateral foot first, and how often they did this. Ten trials towards each direction and extent were analysed for each participant. It can be seen in Table 4.6, that only five participants (E, F, G, Q and U) consistently used an ipsilateral turning strategy when step turning either left or right. When turning to the left, 11 participants (50%) used a contralateral turning strategy, while 12 (55%) used the contralateral strategy when turning to the right. In total, the contralateral strategy was observed in 32 trials (29%) when turning to the left and 51 trials (46%) when turning to the right.

Three FROA participants in particular (D, S and T) had a high frequency of contralateral strategy when turning to the right (ten, nine and eight respectively) compared to when turning to the left (zero, zero and three respectively). Seven participants (HOA: 2; FROA 5) used the contralateral strategy for 50% or more of their trials.

Contralateral strategy dependent on turn direction (regardless of group)

The frequency of contralateral step turning strategy was analysed for differences based on turn directions (see Table 4.6). Using a two-tailed independent samples t- test, participants were more likely to adopt a contralateral strategy when turning to the right (M = 1.23, SE = .029) than when turning to the left (M = 1.15, SE = .024). This was a statistically significant difference $t(438) = -2.32$, $p < .05$.

Table 4.6. The number of trials that participants moved their contralateral foot first

Participant	HOA/ FROA	Turn to Left (n=220)	Turn to Right (n=220)
A	HOA	0	2
B	FROA	2	6
C	FROA	4	0
D	FROA	0	10
E	HOA	0	0
F	HOA	0	0
G	FROA	4	2
H	FROA	0	0
I	HOA	1	7
J	HOA	0	1
K	HOA	1	0
L	HOA	5	0
M	FROA	1	0
N	HOA	1	0
O	HOA	7	1
P	FROA	3	3
Q	HOA	0	0
R	HOA	0	1
S	FROA	0	9
T	FROA	3	8
U	FROA	0	0
V	FROA	0	1
		32 (29%)	**51 (46%)**

Contralateral Strategy dependent on group

In total, participants in the FROA group were more likely to adopt a contralateral strategy (M = 1.25, SE = .029) than those in the HOA group (M = 1.12, SE = .022). This was a statistically significant difference $t(438) = -3.58$, $p < .05$. The frequency of contralateral step turning strategy were analysed for both groups based on step turning directions (see Tables 4.7 and 4.8). When turning to the left, the FROA group adopted the contralateral strategy (M = 1.15, SE = .033) at a similar frequency as those in the HOA group (M = 1.14, SE = .033). This was not statistically significant $t(218) = -3.81$, $p > .05$. However, when turning to the right the FROA group were more likely to adopted the contralateral strategy (M = 1.35, SE = .046) than those in the HOA group (M = 1.11, SE = .030). This difference was statistically significant $t(218) = -4.49$, $p < .05$.

Table 4.7. The number of trials that Healthy Older Adults (HOA) moved their contralateral foot first

Participant	Turn to Left (n=110)	Turn to Right (n=110)
A	0	2
E	0	0
F	0	0
I	1	7
J	0	1
K	1	0
L	5	0
N	1	0
O	7	1
Q	0	0
R	0	1
	15 (14%)	**12 (11%)**

Table 4.8. The number of trials that Falls Risk Older Adults (FROA) moved their contralateral foot first

Participant	Turn to Left (n=110)	Turn to Right (n=110)
B	2	6
C	4	0
D	0	10
G	4	2
H	0	0
M	1	0
P	3	3
S	0	9
T	3	8
U	0	0
V	0	1
	17 (15%)	**39 (35%)**

4.5 Hypothesis Two

There will be no difference in the performance of a step turn between healthy and falls risk older adult participants as measured by the order of movement onset of centre of pressure, eye, head, trunk, pelvis and foot onset.

Kendall's Coefficient of Concordance was used to determine if there was a statistically significant order of onset of movement across the variables. Only trials in which the ipsilateral foot moved first were included. There was a statistically significant order effect in the onset of movement for both groups during step turns to the left and to the right (asymptotic significance $p < .05$) with a moderate level of agreement in that there was little variation to this order of movement onset (Table 4.9).

Table 4.9. Mean Ranks of Onset of Movement during Step Turn

	Step Turn to Left		Step Turn to Right	
	HOA	FROA	HOA	FROA
Centre of Pressure Onset	1.31	1.36	1.34	1.31
Eye Onset	2.94	2.84	2.06	1.90
Head Onset	2.76	2.67	2.74	3.14
Trunk Onset	4.02	4.17	4.31	4.25
Pelvis Onset	4.18	4.02	4.57	4.44
Foot Onset	5.78	5.94	5.98	5.96
N	51	48	50	36
Kendall's *W*	.662	.707	.874	.860
Asymptotic Significance	.000	.000	.000	.000

Note. HOA- healthy older adult; FROA- falls risk older adult; N- sample size; Kendall's *W*- Kendall's Coefficient of Concordance

When turning left, the order of onset of segmental movement were different in the HOA group (firstly COP, followed by head, eye, trunk, pelvis, and foot) compared to FROA (firstly COP, followed by head, eye, pelvis, trunk and foot). When turning right, however, the order of segmental movement onset were the same for both groups (firstly COP, followed by eye, head, trunk, pelvis and foot).

There is strong agreement for COP onset to occur first, and for foot onset to occur last irrespective of group or direction. There is variance in the agreement of mean ranks of eye and head onset (2.94 and 2.76 respectively) in the HOA group as well as the FROA group (2.84 and 2.67 respectively) during step turns to the left. This was also the case in the HOA group during step turns to the right (2.06 and 2.74 respectively).

There is variance in the mean rank agreement of trunk and pelvis onset in the HOA (4.02 and 4.18 respectively) and FROA (4.17 and 4.02 respectively) group when step turning to the left. Variance was also demonstrated in the HOA (4.31 and 4.57 respectively) and FROA (4.25 and 4.44 respectively) when step turning to the right.

As indicated previously (see section 3.10), a Kendall's *W* test closer to 1.0 indicates a stronger agreement in order of onset of movement. There was a statistically significant order for both groups in both directions, with stronger agreement in order during step turns to the right.

A hierarchical cluster analysis was performed on the data with close proximity of clusters representing segments that behaved similarly in terms of movement onset behaviours. Figure 4.2 shows the clustering for the step turns to the left for the healthy; and falls risk older adult groups; and the step turns to the right for the healthy; and falls risk older adult groups respectively. When turning to the left, there is a clear clustering of trunk and pelvis (then with the head) in the healthy older adult group. In the falls risk group, there is a clustering of eye and head (then COP).

When turning to the right, the same trunk and pelvis cluster is also noted in the healthy older adult. In addition, COP and eye form a cluster, and along with head movement, join the initial cluster at a moderate distance. In the falls risk group, two initial clusters are formed- COP with eye, and trunk with the pelvis movement. The COP and eye cluster are joined by the head movement, then with the trunk and pelvis cluster at a moderate distance.

```
  C A S E      0         5        10        15        20        25
Label      Num  +---------+---------+---------+---------+---------+

Trunk       4   -+---+
Pelvis      5   -+   +---------+
Head        3   -----+         +-+
COP         1   ---------------+ +-------------------------------+
Eye         2   -----------------+                               |
Left Foot   6   -------------------------------------------------+
```

Step Turn to the Left: Healthy Older Adult Data Set

```
  C A S E      0         5        10        15        20        25
Label      Num  +---------+---------+---------+---------+---------+

Eye         2   -+-----+
Head        3   -+     +-+
COP         1   -------+ +---------------------+
Trunk       4   ---------+                     +-----------------+
Pelvis      5   -------------------------------+                 |
Left Foot   6   -------------------------------------------------+
```

Step Turn to the Left: Falls Risk Older Adult Data Set

```
  C A S E      0         5        10        15        20        25
Label      Num  +---------+---------+---------+---------+---------+

Trunk       4   -+---------------+
Pelvis      5   -+               |
Head        3   -----------------+-------------------------------+
COP         1   -------+---------+                               |
Eye         2   -------+                                         |
Right Foot  6   -------------------------------------------------+
```

Step Turn to the Right: Healthy Older Adult Data Set

```
  C A S E      0         5        10        15        20        25
Label      Num  +---------+---------+---------+---------+---------+

COP         1   -+-----+
Eye         2   -+     +---+
Head        3   -------+   +-------------------------------------+
Trunk       4   -+---------+                                     |
Pelvis      5   -+                                               |
Right Foot  6   -------------------------------------------------+
```

Step Turn to the Right: Falls Risk Older Adult Data Set

Figure 4.2. **Hierarchical cluster analysis for segmental movement in Step Turn**

4.6 Hypothesis Three

There will be differences in the latency of movement onset of centre of pressure, eye, head, trunk, pelvis and foot movements between healthy and falls risk older adult participants.

Medians (and inter quartile ranges) of onset of movement were calculated using SPSS in order to identify any differences in latencies between groups and directions (Table 4.10).

Table 4.10. Median and interquartile percentiles of Onset of Movement during Step Turn Task

	Step Turn to the Left (ms)				Step Turn to the Right (ms)			
	HOA	IQP	FROA	IQP	HOA	IQP	FROA	IQP
COP	308	217-371	323	233-442	273	217-344	298	238-361
Eye	404	288-521	452	330-561	321	250-375	325	267-411
Head	367	317-450	415	363-512	365	307-420	383	318-450
Trunk	442	379-517	492	418-600	444	391-491	442	405-505
Pelvis	442	371-563	488	399-620	452	413-501	475	415-541
Foot	617	517-783	683	596-835	619	545-713	642	578-741

Note. HOA- Healthy older adult; FROA- falls risk older adult; COP- centre of pressure; ms- milliseconds; IQP- interquartile percentiles

A Kruskal Wallis test was performed to determine if there was any difference in the latency of segmental movement when comparing the healthy older adult group to the falls risk group. As data could not be pooled (see Section 4.2), the two step turn directions were analysed separately.

When step turning to the left, there was no significant difference in the latency of segmental movement by falls risk in COP, eye and pelvis movements (COP: $H(1) = 1.97$, $p > 0.05$; Eye: $H(1) = 2.20$, $p > 0.05$; and Pelvis: $H(1) = 3.457$, $p > 0.05$). However, there was a statistically significant difference by group in the head, trunk and foot when step turning left (Head: $H(1) = 5.72$, $p < 0.05$; Trunk: $H(1) = 5.02$, $p < 0.05$; and Foot: $H(1) = 0.03$, $p < 0.05$) (Table 4.10).

Table 4.11. Healthy compared to Falls Risk Older Adults: Latency in Segmental Movement Onset during Step Turn to the Left

	Centre of Pressure	Onset of Eye Movement	Onset of Head Movement	Onset of Trunk Movement	Onset of Pelvis Movement	Onset of Left Foot Movement
H	1.971	2.204	5.719	5.021	3.457	4.472
Degrees of Freedom	1	1	1	1	1	1
Asymptotic Significance	.160	.138	.017	.025	.063	.034

Note. *H*- Kruskal- Wallis test

There were no statistically significant differences between the groups in onset latencies when turning to the right, (COP: $H(1) = 2.20$, $p > 0.05$; Eye: $H(1) = 0.16$, $p > 0.05$; Head: $H(1) = 1.09$, $p > 0.05$; Trunk: $H(1) = 0.29$, $p > 0.05$; Pelvis: $H(1) = 0.76$, $p > 0.05$; and Foot: $H(1) = 0.69$, $p > 0.05$) (Table 4.11).

Table 4.12. Healthy compared to Falls Risk Older Adults: Latency in Segmental Movement Onset during Step Turn to the Right

	Centre of Pressure	Onset of Eye Movement	Onset of Head Movement	Onset of Trunk Movement	Onset of Pelvis Movement	Onset of Right Foot Movement
H	2.203	.162	1.086	.290	.759	.692
Degrees of Freedom	1	1	1	1	1	1
Asymptotic Significance	.138	.687	.297	.590	.384	.406

Note. *H*- Kruskal- Wallis test

4.7 Hypothesis Four

There will be a consistent pattern of anticipatory postural muscle activity when comparing healthy and falls risk older adult participants.

In hypothesis one, it was established that the ipsilateral strategy was predominately used during step turns towards both directions. Trials in which the ipsilateral strategy was used were extracted for further analysis in this section. An anticipatory postural muscle activity was considered that which occurred between the time of the "Go" signal and the COP movement (See Operational Definitions, Section 1.3). The frequency of onset of muscle activity of the tibialis anterior and gastrocnemius prior to COP movement are presented in Table 4.13.

Table 4.13. Frequency (and percentage of trials) of anticipatory postural muscle activity of tibialis anterior and gastrocnemius during step turn task

		L Gastroc (%)	L TA (%)	R Gastroc (%)	R TA (%)
Turns to the Left	HOA (n=51)	5 (9.8)	2 (3.9)	3 (5.9)	8 (15.7)
	FROA (n=48)	5 (10.4)	2 (4.2)	3 (6.3)	3 (6.3)
Turns to the Right	HOA (n=50)	6 (12.0)	11 (22.0)	4 (8.0)	7 (14.0)
	FROA (n=36)	2 (5.6)	4 (11.4)	2 (5.6)	0 (0.0)
	Total to Left (n=99)	10 (10.1)	4 (4.0)	6 (6.1)	11 (11.1)
	Total to Right (n=86)	8 (9.3)	15 (17.4)	6 (7.0)	7 (8.1)

Note. L Gastroc- left gastrocnemius; L TA- left tibialis anterior; R Gastroc- right gastrocnemius; R TA- right gastrocnemius; APA- anticipatory postural adjustment.

Anticipatory muscle activity during turns to the left

The ipsilateral strategy occurred 99 (71%) of the 110 trials towards the left. The percentage of trials in which each muscle was active in an anticipatory manner is shown in Figure 4.3. Muscles activated in an anticipatory manner in only 23 (23%) of ipsilateral strategy trials when turning to the left. Frequencies were similar for HOA and FROA, except for right (contralateral) tibialis anterior, which activated for 16% of the available ipsilateral trials for the HOA group, compared to 6% of trials for the FROA group. As anticipatory muscle activity occurred infrequently, further analysis was not explored.

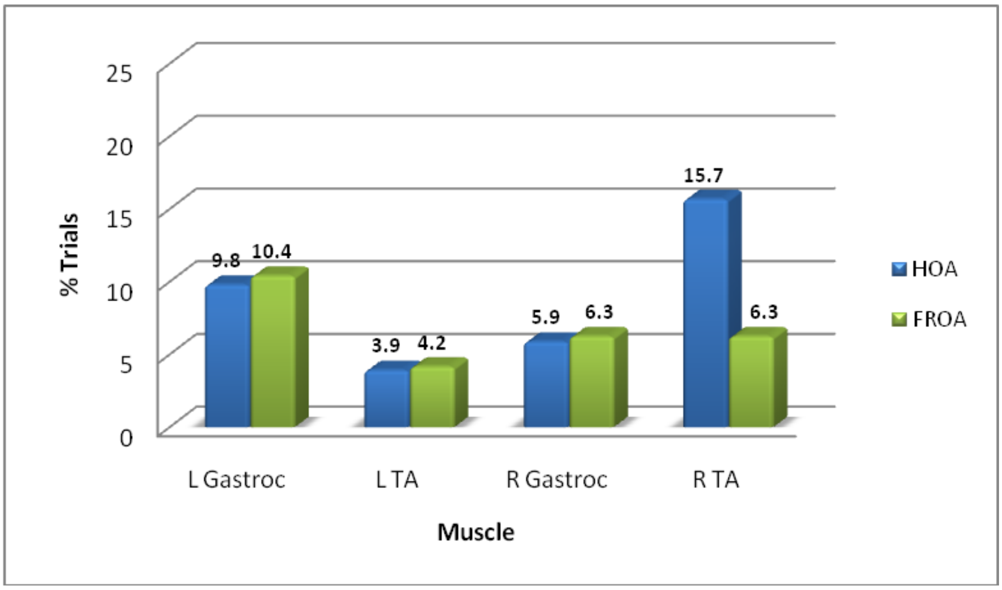

***Figure 4.3.* Anticipatory muscle activity as a percentage of trials during step turns to the left**
Note. HOA- healthy older adult; FROA- falls risk older adults; L Gastroc- left gastrocnemius; L TA- left tibialis anterior; R Gastroc- right gastrocnemius; R TA- right tibialis anterior

Anticipatory muscle activity during turns to the Right

The ipsilateral strategy occurred 86 (54%) of the 110 trials towards the right. The percentage of trials in which each muscle was active in an anticipatory manner is shown in Figure 4.4. Muscles activated in an anticipatory manner in only 25 (29%) of ipsilateral strategy trials when turning to the right. As anticipatory muscle activity occurred infrequently, further analysis was not explored.

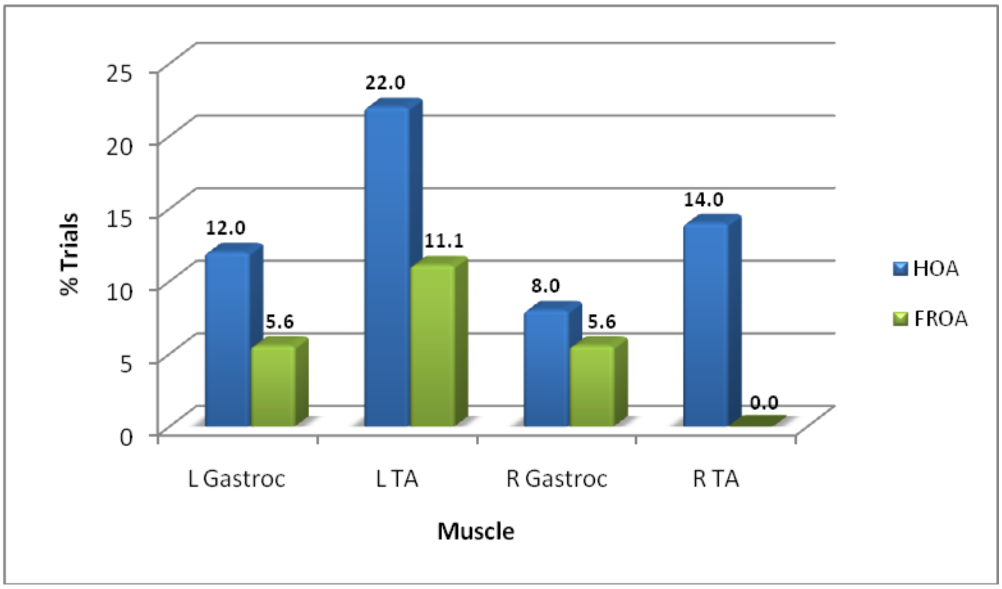

Figure 4.4. **Anticipatory muscle activity as a percentage of trials during step turns to the right**
Note. HOA- healthy older adult; FROA- falls risk older adults; L Gastroc- left gastrocnemius; L TA- left tibialis anterior; R Gastroc- right gastrocnemius; R TA- right tibialis anterior

The muscle with the most consistent observation in trials was the tibialis anterior (TA) in the stance leg of the HOA (16% when turning left; 22% when turning right). However, as no muscle was active in an anticipatory manner in at least 50% of trials, the pattern of anticipatory muscle activity could not be explored further.

5. DISCUSSION

5.1 Introduction

The purpose of this study was to investigate the effect of falls risk on body movement and muscle activity while preparing for and performing a visually guided step turning task. Of particular interest was the effect on step turning strategies; the onset order and latency of body movements; and muscle activity in the anticipatory period.

The discussion will examine each hypothesis in light of the findings of this research. Differences and similarities between the current study and previous research investigating step turning will be discussed. Limitations of the current study will be considered, and reference to clinical implications and suggestions for future research direction will be made.

Balance confidence

The Activity-specific Balance Confidence (ABC) Scale was administered to each participant. There was no significant difference in the mean score between the groups, suggesting that participants from both groups had a minimal fear of falling (Powell & Myers, 1995). Based on the ABC results alone, participants from either group would not be at risk of falling. Lajoie and Gallagher (Lajoie & Gallagher, 2004) determined a cut-off score of 66% and below to indicate those at risk of falls (sensitivity 84.4%; specificity 87.5%). It is worthy of note that the FRAT criteria used in the current study was modified in order to clearly differentiate the two groups (see section 3.5). Scores in the current study (HOA- 84 ± 12.9; FROA 85 ± 16.5) are comparable to the scores indicated by participants in the study by Chapman and Hollands (2007) who found that HOA indicated a mean score 94.89 ± 4.03; and FROA 92.30± 4.79.

Only one participant in the current study (participant S) indicated a score of 49 or less, which would have suggested a fear of falling (Myers, et al., 1996). Interestingly, three of the participants in the FROA group scored themselves at 99 and 100 indicating a high confidence of balance which was above the highest score by a participant in the HOA group of 98. The increased confidence in ability to maintain balance may inadvertently exaggerate the falls risk in these three FROA participants.

5.2 Hypothesis One

There will be differences in the turning strategies when comparing healthy and falls risk older adults

There were differences in the turning strategy used by healthy and falls risk older adults. Although the ipsilateral stepping strategy was predominant during the step turning task, a contralateral stepping strategy was also observed in both groups. FROAs were about three times as likely to use a contralateral strategy compared to HOAs. This was most likely to occur when turning right compared to when turning to the left in that group.

5.2.1 Turning Strategy and Extent of Turn

The ipsilateral strategy was more predominant than the contralateral strategy during the step turning trials and was irrespective of turning direction and group (left 71%; right 54%). These figures are higher than in earlier work by Meinhart-Shibata et al. (2005) who found that older adult group used an isilateral strategy in only 35% of the trials while performing a 180 degrees turning task. The difference may be due to the requirements of the task. The increased use of the contralateral strategy reported by Meinhart-Shibata et al. (2005) may provide an increase in base of support by counter leaving the swinging contralateral leg through a greater range of the 180 degrees turn. This is done while turning on the ipsilateral leg- thereby maintaining ground contact time prior to taking the step forward in the new direction. The use of the contralateral strategy during a greater extent of turn may also reduce the number of steps required, therefore providing more stability (Thigpen, et al., 2000). Although there was an increase in the number of steps taken by older adults, this was not investigated further in Meinhart-Shibata and colleagues' study.

5.2.2 Turning Strategy and Instruction of Speed

Compared to the self-selected pace that was used in Meinhart-Shibata's (2005) study, the increase in ipsilateral strategy may be a direct result of the instruction to "step and turn... ...as quickly as possible" in the current study. The predominance of the ipsilateral strategy may be advantageous in prioritising speed of completion of the task as a result of the reduced extent turn required when compared to findings by Meinhart-Shibata et al. (2005). This strategy may also be advantageous in reducing the amount of internal hip rotation on the ipsilateral leg as would be observed if the contralateral leg lifted first. In a population who are vulnerable to hip related injuries, this may be a habitual pattern that has developed through ageing, and has been incorporated into the anticipatory programme for this task. However, the finding that those at risk of falls are more variable in the use of step turning strategy may suggest that the use of the ipsilateral strategy is less engrained in the anticipatory programme for this at risk population.

5.2.3 Variability in turning strategy

Six participants were consistent in their order of foot movement, with the majority demonstrating some variability in turning strategy. The variability could be a result of a multitude of factors. As opposed to straight line walking, turning from a quiet standing position or while in motion is considered more complex as it requires rotation of the body towards the new direction while maintaining dynamic stability (A. E. Patla, et al., 1991). The multiple degrees of freedom available to complete the step turning task may give reason for the amount of variability of order of segmental movement when compared to gait initiation studies. Increased variability may be a consequence of ageing in that older adults have been described to be less consistent when completing repetitive task; and even more so when tasks require relatively low forces (Latash, 2008). Variability of movement is supported by Cinelli, et al. (2007, 2008) who found that older adults exhibit less consistency in trunk and pelvis movements when turning their head towards a new target while standing. As gaze reorientation requires that the visual, vestibular, and somatosensory systems work together to control balance (A. Patla & Rietdyk, 1993), it was suggested that the en-bloc movement of the trunk and shoulders was a consequence of somatosensory deficit in the older adult. A possible correlation between leg dominance and preferential strategy may also contribute to the observed variability between participants. One participant exhibited a foot preference whereby the left foot moved first towards both directions. This was also the only participant who identified themselves with a left foot preference. Therefore, the use of the contralateral strategy may not always be related to postural control when stability is challenged, but may be a result of preferential movement pattern. As there is no significant difference in the use of ipsilateral or contralateral strategies between the groups, the inclusion of both strategies is recommended in assessment and rehabilitation programmes.

5.3 Hypotheses Two and Three

Hypothesis Two: There will be no difference in the performance of a step turn between healthy and falls risk older adult participants as measured by the order of movement onset of centre of pressure, eye, head, trunk, pelvis and foot onset.

Hypothesis Three: There will be differences in the latency of centre of pressure, eye, head, trunk, pelvis and foot movements between healthy and falls risk older adult participants

In the current study, there were statistically significant differences between healthy and falls risk older adults in the order of movement onset of COP, eye, head, trunk, pelvis and foot when turning to the left. However, there were no differences in the onset of movement when turning to the right.

There were statistically significant differences between healthy and falls risk older adults in the latency of onset of COP, eye, head, trunk, pelvis and foot movement when turning to the left. However, statistically significant differences were not observed when step turning to the right.

5.3.1 Non-Parametric Compared To Parametric Statistics

Before proceeding with the findings of onset of movement in the current study, statistical methods used in previous studies requires some discussion in order to adequately compare and contrast results. The order of onset in the current study was determined using the Kendall’s coefficient of concordance statistic whereby calculations are based on the ranked order of each variable. *W* provides an indication of the extent of agreement between the rankings (Siegel & Castellan, 1988). While Meinhart-Shibata and colleagues (2005) justified their use of both parametric and non-parametric statistics based on the distribution of their data, other studies investigating steering (Hollands & Marple-Horvat, 2001; A. Patla & Rietdyk, 1993; A. E. Patla, et al., 1999), and step turning (Hollands, et al., 2004) have used mean onset latencies of movement to present the average order of onset within the group, rather than the agreement of order across all trials. Hines and Mercer (1997) suggest caution when interpreting mean onset latencies, as they do not always present the most frequent sequence of events. When the mean onset of each segmental movement is used to determine the average order, the result may not accurately represent the most common sequence demonstrated by the participants (Hines & Mercer, 1997).

5.3.2 Order of Onset and Turn Direction

There were no differences between the two groups in the order of onset of movement when turning to the right. Findings included both groups initiating movement with a shift in centre of pressure (COP), followed by eye, then head, trunk, pelvis and foot movement. This is consistent with previous visually guided studies (Cinelli, et al., 2008; Grasso, et al., 1996; Grasso, et al., 1998; Hollands, et al., 2002) as well as investigations of step turning in young adults (Anastasopoulos, et al., 2009; Hollands, et al., 2004). Hollands et al. (2004) indicated a strong temporal order of onset of movement, though the authors did not include COP in their investigation.

When turning to the left, however, there were not only differences between the two groups, but also differences when compared to previous studies as outlined above. Previous investigations have not discriminated between turn directions and therefore the assumption of order of onset is that which is described above for left turns. In the current study, while both groups initiated movement with the shift of COP when turning to the right, this was followed by head then eye movement (reversed in left turns), followed by trunk then pelvis movement in the HOA group, though pelvis then trunk movement in the FROA group. The power of the sample size may be considered influential in this result. However, the current study was deemed sufficiently powered (see section 3.2) based on the onset latency between the head and foot segments in a previous step turning study (Hollands, et al., 2004). Although the sample size is also comparable to those in other turning studies (Anastasopoulos, et al., 2009; Meinhart-Shibata, et al., 2005; Sklavos, et al., 2008; Solomon, et al., 2006), the influence of a larger sample size would be worth exploring further.

5.3.3 En-bloc Movement

The variance in movement order of eye and head; as well as trunk and pelvis in these two groups might suggest that to orient whole body movements, older adults exhibit an eye-head movement followed by a trunk-pelvis movement. This may be observed as an increased rigidity when step turning. Tucker at al. (2008) found that older adults exhibited smaller mean onset latencies between the COP, trunk and head movement when compared to younger adults during voluntary sway. The authors described this movement as ‘en-bloc’ or ‘coupled’ as the older adults exhibited a stronger clustering of body segments compared to the young adults, suggesting that segments moved as a single unit. This may provide a more rigid posture in order to reduce the degrees of freedom to be organised by the postural control system. While a rigid movement strategy can reduce the complexity of control during quiet stance (Horak, Nutt, & Nashner, 1992), this strategy may not be optimal during turning as the degrees of freedom available for voluntary movement and postural responses are reduced (Allum, Carpenter, Honegger, Adkin, & Bloem, 2002; Wu, 1998). As a result, a slowing of movement when initiating and performing a step turn task may be observed to provide more time to compensate.

5.3.4 Centre of Pressure Onset

Results of the current study suggest that onset of movement of the centre of pressure (COP) occurs prior to the onset of eye and head movement. This is somewhat different to findings by Fukushima, et al. (2008) who found no change in COP when performing horizontal head turning movements. Healthy young participants were required to orientate their head to visible vertical and horizontal targets without stepping or turning. While ground reaction forces and COP movement occurred before the onset of *vertical* head movement, there was no change in COP when the participants were asked to make *horizontal* head turns to targets positioned 60 degrees to the left and right of starting position. This may be due to the difference in the relation of the rotational axis of movement to the centre of mass (COM) position of the head during these two movements. During horizontal head turns, the rotational axis remains in line with the mastoid bone- close to the COM of the head, while during vertical head turns the rotational axis is near the spinal segment C1- at a distance from the head, thereby resulting in a COP movement (Fukushima, et al., 2008). In the current study, whole body movements were required, whereby an initial displacement of COP towards the swing leg was necessary to drive the centre of mass toward the stance limb thereby preserving lateral stability prior to eye and head movement (Y Breniere, et al., 1987; Jian, et al., 1993). It is likely that COP movement onset is task dependent, based on the direction of head movement (vertical as opposed to horizontal) and later stepping requirements of the task. This is important in rehabilitation of those considered at risk of falls. Locating an object directly horizontal to eye level would not change the COM of head position, and therefore COP during this visually guided movement. On the other hand, if an object was to be located above or below eye level, COP would be altered and may require more anticipatory postural activity to stabilise the movement. Rehabilitation of postural strategies should therefore challenge patients with both horizontal and vertical head movements with or without step turning.

5.3.5 Segmental Body Movements in Step Turning

The finding that the eyes, head, trunk and pelvis onset of moment preceded foot movement is consistent with previous studies investigating step turning (Anastasopoulos, et al., 2009; Hollands, et al., 2004; A. E. Patla, et al., 1993). While horizontal eye saccades provides a gaze-centred frame of reference during turning, movement of the head provides a head-centred frame of reference (Hollands, et al., 2001), thereby enabling the central nervous system (CNS) an enhanced control of whole body reorientation. When turning to the right, findings from the current study are consistent with previous in that the eye precedes the head, and then is followed by trunk and pelvis before foot onset of movement (Anastasopoulos, et al., 2009; Hollands & Marple-Horvat, 1996; Hollands, et al., 2001). However, order of onset was not consistent when turning to the left. Instead, onset of head movement preceded eye movement. Although there was a strong cluster of head and eye movement in the FROA group (indicating that these segments move similarly), there was only a moderate cluster represented in the HOA group when turning left, and in both groups when turning right. This leads to the suggestion that although the gaze-frame of reference is consistently seen before the head-frame of reference in the younger population, this is not prioritised (or pre-programmed) in the older adults. Instead a less temporally organised onset of movement is demonstrated. Ultimately, it seems to be important that the combination of eye and head movement (regardless of order) ensures that visual and vestibular signals are optimised and angular position of the head in space remains relatively constant prior to the onset of other whole body movements in the older adult. In other words, the head follows the eyes, while the body follows where the head leads.

5.3.6 Latency of Movement Between Groups

Comparisons between the median onset latencies of the current study to available mean onset latencies of previous step turning studies (Anastasopoulos, et al., 2009; Hollands, et al., 2004) are unable to be made. Along with differences in calculations of onset latencies, and age of sample populations, previous studies required participants to realign their whole body at a self-selected pace, hence, absolute mean values reported for those studies were longer than the median values in the current study.

5.4 Hypothesis Four

There will be a consistent pattern of anticipatory postural muscle activity when comparing healthy and falls risk older adult participants.

As anticipatory muscles were infrequently observed in the current study, a pattern of anticipatory muscle activity could not be established.

5.4.1 Timeframe of Anticipatory Muscle Inclusion

Although some tibialis anterior and gastrocnemius muscle activity was observed in the anticipatory period, this was found in 0% and 22% of step turning trials when turning to the left and right respectively. This is in comparison to over 50% of trials in gait initiation and forward stepping studies which also investigated tibialis anterior and gastrocnemius (Assaiante, et al., 2000; Mercer & Sahrmann, 1999; Mickelborough, et al., 2004). This difference may be explained by the differences in definition of the anticipatory period. The beginning of the anticipatory period has been defined as the onset of an auditory or visual cue to move (Mercer & Sahrmann, 1999; Mickelborough, et al., 2004), as well as at a defined period from the onset of focal movement, for example, 500 milliseconds before heel off from the ground (Assaiante, et al., 2000). The end of the anticipatory period has been referred as either the onset of focal muscle activity (Mercer & Sahrmann, 1999), or as the onset of heel or toe off (Assaiante, et al., 2000; Mickelborough, et al., 2004). Previous studies that have defined the anticipatory period on these bases would result in a longer anticipatory period than that used in the current study, which began at the onset of the visual cue, and ended at the onset of COP movement in either the F_x (anteroposterior) or F_y (mediolateral) direction (see Operational definitions section 1.3).

5.4.2 Activation of Stance Tibialis Anterior

The muscle with the most consistent observation in trials was the tibialis anterior (TA) in the stance leg of the HOA (16% when turning left; 22% when turning right). While the percentage of occurrence is low, some discussion is warranted as bilateral TA has been identified to activate in the anticipatory period in previous gait initiation studies (Assaiante, et al., 2000; Brunt, et al., 1991), with the stance leg TA activating first, followed almost simultaneously by the swing leg TA. In gait initiation in young adults, it is thought that the bilateral TA activity provides an external dorsiflexion moment at the ankle to move the body's COM forwards prior to the posterolateral movement of the COP and subsequent COM movement prior to stepping (Y. Breniere, et al., 1981; Brunt, et al., 1991; Crenna & Frigo, 1991; Elble, et al., 1994; Mickelborough, et al., 2004; Okada, Hirakawa, Takada, & Kinoshita, 2001; Tang & Woollacott, 1998). In other words, TA muscle activation occurs prior to the COP movement and focal movement during gait initiation. There is not a clear indication of this occurring in the step turning task, however, especially in the falls risk older adults. However this may be related to task differences in that a step turn task does not require a forward momentum of the COM, rather turning in place requires maintenance of the COM over the base of support.

5.4.3 Anticipatory Muscle Activity and Speed of Task

The required speed of the upcoming task needs to be considered when investigating anticipatory postural activity. Previous studies have advocated the inclusion of a 'fast pace' as it was deemed to improve the 'stereotypy' of electromyography signals (Crenna & Frigo, 1991; Elble, et al., 1994; Mercer & Sahrmann, 1999). Brunt and collegues (1991) reported that during different speeds of gait initiation (slow, normal and fast) the stance TA activated prior to the swing TA in the anticipatory period. Therefore, the limited frequency of observed anticipatory muscle activity is not a result of speed of the task in the current study.

5.4.4 Anticipatory Muscle Activity and Type of Task

As has been noted in the observed stepping strategies (see section 5.2.3), it is probable that the infrequency of anticipatory muscle activity is a result of the complexity of the task and degrees of freedom available. TA presented consistently in an anticipatory manner during gait initiation (Assaiante, et al., 2000; Mercer & Sahrmann, 1999), suggesting a synergistic coupling of muscles for this task. In step turning, it is usually unnecessary for the centre of mass to fall forwards of the foot, this may then result in a lack of anticipatory TA (and gastrocnemius) activation, as seen in the current study. It is proposed that reorientating the body to a new direction during step turns can be achieved by activation of different muscles, within a multitude of different patterns, no specific temporal order to anticipatory muscle activity can be found in these two muscles in isolation.

5.5 Clinical Implications

The majority of older adult participants demonstrated the combined use of both ipsilatral and contralateral strategies during step turn tasks. It may be valuable to include assessment and rehabilitation of both strategies for older adults at risk of falls. Currently there are a number of balance measures that include step turning as an assessment item; Berg balance score (Berg, et al., 1992), Timed up and Go (Shumway-Cook, Brauer, & Woollacott, 2000), and Dynamic Gait Index (Shumway-Cook & Woollacott, 2001). A more detailed assessment of step turning may provide pertinent information to better inform rehabilitation interventions. Interventions may include step turning using both of the described strategies, as well as incorporating more functional activities, such as during meal preparation. Promoting and facilitating the combination of head and eye movement prior to trunk and pelvis movement may provide a more advantageous strategy for the individual who has difficulty in visually guided tasks. Other populations that may be considered appropriate for focused step turning assessment and treatment include neurological conditions such as stroke (who may have developed a ‘preferred turning strategy’ as a result of hemiplegia), Parkinson’s disease (who may present with reduced initiation and increased latency of segmental movement and central rigidity), traumatic brain injury and cerebral palsy.

5.6 Limitations of the Current Study

5.7.1 Convenience Sampling

Recruitment of participants into the current study was made by convenience sampling. Such samples have been suggested to be susceptible to sampling bias as it may result in inclusion of the most cooperative or compliant participants. Although measures were taken to provide a clear separation of healthy and falls risk older adults by means of tightening the inclusion of those that were considered to be at risk of falls the individuals may represent a low-grade of falls risks. Ideally, subjects participating in a study of a measurement should consist of individuals who would be likely to undergo the FRAT screening test in clinical practice, and reflect a continuum of severity from mild to severe (McGinley, Baker, Wolfe, & Morris, 2009). A prospective cohort design with consecutive clinical patients may best to ensure a representative sample and avoid bias (Fritz & Wainner, 2001).

5.7.2 Successful Trials

While the majority of trials were included in the HOA data sets, the number of unusable trials in the FROA group was greater. This was especially evident when in the FROA data set when turning to the right, where only 36 trials out of a possible 55 (66%) could be included for analyses of hypotheses two to four. This was primarily a result of these participants use of a contralateral strategy when turning in that direction, therefore onset, latency and anticipatory muscle analysis could not be completed on these trials.

5.7.3 Further Investigation of Alternate Muscles

During gait initiation, anticipatory postural adjustments in the frontal plane shift the COP towards the swing foot, accelerating the COM towards the stance side (the last leg to leave the ground in gait initiation), allowing the swing foot to be lifted. Both the hip adductors and abductors have been suggested to contribute to this gait initiation movement (Lyon & Day, 1997; Mickelborough, et al., 2004) and could have been included in this study. This is in light of the abduction movement of the ipsilateral leg and possible adduction of the contralateral leg when step turning. As was alluded to previously (see section 5.5.3), inclusion of hip and knee muscles may present a difference in the observed anticipatory muscle activity. While focus on the tibialis anterior and gastrocnemius was justified, it was based on findings primarily from healthy young adults while completing gait initiation tasks.

5.7.4 Learned Effect of Anticipatory Postural Adjustments

Anticipatory postural adjustments are mostly acquired by learning as central organisation depends on the previous experience of the postural requirements associated with the intended task (Massion, 1992). There may be the possibility of a learned effect during what began as a novel experience in the specific step turning task, to a learned experience in the latter trials of the task. This was not analysed in the current study, as it was thought that observed postural adjustments would be drawn from the experiences gained in functional daily tasks requiring similar movement and responses i.e. step turning within a confined space.

5.7.5 Instruction of Speed

Findings of the current study are limited to comparison to those that also included instruction to step and turn ‘as quickly as possible’. As described early, the increased speed was to enable the identification of anticipatory muscle activity. It would also simulate reactive daily activities- for example, quickly step turning to a boiling pot while is seen in peripheral vision. However, it may be suggested that elderly, and indeed those that consider themselves to be at risk of falls, would adopt a more ‘normal’ gait speed in order to be more cautious with their movement and increase the latency to provide processing time.

6. CONCLUSION

Turning is essential for functional movement during many visually guided activities. Although the risk of falling is increased during turning compared to straight line walking, there has been limited investigation of the performance and control of visually guided turning. The purpose of this study was to investigate the effect of falls risk on segmental movement and muscle activity while preparing for, and performing a visually guided step turning task.

The current study suggests that both healthy older adults and those with a falls risk predominantly use an ipsilateral stepping strategy during step turns to locations at an arc of 60 degrees. However, the older adults with a falls risk were about three times as likely to use a contralateral stepping strategy as their healthy counterparts. Findings suggest that older adults may move more en-bloc or with increased rigidity compared to previous studies, hence eye and head, as well as trunk and pelvis moved in a similar way. This may invariably lead to a reduced postural stability during the step turning task. A step turning strategy may be dependent on the direction of turn, especially in the falls risk older adults. This might be related to the maintenance of stability by increasing the time the more dominant foot is grounded.

There was a strong order effect for both groups when turning to the right, in which the centre of pressure moved first, followed by the eye, head, trunk, pelvis and lastly the ipsilateral foot. In other words, there was no statistically significant difference in onset of movement when turning to the right. While there was a strong order effect for each group when turning to the left, there was a statistically significant difference between the two groups, in which the trunk preceded pelvis onset in the healthy older adults, with the reverse was seen in the falls risk older adult group. The onset of head preceded the onset of eye in both groups when turning to the left.

There may be some differences in planning of movement on the basis of There was no significant differences in the latency of movement when turning to the right. However, statistically significant differences between healthy and falls risk older adults were observed when turning to the left.

Tibialis anterior and gastrocnemius were identified as the most predominant anticipatory muscles to activate in gait initiation and steering studies and therefore were investigated. Findings of the current study indicate that there was no consistent activation of lower limb muscles in the anticipatory period- as evidenced by infrequent muscle activity. It is suggested that the absence of anticipatory muscle activity may be a result of two primary reasons. Firstly, gait initiation and steering requires the centre of mass to shift anteriorly, which may account for the TA (and gastrocnemius) activation in these studies. This requirement is not be necessary during step turning. Secondly, as a result of the complexity of the step turning task, a multitude of degrees of freedom may be incorporated to enable this movement; therefore a consistent pattern is not observed.

7. RECOMMENDATIONS FOR FUTURE RESEARCH

Step turning strategies, segmental movement onsets and latencies could be investigated by focusing on populations who have identified with falling during turning, as well as extending the scope to investigate other at risk populations. This may include a Parkinson's disease population who have pathological difficulties with planning and initiating movement; Stroke population who may present with compensatory strategies during the task as a result of primary and secondary impairments; and mild to moderate Cerebral Palsy participants who may also exhibit biomechanical difference when compared to previously studied populations.

As it appears that different turning strategies in the older adult are employed on the basis of step turn direction, a comparison to data from a younger population could determine if this finding is isolated to the older adult groups identified in the current study.

The task could also be extended by varying the extent of step turn direction. It would be of interest to investigate if by reducing the extent of turn (for example, to 30 degrees), that anticipatory muscle activity may be more representative of gait initiation and steering studies (inhibition of gastrocnemius and soleus and activation of tibialis anterior). It is also possible that by increasing the extent of turn may lead to an increased observation of the contralateral strategy.

As step turning is seldom completed in isolation during daily activities, task-specific movements could be investigated by the inclusion of horizontal and vertical reaching to the protocol to investigate adaptation of turning strategies and biomechanical prioritisation.

In recent years technological advancements in virtual reality has permitted the use of realistic virtual scenes to alter visual input (Berard, et al., 2008; Chou, et al., 2009; Reed-Jones, et al., 2009; Reed-Jones, et al., 2009). The use of a virtual moving scene environment that simulated walking towards and turning a corner resulted in participants demonstrating an anticipatory and sequential gaze and axial body segment reorientation, with timing characteristics similar to those seen during real turning (Reed- Jones, et al., 2009). Future studies incorporating step-turning from a quiet stance could add to current literature by adding virtual environments that better represent daily activities while incorporating necessary kinematic, kinetic and electromyographic data that are available in the laboratory setting. For example, a virtual scene of step turning to a representation of boiling pot in the peripheral vision of 60 degrees, or to attending to a microwave after an auditory and then visual cue. Providing ‘real-world’ application of these findings could be achieved by investigation of step turning ability pre and post intervention. This may include the use of virtual rehabilitation that simulates daily step turning activities in a virtual environment using commercially available consoles that could be set up in a clinic, or potentially home settings.

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9. APPENDICES

9.1 APPENDIX A: Ethics Approval

AUT UNIVERSITY
TE WĀNANGA ARONUI O TAMAKI MAKAU RAU

MEMORANDUM

Auckland University of Technology Ethics Committee (AUTEC)

To:	Denise Taylor
From:	**Madeline Banda** Executive Secretary, AUTEC
Date:	25 August 2008
Subject:	Ethics Application Number 08/154 **Eye and body movement strategies during turning tasks in older adults at risk of falls.**

Dear Denise

Thank you for providing written evidence as requested. I am pleased to advise that it satisfies the points raised by the Auckland University of Technology Ethics Committee (AUTEC) at their meeting on 14 July 2008 and that on 22 August 2008, I approved your ethics application. This delegated approval is made in accordance with section 5.3.2.3 of AUTEC's *Applying for Ethics Approval: Guidelines and Procedures* and is subject to endorsement at AUTEC's meeting on 8 September 2008.

Your ethics application is approved for a period of three years until 22 August 2011.

I advise that as part of the ethics approval process, you are required to submit the following to AUTEC:

- A brief annual progress report using form EA2, which is available online through *http://www.aut.ac.nz/about/ethics*. When necessary this form may also be used to request an extension of the approval at least one month prior to its expiry on 22 August 2011;
- A brief report on the status of the project using form EA3, which is available online through *http://www.aut.ac.nz/about/ethics*. This report is to be submitted either when the approval expires on 22 August 2011 or on completion of the project, whichever comes sooner;

It is a condition of approval that AUTEC is notified of any adverse events or if the research does not commence. AUTEC approval needs to be sought for any alteration to the research, including any alteration of or addition to any documents that are provided to participants. You are reminded that, as applicant, you are responsible for ensuring that research undertaken under this approval occurs within the parameters outlined in the approved application.

Please note that AUTEC grants ethical approval only. If you require management approval from an institution or organisation for your research, then you will need to make the arrangements necessary to obtain this.

When communicating with us about this application, we ask that you use the application number and study title to enable us to provide you with prompt service. Should you have any further enquiries regarding this matter, you are welcome to contact Charles Grinter, Ethics Coordinator, by email at charles.grinter@aut.ac.nz or by telephone on 921 9999 at extension 8860.

On behalf of the AUTEC and myself, I wish you success with your research and look forward to reading about it in your reports.

Yours sincerely

Madeline Banda

Executive Secretary

Auckland University of Technology Ethics Committee

Cc: Todd Stretton todd.stretton@aut.ac.nz, Mark Boocock

9.2 APPENDIX B: Advertisement

Volunteers Needed

Can You Help?

The Visually Guided Step and Turn Study

Volunteers **over 65 years of age** are needed for a study examining balance during turning activities. This supervised study is being undertaken at the Akoranga campus of AUT University and is part of a student's Masters Degree thesis.

The aim of the study is to investigate an important response of balance. Little is currently known about the role of vision when people step and turn. This information would be useful as many older adults fall during turning activities, sometimes resulting in injury and loss of confidence.

This study requires approximately two and a half hours of your time to be assessed once in the laboratory. If you:

- **Are over the age of 65**
- **Live in your own home or a retirement village**
- **Can stand and step around without a walking aid**
- **Do not have a known allergy to adhesive taping materials**
- **Do not have a neurological or musculoskeletal condition**
- **Do not have severe vision loss,**

then you may be suitable for this study. Travel vouchers will be provided to compensate for taxi or petrol costs incurred for travel to and from the laboratory at Akoranga.

If you are interested in volunteering with this study, or discussing this further, please contact Todd on the number below. Your help would be most appreciated.

Todd Stretton: Contact (09) **921 9999 extension 7639** (do leave a message if unattended)

Denise Taylor: Contact (09) 921 9680

9.3 APPENDIX C: Participant Information Sheet

Participant Information Sheet

Date Information Sheet Produced:

8th September 2008

Project Title

Eye and body movement strategies during turning tasks in older adults at risk of falls.

Researchers: Todd Stretton and Associate Professor Denise Taylor
Address: AUT University, Private Bag 92005, Auckland
Phone Number: (09) 921 9999 extension 7639

An Invitation

You are invited to take part in a research study that will explore an early part of your balance response as you turn and step. This supervised study is the work of a qualified physiotherapist as part of my Master degree. You may be eligible for this study if you meet the following entry criteria:

- Are over the age of 65
- Live in your own home or a retirement village
- Can stand and step around without a walking aid
- Do not have a known allergy to adhesive taping materials
- Do not have a neurological or musculoskeletal condition
- Do not have severe vision loss

Your participation in this study is voluntary, and you may withdraw at any time without any adverse consequences.

What is the purpose of this research?

The aim of this study is to examine an early part of a balance response called an anticipatory postural adjustment (APA). It has been established that when taking a step forwards, that APAs take place quickly- usually before you can see or feel movement. However, not much is known about APAs when people turn and step, even though this is a time when people are at risk of falling. This study aims to find out the sequence and timing of eye and body movements when a person turns and takes a step around at a quick though comfortable pace.

How do I join the study?

If you wish to join the study, please contact:

Todd Stretton (09) 921 9999 extension 7639 (do leave a message if unattended)

How are people chosen to be asked to be part of the study?

- If you meet the entry criteria of: Are over the age of 65 years old; you live in your own home or a retirement village; you can stand and step around without a walking aid; you have no neurological or physical injury or severe loss of vision; and no known allergy to taping materials; and can spare two and a half hours of your time, then we welcome your assistance.

What do I bring?

It is preferable if you do not apply any creams, lotions or ointments on the morning of your appointment in the laboratory. This is to ensure accurate recordings. If these are essential to be applied- discuss this with the researcher.
It is also preferable if you provide your own:

- Short-sleeved shirt or singlet
- Pair of shorts
- Dressing gown/ robe

However, a selection of short-sleeved shirts and singlets, as well as different sized shorts will be available at the laboratory should you not be able to supply your own.

What to Bring:

- Short-sleeved shirt or singlet
- Pair of shorts
- (Dressing gown/ robe)

A private changing area is available at the laboratory, and extra heating will be provided within the laboratory. Refreshments will also be available during your appointment.

What will happen in this research?

When you ring, the researchers will discuss any questions or concerns you may have about participating in the study. You will then be given a week to consider if you would like to take part. If you decide to participate, you will be asked to complete two screening questionnaires which can be done over the phone. A third questionnaire will be sent to you (with a self addressed envelope) along with an appointment time for you to attend the research laboratory.

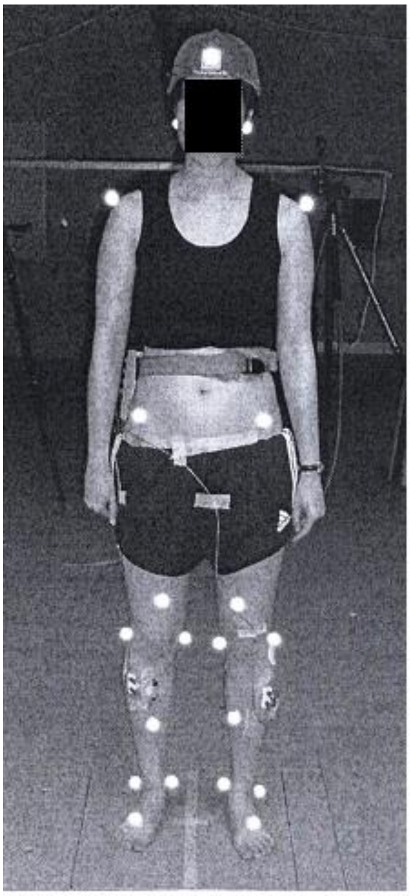
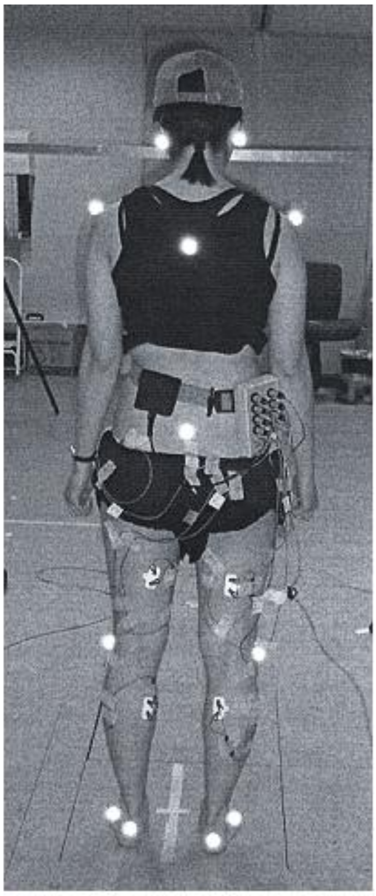
When you arrive for your appointment, the details on this sheet will be discussed with you to check that you understand the details and are happy to participate. You will be asked to sign a consent form and will be given one copy to keep. Next you will have your weight and height recorded which is required for computer calculations.

You will be asked to change into a pair of shorts and singlet so that reflective markers and small electrodes can be placed on different muscles on your head, shoulders and legs.

If you request, a female researcher will be available to prepare and monitor female participants during data collection. Please feel free to discuss this with Todd prior to your appointment.

The electrodes that detect muscle activity are about four centimetres in size and have self adhesive pads. A little extra tape may be needed to assist with adhesion. It will be necessary to shave off hair skin where the electrodes will stick as this will help with adhesion and make removal of the electrodes more comfortable. The patch of skin where the electrode will stick will be rubbed with wool and gel to improve the recording of muscle activity. There will be four electrodes put on each leg including on the hip and thigh. In order to measure your head movements, you will be asked to wear a hat with some reflective markers on it. There will also be some electrodes placed on your forehead to detect eye movement. All the information from the electrodes and hat will be sent to a belt that you wear around your waist and will be recorded by the computer.

Preparation of the markers, electrodes and leads may look like the following:

You will then be asked to stand on a force plate concealed under flooring. You will be asked to stand and face a central light. When you see another light turn on, you will step and turn towards it at a comfortable pace. You will be asked to do this for up to sixty trials with rests as needed.

What are the discomforts and risks?

There may be a small chance that you are allergic to the adhesive pads on the electrodes, or that you may receive a small cut whilst being shaved. There may be some sensitivity to the rubbing of the wool on the skin. If this occurs, you will have access to the necessary health and counselling services at AUT.
Also, there may be a slight chance of a fall, slip or trip.

How will these discomforts and risks be alleviated?

To minimise any risk of allergy, low allergy taping products will be used. To reduce the risk of a small cut while shaving, good lighting and care will be used to avoid this and there will be a first aid box in the laboratory.
In order to minimise the risk of falls, a second person or 'spotter' will be closely available to provide physical assistance. The laboratory will also be kept clear of all potential hazards.

You will be closely monitored during the trials to ensure that you are comfortable, and given opportunities to rest. You are also free to indicate when you need to rest or stop.

What are the benefits?

There are no direct benefits to you. However, your participation is helpful in furthering the knowledge in this area which may eventually improve the rehabilitation of balance for older adults. You will have the experience of participating in a modern research laboratory.

What compensation is available for injury or negligence?

In the unlikely event of a physical injury as a result of your participation in this study, rehabilitation and compensation for injury by accident may be available from the Accident Compensation Corporation, providing the incident details satisfy the requirements of the law and the Corporation's regulations.

How will my privacy be protected?

Your confidentiality will be maintained in the following ways. No material which could personally identify you will be used in any reports on the study. Your identity will remain confidential to the researchers. Data collection in this study will be kept secure in a locker filing cabinet and office. After six year, this data will be destroyed.

What are the costs of participating in this research?

There is no monetary cost to you. It will involve approximately two and a half hours, excluding travel time to and from the research laboratory at Akoranga Drive, Northcote. Travel vouchers will be provided to compensate for taxi or petrol costs incurred for travel to and from the lab.

What opportunity do I have to consider this invitation?

You will have a week to consider whether to take part after you phone the researcher.

How do I agree to participate in this research?

On the day of the assessment the key points of this Information Sheet will be discussed by the researcher to ensure that you have clearly understood the information. You will then need to complete a Consent Form before the assessments begin.

Will I receive feedback on the results of this research?

Yes. If you wish, a summary of the results will be sent to you when the study is completed. It is usual for there to be substantial delay between the time of your participation and the time of receiving these results. The results may be published in a journal and presented at a conference. The results may be used for publicity purposes.

What do I do if I have concerns about this research?

You are welcome to discuss this information with Todd who will attempt to answer any questions you may have.

Any concerns regarding the nature of this project should be notified in the first instance to the Project Supervisor, *Denise Taylor, denise.taylor@aut.ac.nz, 921 9680*.

Concerns regarding the conduct of the research should be notified to the Executive Secretary, AUTEC, Madeline Banda, *madeline.banda@aut.ac.nz*, 921 9999 ext 8044.

Whom do I contact for further information about this research?

Researcher's Contact Details:


Todd Stretton (Masters Degree Student). Phone (09) 921 9999 extension 7639. Email todd.stretton@aut.ac.nz

Project Supervisor's Contact Details:

Associate Professor Denise Taylor. Phone (09) 921 9680

Approved by the Auckland University of Technology Ethics Committee on *8th September 2008*, AUTEC
Reference number *08/154*

9.4 APPENDIX D: Consent Form

Consent Form Consent to participate in Laboratory Research	

Project title: ***Eye and body movement strategies during turning tasks in older adults at risk of falls***
Project Supervisor: ***Associate Professor Denise Taylor***
Researcher: ***Todd Stretton***

○ I have read and understood the information provided about this research project in the Information Sheet dated 8th September 2008.
○ I have had an opportunity to ask questions and to have them answered
○ I understand that I may withdraw myself or any information that I have provided for this project at any time prior to completion of data collection, without being disadvantaged in any way
○ I meet the age criteria of being over the age of 65 years old
○ I live in my own home or a retirement village
○ I am able to stand and step around without the use of a walking aid
○ I do not have any known allergy to adhesive taping materials
○ I do not have any neurological or physical injury that impairs my physical performance
○ I do not have severe vision loss
○ I agree to take part in this research
○ I wish to receive a copy of the report from the research (please tick one): Yes ○ No ○

Participant's signature: ....

Participant's name: ....

Participant's Contact Details (if appropriate):
....
....
Date:

Approved by the Auckland University of Technology Ethics Committee on 8th September 2008 AUTEC Reference number 08/ 154

Note: The Participant should retain a copy of this form.

9.5 APPENDIX E: Telephone Mini-Mental State Examination (T-MMSE)

Participant ID:	
Date:	/ /20

Telephone Version of Mini-Mental State Examination (t-MMSE)[i]

Orientation						
What is the year, season, date, day, month?	Y	S	Dt	Dy	M	/5
What country / city / area / street do you live in?	Co	Ci	A	S		/4
Registration						
Name 3 objects: *comb, pen, cup* Ask person to repeat						/3
Attention						
Spell '*World'* backwards D L R O W	D	L	R	O	W	/5
Recall						
Ask the person to recall the 3 items mentioned earlier						/3
Language						
Identify the object you are speaking into						/1
Repeat the following *;"No ifs, ands or buts"*						/1
"Say hello, tap the mouthpiece of the phone 3 times and then say, I'm back"						/3
Give a phone number where you can be reached						/1
	Score (0-26)					/26

T-MMSE Completed By:

Name:		Signature:		Date:	/ /20

[1] Newkirk, L. A. (2004). Validation of a 26-Point Telephone Version of the Mini-Mental State Examination. *Journal of Geriatric Psychiatry and Neurology* , *17* (2), 81- 87.

9.6 APPENDIX F: Falls Risk Assessment Tool (FRAT)

Participant ID:	
Date:	/ /20

Falls Risk Assessment Tool (FRAT)[i]

		YES	NO
1	Is there a history of any fall in the previous year? *How assessed? "Have you had any falls in the last year?" "By falling we mean a sudden unintentional change in position causing one to land on a lower level"*		
2	Is the person on four or more medications per day? *How assessed? "How many medications do you take each day?"*		
3	Does the person have a diagnosis of stroke or Parkinson's disease? *How assessed? "Have you ever been told by a doctor that you have had a stroke, or have Parkinson's disease?"*		
4	Does the person report any problems with their balance? *How assessed? "Have you had any problems with your balance?"*		
5	Is the person unable to rise from a chair of knee height without using arms? *How assessed? "Are you able to get up from a knee height chair, without using your arms?"*	unable	able
	SCORE (0-5)		

☐ **Healthy Older Adult (0- 2)** ☐ **Falls Risk Older Adult (3-5)**

Eligible for inclusion?	☐ **Yes**	☐ **No**	☐ **Don't know**

FRAT Completed By:

Name:		Signature:		Date:	/ /20

[1] Nandy, S., Parsons, S., Cryer, C., Underwood, M., Rashbrook, E., Carter, Y., et al. (2004). Development and preliminary examination of the predictive validity of the Falls Risk Assessment Tool (FRAT) for use in primary care. *Journal of Public Health, 26*(2), 138- 143.

9.7 APPENDIX G: Activity-specific Balance Confidence (ABC) Scale

Participant ID:	
Date:	/ /20

Activities-specific Balance Confidence (ABC) Scale[i]

Please answer the following questions by marking on the line beside each statement how confident you feel about performing each of the activities without losing your balance or becoming unsteady (that is, try to imagine your degree of confidence, if you were to perform these activities).

Please tick the box that best indicates your confidence level

"How confident are you that you will not lose your balance or become unsteady while…

0 = no confidence 100 = extreme

	0	**10**	**20**	**30**	**40**	**50**	**60**	**70**	**80**	**90**	**100**
1. Walking around the house											
2. Up and down stairs											
3. Picking up slipper from floor											
4. Reaching at eye level											
5. Reaching on tiptoes											
6. Standing on chair to reach											
7. Sweeping the floor											
8. Walking outside to nearby car											
9. Getting in/out of car											
10. Walking across parking lot											
11. Walking up and down ramp											
12. Walking in crowded mall											
13. Walking in a crowd /being bumped											
14. Getting on & off an escalator while holding rail											
15. Getting on & off an escalator, not holding rail											
16. Walking on icy sidewalk											

[i] Powell, L., & Myers, A. M. (1995). The Activities-specific Balance Confidence (ABC) Scale. *Journal of Gerontology*, *50A*(1), M28- 34.