Effects of Dual (Cognitive) Tasking on Free Walking in Patients with a Peripheral Vestibular Disorder

By

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2015

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Submitted in partial fulfilment of the requirements of the Degree of Doctor of Philosophy of University College London

I, Amal A. Al-Shaikh Sulaiman confirm that the work presented in this thesis is my own. Where information has been derived from other sources, I confirm that this has been indicated in the thesis.

Abstract

This thesis examines the effect of dual tasking on dynamic balance in patients with unilateral peripheral vestibular disorders, both in indoor laboratory and in outdoor urban environments.

A novel dual-tasking the functional gait assessment test (FGA) and an outdoor urban walking task around London Bridge using an accelerometer device were used to examine the effect of dual tasking on walking velocity and acceleration of various body segments. In addition, behavioural assessment using the dys-executive syndrome tests battery (BADs) was undertaken to assess participants' cognitive abilities and their impact on performance under the dual task condition.

The above measures were first applied to healthy participants assigned to young and old age groups (Chapter 3). Although both study groups had reduced FGA scores under the dual tasking condition, the older healthy group had significantly lower scores that may increase their risk of falls. The trunk medio-lateral (ML) acceleration was significantly reduced in older healthy adults, and the trunk attenuation rate (TAR) was reduced in dual tasking.

Case control trials were carried out to compare the performance of patients diagnosed with unilateral peripheral vestibular disorders (UVD) relative to healthy age matched controls, while carrying indoor assessment (Chapter 4) and outdoor assessment tasks (Chapter 5).

The addition of cognitive tasks adversely affected the FGA scores in both groups, though UVD group had a significantly higher risk of falls (in Chapter 4). Cognitive scores were significantly lower in the UVD group in three sub-tests of the BADs test battery.

Walking velocity was significantly reduced in the patients group under single and dual task conditions (Chapter 5). Cognitive tasking resulted in significant reduction in the anterior-posterior (AP) and vertical (V) acceleration of the UVD group. ML head acceleration was significantly higher than ML Trunk Acceleration in UVD with dual tasking.

In conclusion, our novel approach of implementing a dual tasking paradigm while walking in an outdoor environment showed that dual tasking interferes with postural stability. This will most likely put patients at risk of falls in multitasking situations commonly encountered in everyday life. This finding could be used to inform patient rehabilitation programmes currently in use.

Acknowledgments

A special appreciation goes to my supervisors. Dr Bamiou, thank you very much for your tremendous support and constant guidance and encouragement throughout my PhD. You were always available whenever I needed you. I found your tips and recommendation significantly valuable and insightful. Many thanks goes to Dr Pavlou for her valuable input and advice. I am delighted with the expertise and advice received; these were the corner stone enabling me to complete this thesis.

Many thanks to all the patients and volunteers who agreed to participate in the studies.

I would like to thank the late Prof. Roger Woledge for his help in writing Matlab programmes and for Ms. Deborah Ridout for her statistical support.

Many thanks to the audiologist at the neuro-otology department in NHNN. Albert, Lucie, Fan, and Nehzat; thank you very much for all your help and kindness. I will miss all of you so much!

At King's College London, I would like to thank Tony, Helen, and Lindsey for accommodating me and for always helping me find a room for testing.

I also want to extend my deep gratitude to my parents and my brother Ali for their continuous love and support.

Joman and Ali you are amazing kids! Sorry you had to miss lots of fun on the weekends! Thank you Joman for all your help and for being a brilliant big sister. God bless both of you.

Saving the best ‘til last…

I owe the biggest recognition to my husband for all his sacrifices and continuous love and support. I cannot thank you enough!

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Table of Abbreviation

AN	Acoustic Neuroma.
AP	Anteropsterior
BADs	Behavioural Assessment of Dysexecutive Syndrome
BPPV	Benign Paroxysmal Positional vertigo
BVD	Bilateral Vestibular Disorders
CG	Centre of Gravity
CPAT	Cerebellar Pontine Angle Tumour
FGA-S	Functional Gait Assessment as a single task
FGA-M	Functional Gait Assessment with motor task
FGA-L	Functional Gait Assessment with literacy Task
FGA-N	Functional Gait Assessment with Numeracy task
HA-I	Time from heel strike to forefoot strike
HA-II	Time from heel off to forefoot off
TA-off	Early swing phase
TA-on	Early stance phase
TUG	Timed Up & Go
L-AN	Large Acoustic Neuroma
ML	Mediolateral
OPCA	Olivopontocerebellar Atrophy
PVD	Peripheral Vestibular Disorders
RMS	Root Mean Square
RQA	Recurrent Quantification Analysis
S-AN	Small Acoustic Neuroma
SCD	Spino-Celebellar Degeneration
TAR	Trunk Attenuation Rate
UVH	Unilateral Vestibular Hypofunction
UVN	Unilateral Vestibular Neurotomy
V	Vertical
VN	Vestibular Neuritis

CHAPTER 1 Introduction

1.1 General Introduction

Walking and mobilization are essential human functions. They are processes that require the interaction and integration of many sensory inputs, including vision, proprioception, and vestibular inputs. The main goal of dynamic balance control is to maintain a safe forward progression of the body while minimizing the displacement of the center of gravity over the base of support. Vestibular dysfunction affects one third of the UK and US populations (Agrawal et al., 2009, Roydhouse, 1974). Moreover, it has been reported that the prevalence of vestibular dysfunction increases with age (Agrawal et al., 2009, Sheldon, 1955). Vestibular dysfunction is debilitating and can result in postural and gait problems and, consequently, falls and injuries (Agrawal et al., 2009, Cavanaugh et al., 2005, Herdman et al., 2000, Marchetti et al., 2008). The incidence of fall-related injuries requiring medical attention among patients with UVD is similar to that found in community-dwelling individuals (Herdman et al., 2000). Fall-related injuries have a great impact on patients' quality of life (Mira, 2008) and government spending on health care.

Vestibular patients are reported to have cognitive deficits (Hanes and McCollum, 2006, Smith and Zheng, 2013). The addition of a cognitive task when performing a balance task might affect the balance strategy used by the patients, and might affect their cognitive performance. This might, in turn, increase the risk of falls when carrying out day-to-day activities in this multitasking world. This PhD thesis investigated the effect of dual cognitive tasking on patients with unilateral peripheral vestibular disorders and in healthy

adults, and the impact it has on dynamic balance. Specifically, the thesis investigated the effect of dual tasking on functional gait assessment and on free walking in an outdoor environment in healthy young versus older adult group and in UVD patients versus age-matched controls. Cognitive assessment using the dys-executive syndrome test battery (BADs) was carried out for both groups and correlations with various dynamic tasks were investigated.

The aim of this introductory chapter is to provide a background for the experiments described in later chapters. This chapter comprises: 1) an overview of balance control; 2) a description of the role of cognition in gait and posture control; 3) a description of how gait is evaluated in vestibular patients including different systems and parameters used; and 4) a discussion of vestibular dysfunction and cognitive impairment.

1.2 Overview of Balance Control

The control of balance is a complex function mediated through the integration of inputs from three sensory systems: vision, proprioceptive, and vestibular. Disturbance in any one of these system will result in symptoms of imbalance and unsteadiness. In order to maintain continuous orientation and balance, these sensory inputs are re-weighted according to environmental and situational needs (Horak, 2006).

1.2.1 Vestibular System

The peripheral vestibular receptors consist of the maculae of the saccule and utricle and the cristae of the three semi-circular canals. This epithelium detects

linear acceleration and rotational acceleration, respectively. The hair cell epithelium is a mechano-electrical transducer that converts the movement of the endolymph into electrical signals. These signals are transmitted to the vestibular nuclei though the vestibular nerve fibres. These vestibular nuclei form the first relay station of the vestibular nerve from which several ascending and descending vestibular tracts emerge. The vestibular nuclei receive many efferent fibers from the cerebellum, reticular formation, spinal cords, cortex, and contralateral vestibular nuclei. The integration of all these inputs results in an appropriate response that is carried through the vestibulo-ocular pathway (Figure 1.1, cf. Purves et al., 2001), the vestibulo-spinal and vestibulo-colic pathways (Figure 1.2, cf. Purves et al., 2001). The vestibule-ocular reflex plays a key role in gaze stabilization while the head is moving. The vestibulo-colic reflex and the vestibulo-spinal reflex are essential to drive appropriate responses in the neck muscles (orienting the head relative to gravity), and to maintain balance and posture. This fascinating process provides ongoing information regarding head position and aids in the maintenance of orientation and equilibrium.

Impairment in the vestibular system may affect the integration of vestibular cues with other sensory cues, resulting in decreased stability. Patients with vestibular dysfunction may suffer from impaired vertical perception (Vibert et al., 1999) and distorted internal representations of verticality. Curthoys et al. (1991) reported that patients with unilateral vestibular disease may experience significant deviation in subjective visual vertical tests toward the lesion side following unilateral vestibular neurectomy. Hirasaki et al. (1999) suggested

that an impaired vestibulo-colic reflex might lead to poor head stability while walking. In addition, impaired VOR is known to lead to an inability to fix an image with a corresponding head movement. This leads to blurred vision and, consequently, instability and imbalance (Curthoys and Halmagyi, 1995).

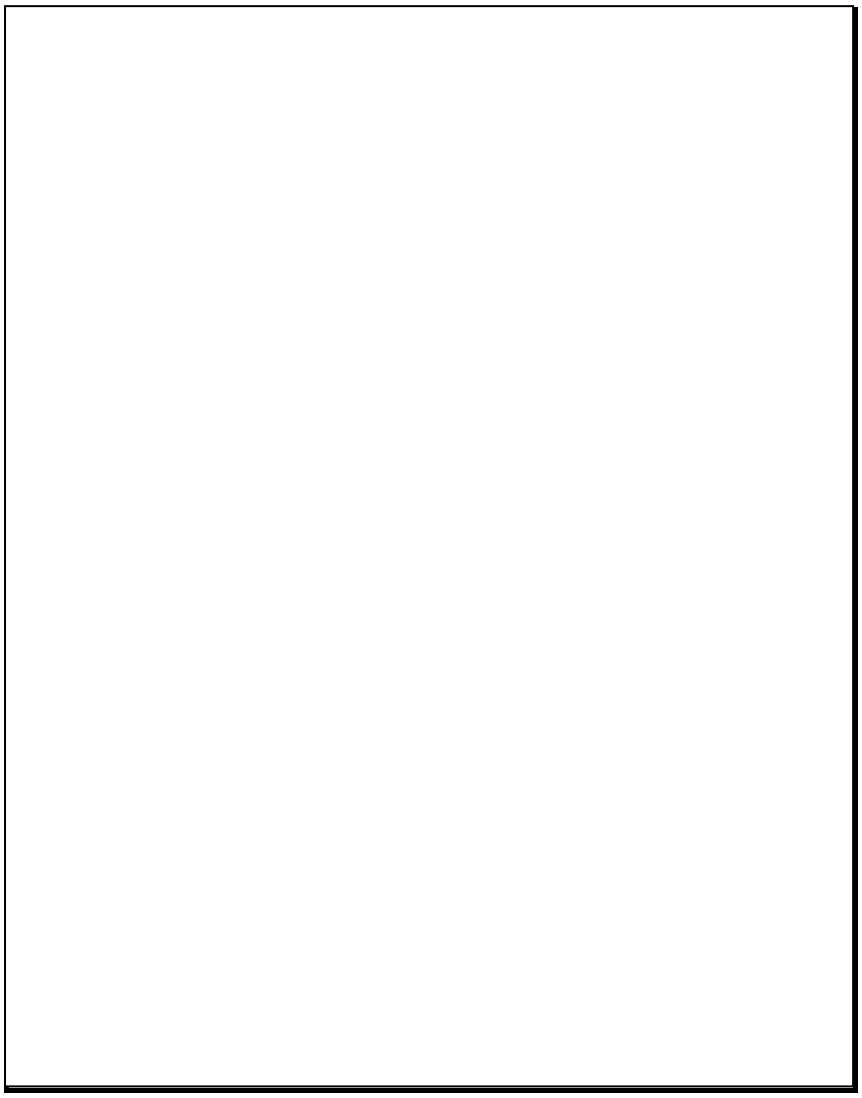

Figure 1.1. Connections underlying the vestibulo-ocular reflex (Purves et al., 2001).

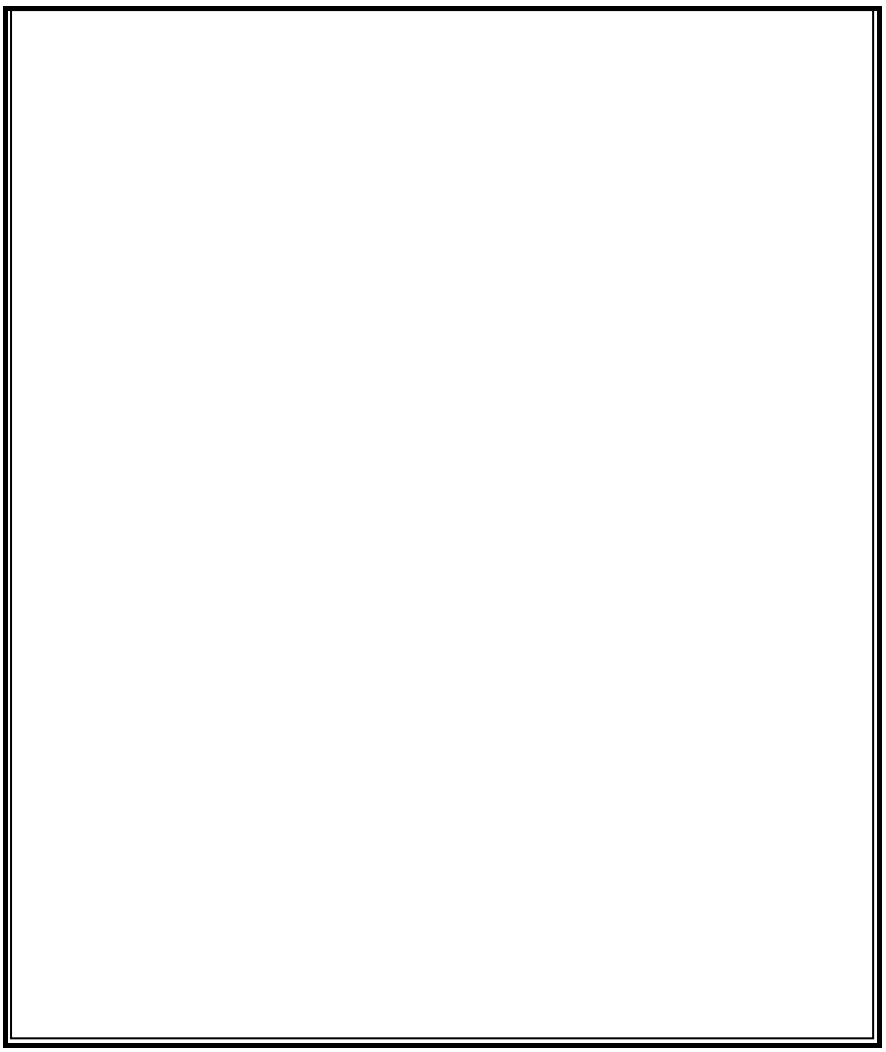

Figure 1.2. Descending projections from the medial and lateral vestibular nuclei to the spinal cord (Purves et al., 2001).

1.2.2 Vision

Visual input provides cues about the surrounding environment and our position within it. Visual input may be interpreted by the brain as self-motion, especially in context of another moving scene (such as a slowly moving train). In the presence of an intact vestibular and proprioceptive system, this visual input will be reweighted and interpreted as movement of the environment, rather than self-movement (Redfern et al., 2001). In the presence of vestibular dysfunction, the weighing of the inputs might be affected, resulting in patients becoming visually dependent. Affected patients experience an exaggerated reliance on vision for spatial orientation and are unable to flexibly re-weigh multiple sensory inputs. These patients may develop visual vertigo due to over reliance on visual cues. They may also complain of dizziness, imbalance, and disorientation in visually busy environments, i.e., as walking in supermarket aisles or train platforms (Bronstein, 1995, Guerraz et al., 2001).

1.2.3 Proprioception

Proprioceptive information from the joints, muscle spindles, and Golgi tendon organs in muscles provide information about one's position in space. In a well-lit environment and with a firm base of support, healthy persons rely on somatosensory (70%), visual (10%), and vestibular (20%) inputs to maintain postural stability (Horak, 2006, Peterka, 2002). Patients with vestibular or somatosensory impairment are limited in their ability to re-weigh sensory inputs and are more prone to fall (Horak, 2006).

In the acute stage of unilateral vestibular dysfunction, patients rely mainly on somatosensory cues (Han et al., 2011, Herdman, 1998). Vestibular patients will rely on the ankle strategy (i.e., swaying predominantly around the ankles with minimal motion around the hips and knees) rather than the hip strategy (i.e., out of phase movement of the trunk and hip) to control posture, even when the hip strategy is needed to maintain balance (Figure 1.3, cf. Kisner and Colby, 2007)**)**. This may result in abnormal coordination of postural strategies resulting in excessive hip sway (Horak et al., 1990) and consequent falling on unstable or slippery surfaces (Ford and Marsden, 1997, Han et al., 2011).

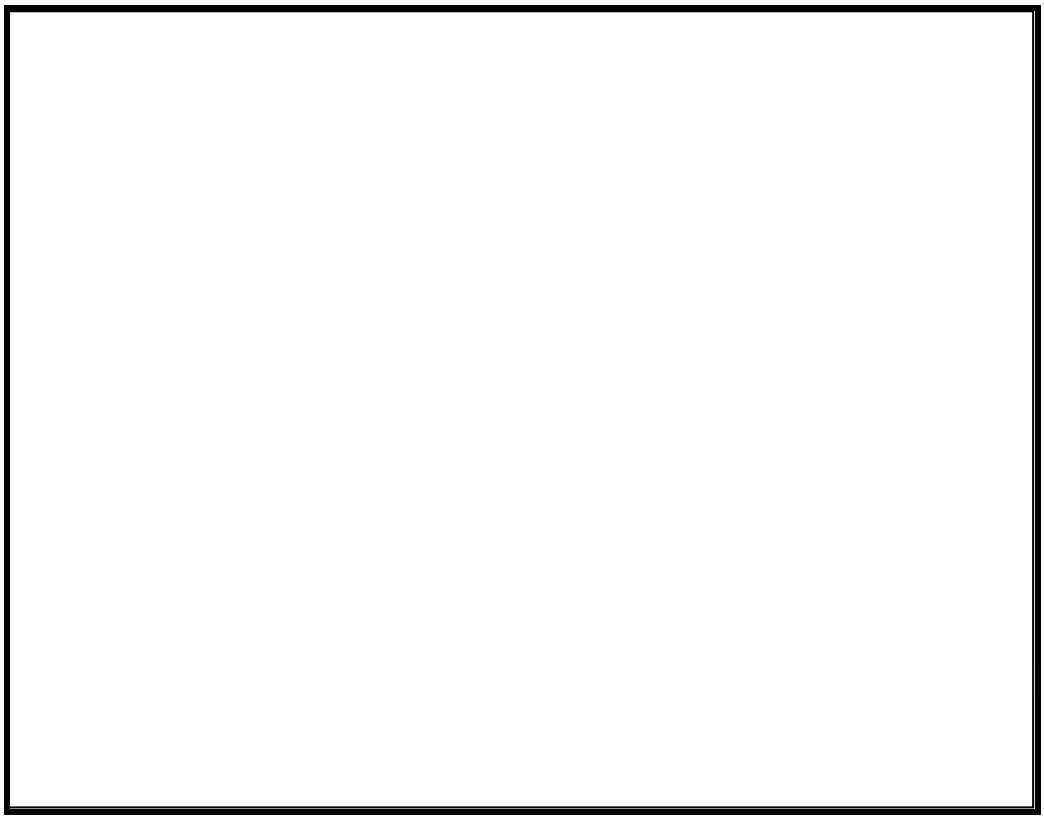

Figure 1.3. The movement strategies for recovery of balance: ankle, hip, and stepping strategies (Kisner and Colby, 2007).

1.3 The Role of Cognition in Gait and Posture Control

Walking is no longer considered to be an automatic activity that require minimal cognitive input. Attention and executive function are important in maintaining posture and dynamic balance. Executive function refers to various cognitive processes that use and modify information from many cortical sensory systems to modulate and produce behaviour (Adams R and O., 2003, Yogev-Seligmann et al., 2008). Execution function has been described as comprising (Lezak et al., 2012) four main aspects: volition, planning, response inhibition, and action monitoring. Impairment in one or more of these components may impair the ability to walk and navigate safely and efficiently. Table 1.1 describes these four components of executive function and the impact of their impairment on gait and safe navigation.

Executive function component	What is it?	Impact on gait and navigation
Volition	The capacity to initiate activity and behaviour	Impaired volition decreases the inner motivation to move
Planning	The ability to identify and organize elements to produce an action	Results in a deficit in decision making when walking in a complex environment (e.g., Losing the way or spending a great deal of time and effort trying to get to a place)
Response inhibition	The ability to ignore irrelevant sensory inputs over the primary reflex	Response inhibition is important to enable an appropriate amount of attention to be placed on gait when navigating a complex environment by ignoring other distractors in the setting
Response monitoring	The ability to compare ongoing actions with internal plans that facilitate decision making and flexible behavioural adjustment	Impaired response monitoring affects the individual's ability to flexibly adjust his/her gait, which might increase the chance of fall and injury (e.g., falling down when exposed to unanticipated obstacles on the floor while walking)
Attention	Ability to allocate attention appropriately to tasks performed simultaneously	Impaired attention will affect performance on either or both tasks performed simultaneously (e.g., stopping walking while taking or stopping talking while walking)

Table 1.1. Executive function components and the impact of their impairment on gait and navigation, adapted from Yogev et al., (2008).

The role of attention and executive function in maintaining balance was studied by implementing a dual task paradigm in which a motor and a cognitive task were administered and performed simultaneously by participants. A literature review revealed that the dual tasking paradigm has been used in many participant populations because it has implications for safety in certain populations at high risk for falls. This includes healthy older participants (Beauchet et al., 2005, Doi et al., 2011, Hollman et al., 2007, Lundin-Olsson et al., 1997, Maylor and Wing, 1996, Pellecchia, 2003, Siu and Woollacott, 2007, van Iersel et al., 2007), as well as patient groups, including stroke patients (Plummer-D'Amato et al., 2008) dementia sufferers (Allali et al., 2007), and Parkinson's sufferers (Morris et al., 2000, O'Shea et al., 2002, Rochester et al., 2004, Stegemöller et al., 2014). Table 1.2 summarizes the main findings of relevant studies.

Table 1.2. Dual tasking studies among different participant populations.

Author	Participants	Motor task	Cognitive task	Main findings
(Pellecchia, 2003)	Healthy young adults (n=20)	Standing	Digit reversal Digit classification Counting backward by 3s	Postural sway increases with the attentional demand of the cognitive task.
(Siu and Woollacott, 2007)	Healthy young adults (n=11)	Standing	Visual spatial task under 3 prioritization conditions	Verbal reaction time significantly increased when priority was given to the motor task. Postural performance was the same in all prioritization conditions.
(Maylor and Wing, 1996)	Two groups of volunteers (mean ages of 57 and 77)	Standing	(1) Random digit generation; (2) Brooks' spatial memory; (3) backward digit recall; (4) silently counting from 1-100; (5) counting backward in threes (aloud)	Postural stability was adversely affected by age in all conditions.
(Lundin-Olsson et al., 1997)	Frail older adults (n=58)	Walking	Talking	“Stops walking when talking" has a positive predictive value for falls in elderly people.
(Beauchet et al., 2005)	Frail older adults (n=16)	Walking	Arithmetic and verbal fluency tasks	Mean stride time increased significantly under dual tasking conditions compared with single condition. The coefficients of variation increased significantly only when participants walked and performed the arithmetic task, not the verbal fluency task.

(Hollman et al., 2007)	Healthy young(n=20) Healthy middle aged (n=20) Healthy elderly (n=20)	Walking	Spelling five letter words in reverse order	Older participants walked more slowly than middle and young adults, and the difference in gait velocity was greater under dual task conditions.
(Van Lersel et al., 2007)	Healthy elderly (n=59)	Walking	Numeracy task (subtracting 7 from 100 and 13 from 100) Literacy task (citing words starting with letters “K” and “O”)	Dual tasks resulted in decreased gait velocity, increased stride length and time variability.
(Doi et al., 2011)	Healthy elderly (n=34)	Walking	Subtracting 7 from 100, coloured stroop test	Dual tasking had an effect on trunk attenuation rates in the medio-lateral and vertical directions. The medio-lateral trunk attenuation rate was significantly reduced with the serial seven subtractions compared with the rate during the stroop test.
(Stegemöller et al., 2014)	Parkinson’s disease (n=35)	Walking	Counting backwards by 3s	Reduced stride length and speed, and increased double support time.
(Rochester et al., 2004)	Parkinson’s disease (n=20)	Simple walking; dual motor task; dual cognitive task; multiple task	Talking (replying to examiner questions)	Performance of a dual cognitive and multitask resulted in significantly slower gait speed and mean step length in Parkinson’s subjects.
(O'Shea et al., 2002)	Parkinson Disease (n=15)	Walking	Coin transfer Counting backwards by 3s	Reduced stride length and speed, and increased double support time when participants had to change from single task performance to dual task performance.

(Morris et al., 2000)	Parkinson Disease without hx of fall (n=15) Parkinson Disease with hx of fall (n=15) Control (n=15)	1.Free Standing 2. Standing with self-initiated movements (arm raise test, step test). 3. Standing with an unexpected external perturbation in upright stance	Backwards recitation of week days	The concurrent task produced a significant deterioration in performance for the arm raise test in all groups, the step test for the PD fallers and controls, and for tandem stance in the PD fallers. PD fallers had a more severe initial deficit than controls, deterioration placed them in that part of the balance continuum at high risk of losing equilibrium.
(Allali et al., 2007)	Demented older adults (n=16)	Walking	Forward and backwards counting	The coefficient of variation of stride time was significantly higher under both dual tsk conditions compared with during the simple walking task. The coefficient of variation of stride time was significantly higher under backwards counting compared with forwards counting.
(Plummer-D'Amato et al., 2008)	Post stroke (n=13)	Walking	Visuospatial task; working memory task	Dual tasking significantly affect gait speed, stride time, average stride length, and cadence.

Despite the differences in the type of study participants and the dual tasks employed, it is clear that gait is not automatic and requires attention, i.e. as reflected in dual task situations. The dual task related changes in gait parameters including decreases in walking velocity, decreased stride length, decreased cadence, increased stride time variability, increased double support time, and increased body sway. The observed difficulties in performing dual tasks led to the development of many neurophysiological theories attempting to understand the processes behind this interaction (Pashler, 1994). There are three main theories that explain cognitive dual task interactions (outlined below).

1.3.1 Capacity Sharing Theory

The capacity sharing theory assumes people share processing capacity among different tasks performed. It follows that attention will be divided between two tasks when both are performed simultaneously. Dual task interference will occur whenever the available resources are exceeded, resulting in a decline in the performance of either or both tasks (Tombu and Jolicoeur, 2003). Generally speaking, people can fairly carry out many different activities at the same time by flexibly allocating the required attention for each task. However, when one task becomes difficult, more emphasis is allocated to it. This may adversely affect performance on the other task.

1.3.2 The Bottleneck Theory (Task Switching Model)

The bottleneck theory assume that dual task interference depends on the type of task rather than the amount of attention required to carry it out. Hence, on this model, dual task interference will occur only if the two tasks use the same neural network in processing. For example, performing two motor tasks

simultaneously will cause interference, because both tasks compete for the same neural pathways (Ruthruff et al., 2001).

1.3.3 The Cross-talk Model

In contrast with the bottleneck theory, cross-talk models model assume that carrying out two similar tasks simultaneously will reduce dual task interference because both tasks will be processed using the same pathway. This will increase the efficiency of processing because less attentional resource capacity is being utilised.

Overall, there is no agreement on which theory best describe human information processing and dual tasking costs. Nonetheless, the capacity sharing theory is the most widely accepted theory.

1.4 Gait Assessment in Patients with Vestibular Disorders

Gait disorders associated with loss of sensory input may be less obvious than those resulting from musculoskeletal or cerebellar disorders with common features of gait widening, shortened stride, and careful turns (Nutt et al., 1993). However, their impact on patients' daily activities and quality of life is of paramount importance (Mira, 2008).

A review of the literature on gait assessment in vestibular patients reveals that in addition to clinical observation (Table 1.3), several methods have been used in the assessment of gait in vestibular patients. These include: (1) Wearable devices with a motion sensor system (Table 1.4); (2) Video image processing systems (Table 1.5); and (3) Floor sensor-based systems (Table 1.6).

In addition to being sensitive, reliable, accurate, and reproducible, any gait analysis system should be able to obtain and record data that cannot be observed by clinical examination (Katoh et al., 1983). Figure 1.4 outlines the technological and analytical methods currently used in gait analysis systems.

It appears that a trend in previous studies has been to conduct experiments in indoor environments that are well controlled and lacking in unpredictable changes that may be encountered in a real-world situation. Walking velocity and stride length are among the most commonly used parameters, and both are reduced in patients diagnosed with vestibular disorders when compared with healthy subjects. In addition, veering toward the affected side has been reported in many studies, especially under the eyes-closed condition.

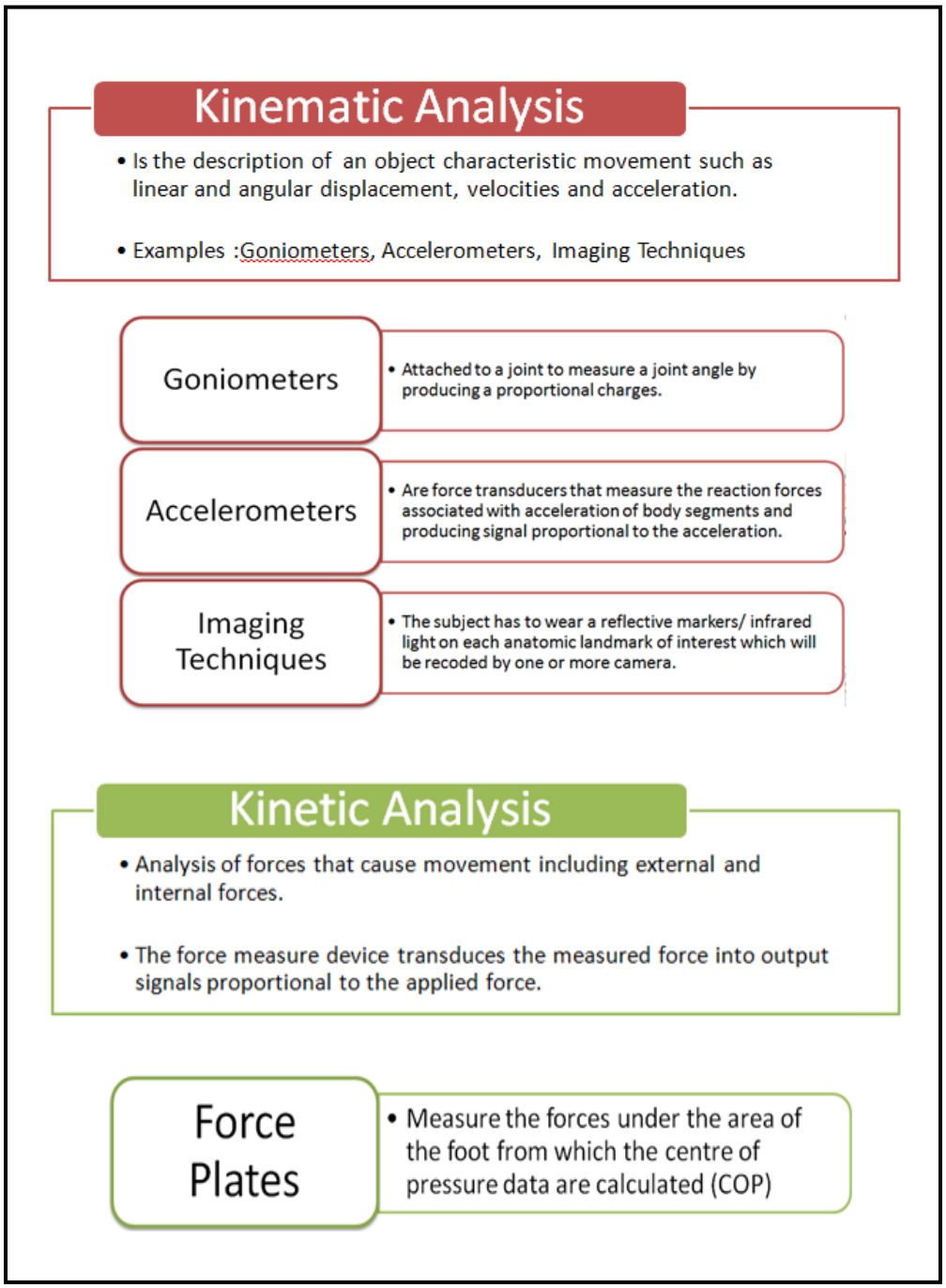

Figure 1.4. Kinematic and Kinetic Gait Analysis.

Author	Number of subjects	Test environment	Main findings
(Brandt et al., 1999)	4 PVD	Indoor 10 m straight walk way	- Gait deviation toward the affected ear was inversely related to walking velocity in a straight path.
(Cohen, 2000)	24 HC 55 PVD 31 AN	Indoor 7.62 m straight walk way	- Decreased walking velocity in PVD compared to AN and HC under eyes opened condition - Decreased walking velocity and increased veering angle in PVD compared to AN and HC under eyes closed condition
(Cohen and Kimball, 2002)	53 PVD 31 AN 24 HC	Indoor 7.62 m straight walk way	- Increased walking velocity and decreased veering under eyes closed testing condition.

Table 1.3. Studies assessing gait by clinical observation. (HC)Health Control; (PVD) Peripheral Vestibular Disorders, (AN) Acoustic Neuroma

Author	System used	Number of subjects	Test Environment and Parameters	Main findings
(Allum et al., 2001)	Digital angular velocity transducer	15 Acute UVL 26 Chronic CPAT 88 HC	- **Indoor, stance/gait tasks** - Trunk angular velocity in roll and pitch - Trunk displacement in roll and pitch	Trunk roll angle and pitch angular velocity has high sensitivity rate for HC and Acute UVL but fails to classify patients with CPAT.
(Wilhelmsen et al., 2010)	Triaxial accelerometers	21 Vestibular Neuritis 0 HC	- **Indoor, 8.5 m** - Acceleration along ML, AP, V (Upper and Lower Trunk) - Spatiotemporal gait parameters, cadence and step length	Vestibular rehabilitation results in significant attenuation of upper trunk acceleration in ML and AP Acceleration, reduction in cadence and increase in step length
(Labini et al., 2012)	Triaxial accelerometers	22 Peripheral UVH 39 HC	- **Indoor, 6 m** - Walking speed - Spatiotemporal gait parameters (stride, stance, and swing duration). - Acceleration along ML, AP,V - Angular velocities: Roll, pitch, yaw	There was no significant difference in temporal gait parameters between study groups. The recurrent quantification analysis showed that vestibular hypofunction subjects showed lower movement regularity and potential balance impairments as evidenced by lower values in all RQA parameters for most measures acquired

Table 1.4. Studies assessing gait through the use of wearable devices with motion sensor systems. (UVH) Unilateral Vestibular Hypofunction, (CPAT) Cerebellar Pontine Angle Tumour, (ML) Mediolateral, (AP) anteroposterior (V) Vertical, (RQA) Recurrent Quantification Analysis

Table 1.5. Studies assessing gait using 3D imaging systems.

Author	System used	Number of subjects	Test environment & dependent measure	Main findings
(Borel et al., 2004)	Video motion Analysis	9 Meniere's patients 10 HC	**- Indoor, 5.5 m** -Walking velocity - Step length - Step frequency - Locomotion trajectory deviation	Before UVN, patients had significantly reduced walking velocity compared with controls under normal and fast walking speed tasks with eye opened or closed conditions. However, there was no significant veering. After UVN, at 1 week, there were significant decreases in gait speed and deviation toward the operative side in the eyes closed condition. After 3 months, the deviation recovered for normal speed but not for fast walking in the eyes closed condition.
(Seidel and Krebs, 2002)	Optoelectronic system	32 cerebellar dis. 36 vestibular dis. (18) Bilateral (8) Unilateral Lt (10) Unilateral Rt. 34 HC	**- Indoor, 10 m** Base of support width	No significant differences in the width of support between all patients groups and healthy controls with preferred walking speed.
(Krebs et al., 2002)	SELSPOT II motion analysis system	22 vestibulopathy 22 HC	**- Indoor, 10 m** Base of support width	Gait width during preferred walking speed did not show any differences between study groups, however this was at the expense of slower gait in the vestibular group. Gait width during paced walking speed of 120 steps/min increased in the patient group.
(Tucker et al., 1998)	SELSPOT II	8 BVD 16 HC	**-Indoor, 10 m**	During paced gait of 120 steps/min, the used gait parameters did not differ

			The cycle time - Double and single stance phase durations - values and timing of CG forward velocity, - CG vertical displacement	significantly between study groups. However, at free walking there was a significant increase in cycle time and double stance time, and significant decreases in CG maximum and minimum horizontal velocity in the BVD. No difference was noted in this measure for the control group between free and paced gait conditions.
(Paquet et al., 2006)	3D video system	8 UVD	-**Indoor, 10 m** -Angular rotation and acceleration at head, upper trunk and pelvis	Angular acceleration at the head, trunk, and pelvis were not significant between head turns toward the intact or lesion sides.
(Mamoto et al., 2002)	3D video system	9 UVD 9 BVD 9 HC	**-Indoor, treadmill** -Stride length -Step frequency -Walking speed -Translational and angular movements at the head, trunk & hip	Stride length and walking velocity were significantly reduced in UVD and BVD compared with controls. Head translation in pitch and roll were significantly higher in patient groups.
(Lang et al., 2013)	3D video system	8 patients with UVD 10 HC	**- Indoor, 8 m** Gait cycle parameters (stride time, cadence, single support, step width) - Angular movement	There was a significant reduction in stride length and an increase in step frequency. Consequently, there was an increase in walking velocity in UVD compared with controls during normal and fast walking with eyes closed. UVD showed significant reduction in trunk

			of head, trunk, and hip in yaw, pitch, and roll planes	oscillation in the yaw axis and in hip sway in roll axis.

(HC) Healthy Control, (UVD) Unilateral Vestibular Disorders, (BVD), Bilateral Vestibular Disorders, (CG) Centre of Gravity, (UVN) Unilateral Vestibular Neuretomy

Table 1.6. Studies assessing gait using a floor sensor system.

Author	System used	Number of subjects	Test environment and parameters used	Main finding
(Ishikawa et al., 1993)	Foot switches & electromyography	21 Peripheral Vestibular 10 Central Vestibular 14 HC	- **Indoor, 7 m** - (HA-I) - (HA-II) - Durations of stance, swing and double support	HA-I had the highest occurrence rate of abnormality in both patients groups with poor specificity
(Ishikawa et al., 1995a)	Foot switches & electromyography	11 VN 10 L-AN 14 HC	- **Indoor, 7 m** - (HA-I) - (HA-II) - (TA-off) - (TA-on) - Durations of stance, swing and double support	The overall abnormality levels were higher in L-AN. HA-I was highly abnormal in both patients groups.
(Ishikawa et al., 1995b)	Foot switches & electromyography	11 VN 10 L-AN 10 OPCA 14 HC	- **Indoor, 7 m** - (HA-I) - (HA-II) - (TA-off) - (TA-on) - Durations of stance, swing and double support	HA-I had high sensitivity but no specificity. HA-I was highly abnormal in OPCA followed by L-AN compared with the VN group.
(Ishikawa et al., 2001)	A tactile sensor	4 VN **(average age 62)** 6 L-AN **(average age 58)** 6 SCD	- **Indoor, 8m** - Coefficient of variation of stance, swing, and double support durations - Foot pressure	All gait cycle parameters were high in all patient groups and became higher in the visual deprivation condition, reaching significant levels in L-AN. In VN and L-AN, foot pressure was greater toward the lesion side,

		(average age 42) 30 HC **(average age 30)**		difference - Trajectories of centre of force (TCOF)	especially with visual deprivation.
(Ishikawa et al., 2004)	A tactile sensor	25 S-AN 18 L-AN 18 HC	-	**Indoor, 8 m** - Coefficient of variations of stance, swing, and double support durations - Foot pressure difference - Trajectories of centre of force (TCOF)	The coefficient of variation of swing was high in both groups. Foot pressure difference was significant in L-AN.
(Perring and Summers, 2007)	Force sensitive resistors	20 vestibular patients 18 healthy controls	-	**Indoor, 256 steps** - SD of stride time - Mean stride time	The standard deviation of stride time during normal walking speed was significantly high in vestibular patients compared with controls
(Angunsri et al., 2011)	A tactile sensor	92 patients with various vestibular pathology - 17 VN - 31 S-AN - 27 L-AN - 17 SCD 26 healthy controls	-	**Indoor** - Coefficient of variation of stance, swing, and double support durations - Morphological analysis of foot pressure progression during stance - Integration of foot pressure	Gait instability was correlated with CV of stance and swing in all patient groups and became prominent with eyes closed. Integration of foot pressure was greater in the lesion side foot in VN followed by AN, especially in the absence of a visual clue.
(Yin et al., 2011)	A tactile sensor	22 S-AN 9 HC	-	**Indoor, 8m** - CV of stance, double	CV of stance, and swing in S-AN, did not differ significantly from the control

			support and swing - Foot pressure difference - The area ratio of TCOF	group under both eyes open and eyes closed conditions
(Wang et al., 2011)	A tactile sensor	11 S-AN 10 HC	- **Indoor, 8m** - CV of stance, double support and swing - Foot pressure difference - The area ratio of TCOF	CV of swing and the area ratio of TCOF were significantly higher in S-AN compared with controls with visual deprivation
(Schniepp et al., 2012)	Pressure sensitive carpet	40 Cerebellar ataxia 22 BVL 51 Healthy control	- **Indoor, 6.7 m** - CV of stride time	CV of stride time was high in the BVL group during slow walking; however, it was normal during medium and fast walking speeds.

(VN) Vestibular Neuritis, (L-AN) Large Acoustic Neuroma, (S-AN) Small Acoustic Neuroma, SCD (Spinocerebellar Degeneration), (OPCA) Olivopontocerebellar Atrophy, (HC) Health Control, (HA-I) time from heel strike to forefoot strike, (HA-II) time from heel off to forefoot off, (TA-off) location of the first and second peak of muscle contractions of tibialis anterior from early swing phase to early stance phase (TA-on)

1.5 Vestibular Dysfunction and Cognitive Impairment

Animal studies suggest that vestibular dysfunction is linked with cognitive impairment (Russell et al., 2003, Stackman et al., 2002, Wallace et al., 2002). Russell et al. (2003) demonstrate that rats with bilateral labyrinthectomy perform significantly worse than controls when tested in a reference memory radial maze. The authors explain that these results are not simply due to the inability to move, but may relate to the way the brain uses vestibular information to create spatial representations and determine behavioural strategies. Stackman et al. (2002) support this view with their demonstration that temporary inactivation of the vestibular system leads to a decrease in the discharge of hippocampal place cells and direction-specific postsubicular cells, without altering animal motor function. In humans, many neuroimaging studies establish the strong connection between the vestibular and cognitive systems. Brandt et al. (2005) demonstrate that patients with acquired bilateral vestibular loss develop a significant selective atrophy of the hippocampus as shown in MRI volumetry. In addition, when those patients are tested using a virtual variant of the Morris water task, they exhibit significant spatial memory and navigation deficits. However, such changes were not evident in patients with unilateral vestibular loss (Hufner et al., 2007, Hufner et al., 2009). Nonetheless, Zu Eulenburg et al. (2010) report that patients with unilateral vestibular dysfunction have a relative atrophy, observable in the left posterior hippocampus and the right superior gyrus.

Casting animal and imaging studies to one side, some authors have tried to explore the effects of vestibular dysfunction on cognition using behavioural tests.

Grimm et al. (1989) conducted one of the first studies of cognitive function in individuals with vestibular dysfunction. From a total sample of 102 patients diagnosed with perilymph fistula syndrome, more than 95% suffered from long-term disorientation in any situation involving conflict between visual and vestibular information. Moreover, more than 85% of the patients reported memory loss of some sort. In a sub-group of participants, quantitative assessment was performed using digit symbol, block design, and picture arrangement. All were in the impaired range, despite normal levels of intellectual function. In another sub-group of these patients, scores on auditory recall and learning and paired associate learning were all below the normal range, despite normal Digit Span and Visual Reproduction test scores. In addition, many of these patients suffered from affective symptoms, such as anxiety and depression.

In a study by Guidetti et al., (2008), subjects suffering from labyrinthine hypofunction, even if well compensated, exhibit impaired visuo-spatial short-term memory, as demonstrated by the Corsi block test results. In addition, patients with vestibular disorders frequently experienced symptoms of depersonalisation and derealisation (Jauregui-Renaud et al., 2008a, Jauregui-Renaud et al., 2008b, Sang et al., 2006, Smith and Zheng, 2013). This may occur because distorted vestibular signals mismatch with other sensory inputs and create incoherent frames of spatial reference. These make the patient feel that he or she is detached or separated from the world, adversely affecting their attention level. Black et al. (2004) found that two-thirds of patients with gentamicin toxicity experienced disruption of cognitive function, especially

recent memory. Risey and Briner (1990) reported that vestibular patients have dyscalculia.

Moreover, Gizzi et al., (2003) used the Neurobehavioral Symptom Inventory to measure a range of neurological and psychological symptoms in 200 patients with balance disorders. The results showed that cognitive complaints were more common in dizzy patients with a history of brain trauma. There was no significant correlation between the diagnosis of vestibular dysfunction and the frequency of cognitive complaints.

In a study by Schautzer et al., (2003), a computerized versions of the Morris water maze task was used to assess spatial memory in 10 patients with bilateral vestibular loss as a result of NF2. Only 50% of patients could directly navigate to the hidden platform on the screen, compared with 100% of controls. This may reflect deficits in memorising spatial locations for patients with bilateral vestibular dysfunction. In addition, patients diagnosed with unilateral vestibular disorders are reported to have decreased concentration, auditory short term and spatial memory deficits (Hanes and McCollum, 2006). Based on these finding, it has been strongly suggested that vestibular dysfunction may interfere with balance tasks, especially under dual or multitasking situations. Previous studies examining the effect of cognitive tasks on balance performance in patients with vestibular disorders compared with healthy subjects have mainly assessed posture (Redfern et al., 2004, Yardley et al., 2001), while studies assessing dynamic balance-cognition interactions in vestibular-impaired subjects are very limited. These studies (Table 1.7) suggest that the presence of an underlying vestibular pathology increases the attentional demand required

to control postural and dynamic balance. Moreover, the addition of a cognitive task when performing a balance task results in greater reliance on available cognitive resources, and the need to divide attention between two tasks. The reliance on available executive functions resources become more significant as the complexity of either the motor or the cognitive task increases (Ble et al., 2005). This may reveal minor gait dysfunction even in healthy subjects.

Table 1.7. Studies assessing gait while conducting a cognitive task.

Author	System used	Number of subjects	Cognitive Task used	Testing Environment and dependent measure	Main findings
(Nascimbeni et al., 2010)	STEP 31 gait analysis system (Wearing sole sensors)	14 VN (had rehabilitation) 17 HC	Backwards counting by 3 starting from 300	**Indoor, 12 m** Spatio-temporal gait parameters FC, DS, swing, ST	Both controls and patients showed conservative gait during the dual task but patients performed significantly worse in the cognitive task.
(Roberts et al., 2011)	Observational method	15 VVD 15 BPPV 15 HC	4 walking task: 1) Walking 2) Walking & naming 3) Walking & nodding 4) Walking, naming & nodding.	**Indoor, 7.6 m** 1) The veering onset 2) The velocity 3) The angle of veering	Walking velocity was significantly reduced and veering increased in patient groups compared with control with the addition of a cognitive task. The patients groups did not differ significantly from each other.
(Bessot et al., 2012)	Observational method	12 BVD 12 HC	Backwards counting by 2 starting from two digit odd numbers	**Indoor, 10 m** Walking velocity	Gait velocity was significantly reduced in the patient group during dual task conditions. Dual task scores were significantly lower in patients with BVD compared with controls.

(VN) Vestibular Neuritis, (VVD) Various Vestibular Disorders, (HC) Healthy control, (BPPV) Benign Paroxysmal Positional vertigo,

(BVD) Bilateral Vestibular Disorder

1.6 Limitations of Previous Studies

Despite using many gait analysis techniques to evaluate gait in patients with vestibular disorders, all previous investigations have been carried out in controlled indoor laboratories. The walking distance used to infer results has been limited and short, with a maximum of 12 meters in length (as shown in the literature review).

Walking velocity and stride length were among the most commonly used parameters and both were reduced in patients with vestibular disorders compared with healthy subjects. In addition, veering toward the affected side was reported in many studies, especially under the eyes closed condition. However, all previous studies were conducted in indoor controlled laboratories which fail to expose the patients diagnosed with vestibular disorders to the challenges they may encounter in everyday life. Patients with vestibular dysfunction report most of their symptoms in outdoor urban environments where they are exposed to unpredictable changes.

Being visually sensitive, patients with vestibular dysfunction may experience symptom exacerbation in crowded places or areas with repetitive visual patterns, such as supermarkets. Moreover, patients need to turn their head repeatedly to be more vigilant and overcome challenges they might encounter while walking, such as slippery, uneven surfaces, or night-time difficulties such as having fewer visual cues present, or even just responding to auditory stimuli. It is important to assess the balance strategies of these patients in real environments as this is where patients report most of their symptoms.

In addition, the cognitive studies conducted in vestibular patients confirm the presence of a connection between vestibular dysfunction and cognitive impairment. However, the prevalence and type of cognitive impairment associated with different vestibular diagnosis has not been established. Moreover, the effect of dual tasking (which is linked with cognitive skills) on vestibular patient dynamic balance has not been studied extensively.

Dual tasking ability is of paramount importance to negotiate day-to-day activities safely without further increasing the risk of fall. The outdoor environment is more challenging and requires a fair level of dual tasking ability. This fact increases attentional demand and the need to flexibly shift concentration between more than one tasks while carrying on with daily life functions such as walking safely without compromising dynamic balance.

1.7 Aims of the Thesis

This thesis intends to examine the following:

a. The effect of dual tasking on dynamic balance in an indoor-controlled laboratory using a novel dual-tasking FGA test.
b. The effect of dual tasking on the walking velocity and acceleration at various body segments while walking in an outdoor urban route around the London Bridge area.
c. Participants' cognitive ability and its impact on their performance under dual task conditions.

The above will be investigated in healthy participants assigned to young and old age groups (Chapter 3), and in patients with unilateral peripheral vestibular

disorders relative to age-matched healthy controls (Chapters 4 and 5). The findings will aid in understanding dual tasking interference with dynamic balance and the impact it has on fall risk and patient safety. This information may be useful in informing patient rehabilitation programmes that are currently in use.

1.8 Hypotheses

We hypothesised that older healthy adults and patients diagnosed with vestibular disorders would have greater difficulty in maintaining dynamic balance while performing cognitive tasks, and that the level of difficulty would increase with urban walking due to the challenging nature of outdoor environment (i.e., placing great demand on available attentional resources). In addition, we hypothesised that aging processing and vestibular dysfunction would adversely affect executive functions, which might then exceed participants' processing capacity, impairing their ability to flexibly shift attention between more than one task, or to at least to be able to direct their attention to the most important task (in this case maintaining balance and avoiding falls).

CHAPTER 2 Materials and Methods

All methods and materials used in the following three chapters are detailed in this section.

After the participant signed the consent form, and had any questions answered, he/she was asked to fill in the questionnaires. This was followed by cognitive assessment using the dys-executive syndrome test battery (BADs). Following this, indoor gait assessment took place, including the timed up and go test (TUG) and the functional gait assessment (FGA). Finally, the testing session was completed with the outdoor walking task.

2.1 Questionnaires

2.1.1 The Dizziness Handicap Inventory (DHI)

The DHI is a 25-item questionnaire (Jacobson and Newman, 1990) that evaluates the self-perceived handicap imposed by dizziness in vestibular patients. Each item was scored as following: 0 (never), 2 (sometimes) and 4 (always). The maximum total score was 100 and the minimum was 0. The items were sub-grouped into three domains representing functional, emotional, and physical aspects of dizziness and unsteadiness. The following maximum scores were obtained for each domain: 28 for physical, 36 for emotional, and 36 for functional. The DHI scale score increased with an increase in the frequency of dizziness episodes, with cut-off scores of 0-30 for mild, 31-60 for moderate, and 61-100 for severe (Whitney et al., 2004b).

2.1.2 The Situational Vertigo Questionnaire (SVQ) (Guerraz et al., 2001)

The SVQ (Guerraz et al., 2001) is a 19-item questionnaire that measures the frequency of symptom provocation or exacerbation in environments with visual-vestibular conflict or intense visual motion (i.e., walking down supermarket aisles). Scores ≥ 0.7/4 indicate symptoms of space and motion discomfort (Pavlou et al., 2006).

2.1.3 The Activities of Balance Confidence Scale (ABC) (Powell and Myers, 1995)

The ABC (Powell & Myers, 1995) is a 16-item scale comprising activities at various levels of difficulty. Respondents are asked to rate themselves for each item from 0% (no confidence) to 100% (complete confidence) in performing the activities indicated, without losing balance or becoming unsteady. The total score is the average score of all items with lower scores indicating less confidence and more handicaps. Scores < 67% indicate a risk for falls (Lajoie & Gallagher, 2003).

2.1.4 The Vertigo Symptom Scale (VSS) (Yardley et al., 1992)

The VSS (Yardley et al., 1992) addresses the frequency of patients' symptoms in the last month. It has two subscales: a vestibular scale (e.g., feelings of spinning or moving, unsteadiness), and an autonomic scale (e.g., hot or cold spells, feeling faint). Each item is rated between 0 and 4, with higher scores indicating greater impairment.

2.1.5 The Vestibular Disorders Activities of Daily Living Scale (VD-ADL)

The VD-ADL (Cohen & Kimball, 2000) is a 28-item scale that evaluates the effect of vertigo or balance disorders on daily living activities. Each item is rated from 1 (independent) to 10 (can no longer perform). The activities are divided into three sub-scales (functional, ambulation, and instrumental). Higher scores indicate more severe disability.

2.1.6 The Hospital Anxiety and Depression Scale (HAD)

The HAD (Zigmond & Snaith, 1983) is a 14-item scale that screens for depression and anxiety symptoms independently. Each item is scored from 0 to 3. The total score for each sub-scale ranges from 0 to 21. For each sub-scale (i.e., anxiety or depression), the scores are categorized as follows: normal (0-7), mild (8-10), moderate (11-14) and severe (15-21).

2.2 Indoor Gait Assessment

2.2.1 Timed Up and Go Test (TUG)

The TUG is test developed to quantify functional mobility in frail elderly persons (Podsiadlo & Richardson, 1991). Participants are asked to sit comfortably with their back against a chair. On the word “go” they must stand up and walk for 3 metres at their normal pace, and then turn around and walk back to the chair. The patient is timed from the word “go” and until he/she is re-seated. The cut-off score that indicates an increase in the risk of falls in community-dwelling older adults is 13.5 seconds (Shumway-Cook et al., 2000). Whitney et al. (2004a)

suggest that a TUG score of 11.1 be used as a cut off point for patients with vestibular disorders.

2.2.2 Functional Gait Assessment (FGA)

The FGA (Wrisley et al., 2004) is a gait assessment with 10 gait-related tasks that need to be completed along a marked runway 30.48 cm (12 inch) wide and 6 m (20 ft.) long (Appendix 8.9). It includes 7 (of 8) items from the original Dynamic Gait Index (DGI) (Shumway-Cook and Woollacott, 1995). The other 3 items include; gait with narrow base of support; ambulating with eyes closed; and ambulating backwards. These 3 items were added because they have been described as difficult to perform by people with vestibular disorders, and because they help to overcome the ceiling effect encountered in the DGI. Each task is scored from 0 to 3, as follows: 0 (severe impairment), 1 (moderate impairment), 2 (mild impairment), 3 (normal ambulation). The total score is calculated by adding the individual scores. The maximum score is 30 and a score ≤ 22 has been found to be effective in predicting falls in community-dwelling older adults (Wrisley and Kumar, 2010). The FGA demonstrates an overall decrease in total score with increasing age. Normative data in healthy UK adults has been reported, see Table 2.1 (Walker et al., 2007).

Age	Min score	Max score	Mean	SD	95% CI
40-49	24	30	28.9	1.5	28.3-29.5
50-59	25	30	28.4	1.6	27.9-29.0
60-69	20	30	27.1	2.3	26.5-27.7
70-79	16	30	24.9	3.6	23.9-26.0
80-89	10	28	20.8	4.7	19.2-22.6

Table 2.1. FGA scores and age groups.

For the purposes of the present study, the participants had to complete the FGA without and with dual tasking. The protocol included:

a) Single task (FGA-S);

b) FGA with a motor task requiring carrying a cup of water in the dominant hand (FGA-M);

c) FGA while performing a cognitive numeracy task (FGA-N);

The numeracy tasks include subtraction from 100 in 7s, multiplication tables of 8, and division tables of 7.

d) FGA while performing a cognitive literacy task (FGA-L).

The literacy tasks include naming alternate letters of the alphabet, alternate days of the week, and alternate months of the year. The responses to the cognitive tasks were recorded using a recorder and scored for the number of responses and number of errors for each FGA item.

2.3 Outdoor Gait Assessment

2.3.1 The Accelerometer Device

Three tri-axial accelerometers (MTx, Xsens Technology, Netherlands) were used to measure medio-lateral (ML), anterior-posterior (AP), and vertical (V) accelerations of the head, neck, and trunk while performing urban walking. The first motion sensor was attached to the posterior aspect of the head using an elastic head band. The other two motion sensors were attached by sport tape placed directly over the skin at the level of C7 and L3 spinous processes, respectively (Figure 2.1).

Each motion sensor had the following proportions: W 38mm, L 53mm, H 21 cm, WT 30 grams. The three motion sensors were connected to Xbus Master (data logger) (W 10cm, L 15cm, H 4 cm WT 226 grams, with batteries) which was connected to a laptop. The portable computer (W 260mm, L 365mm, H 38 cm, WT 2.9 Kg) and the Xbus Master were placed in a back bag carried by the participant throughout the outdoor walking assessment. Prior to the start of walking, patients were checked for any movement restriction caused by the wires. Participants were given instructions to wear comfortable clothes and flat shoes, to walk at their normal speed, and were not given any prioritization instructions during dual task walking.

2.3.2 Accelerometer Calibration and Orientation

At the start of each testing session, each motion sensor (when placed on a horizontal surface) had -1 g output in the vertical axis and 0 g in the horizontal axis. The orientation of the motion sensor was maintained when placed over the three body segments with X in the coronal plane pointing toward the right of the participant, Y in the vertical direction pointing upward, and Z in the sagittal plane, pointing backwards (opposite to the direction of walking). Once the motion sensors were attached to the participant, a static calibration was performed with the participant in their standing anatomical position. The purpose was to compensate for any errors that might result from misalignment of the vertical axes with the gravity vector. This calibration changed the orientation of the axes to the following: Y was in the sagittal plane pointing anterior toward the direction of walking; Z was vertical, pointing upward; and the direction of X did not change. (Figure 2.2).

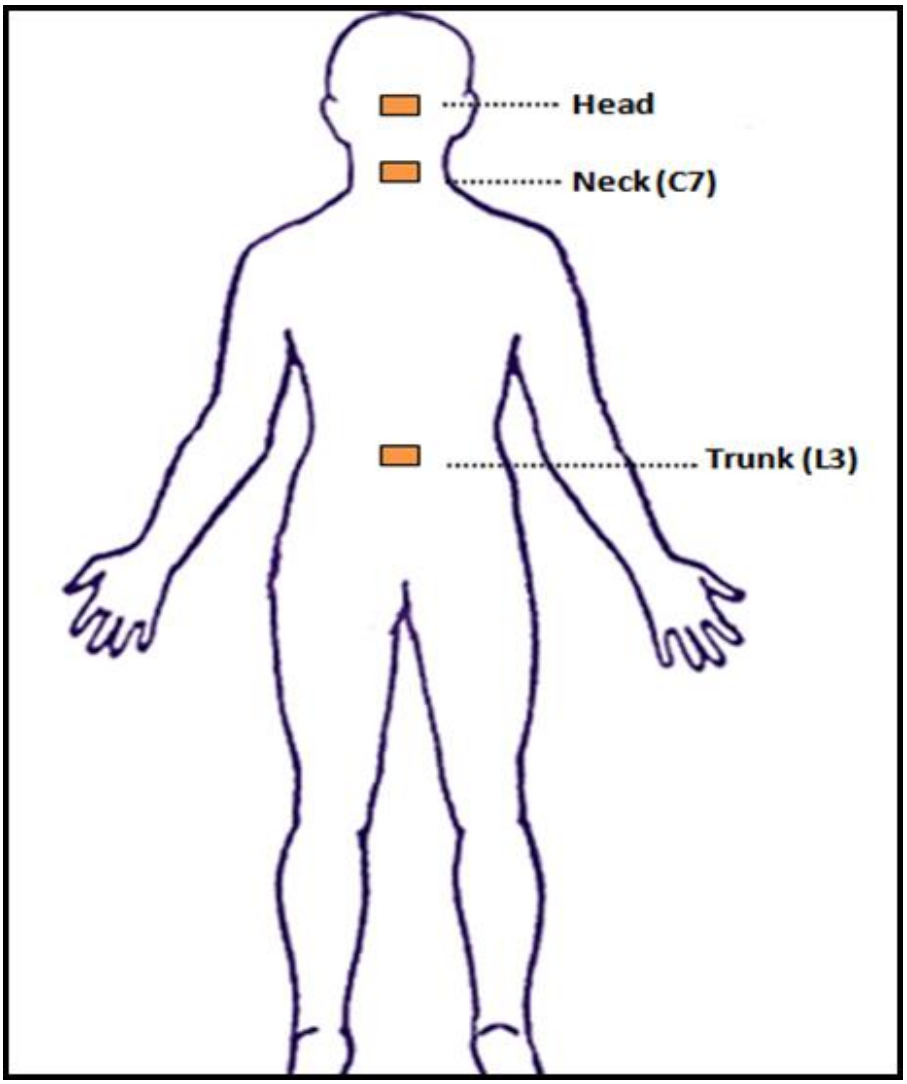

Figure 2.1. Three tri-axial accelerometers attached to the head, neck (C7) and trunk (L3).

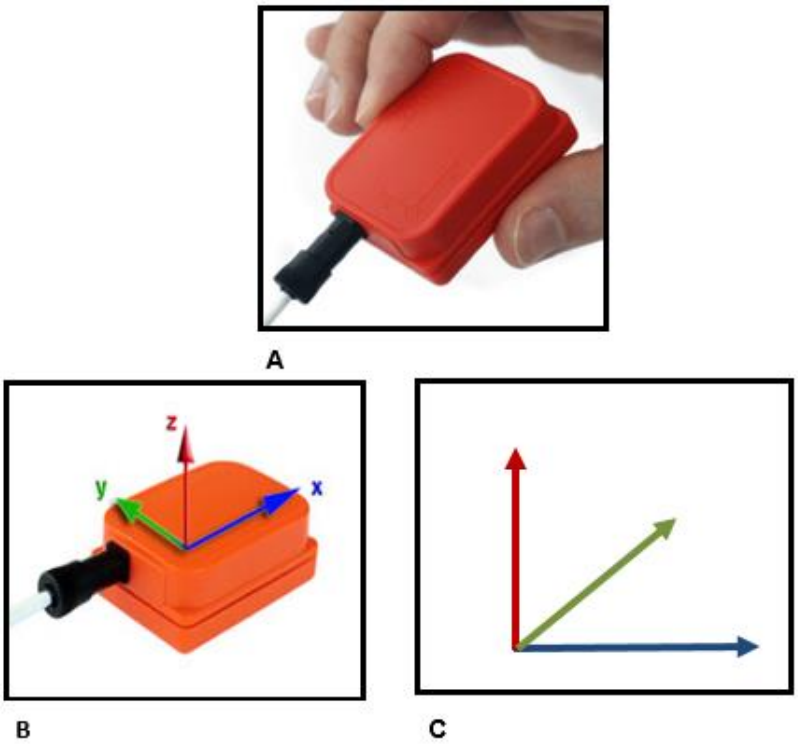

Figure 2.2. A. The motion Sensor; B. The orientation of axis before calibration; C. The orientation of axis after calibration.

2.3.3 The Urban Walking Route

Five walking segments around the London Bridge area were determined in advance. These segments included (Figure 2.3):

1. an area with colonnade flooring (check board with white & black pattern);
2. a busy area in London Bridge tube station;
3. a quiet area;
4. a cobble stoned area; and
5. crossing Borough High Street.

For each segment, a 30-meter distance was determined using existing fixed landmarks, except for the street crossing segment which was 16.8 m. In addition, patients had to treat their walking as a single task (i.e., just be walking)

and then as a dual task (i.e., walk while carrying out a cognitive task). The responses to the cognitive task were recorded in a smart phone device carried by the participants. The cognitive tasks included: times tables for 6, division tables for 9, counting backwards from 100 in 3s, and naming alternate letters of the alphabet, alternate months of the year, and alternate days of the week. The cognitive tasks were randomized between patients and between walking segments. Recording started at the beginning of the first segment and finished at the end of last one. All participants were advised to walk at their preferred walking speed and to pause for 10 seconds at the start and at the end of each segment. This was mandatory to be able to identify the segments of interest when analysing the signals. The outdoor walking always took place between 10:30 and 11:30 or 14:30 and 15:30 to allow for similar levels of pedestrian and traffic congestion.

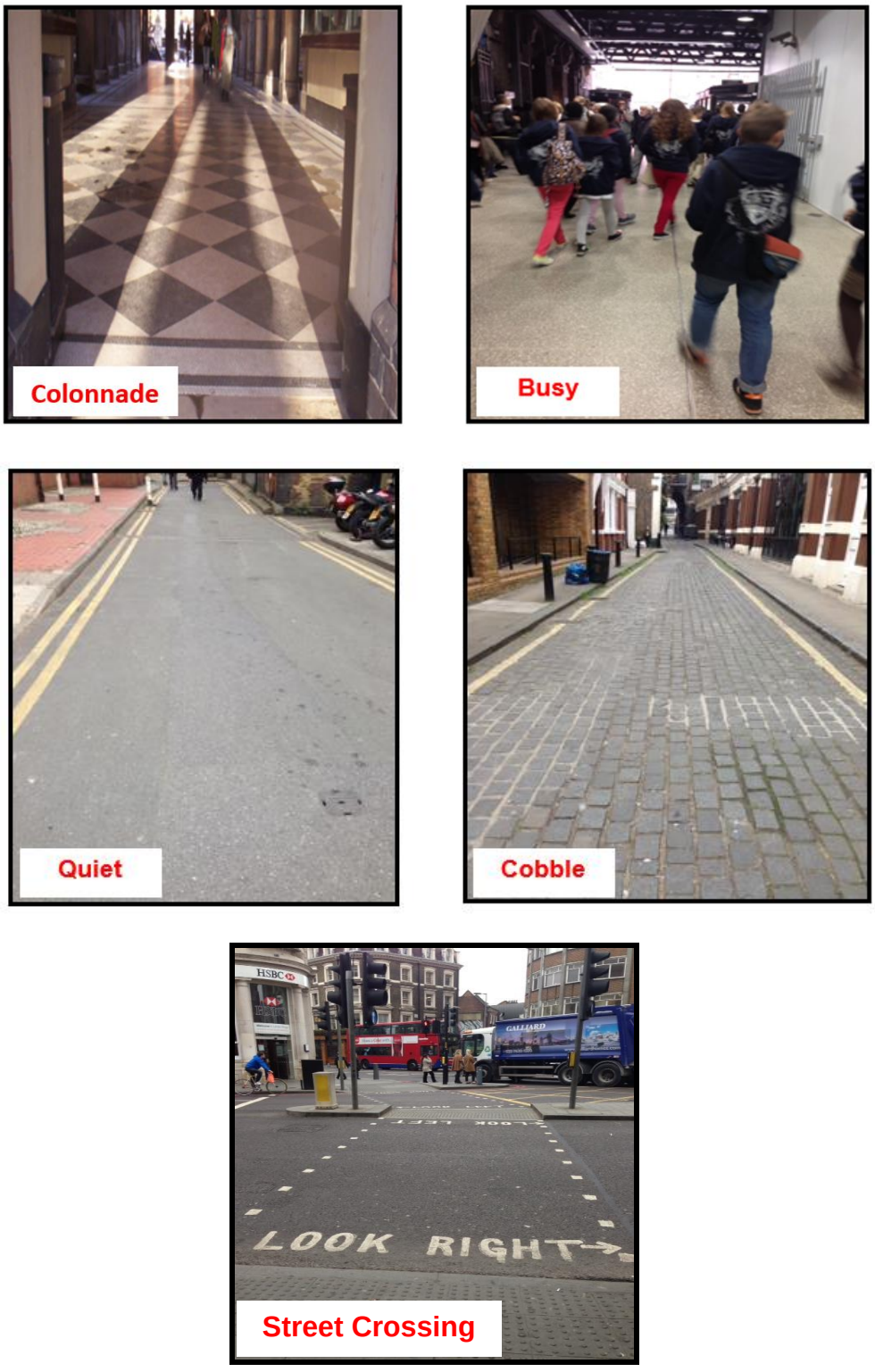

Figure 2.3. The urban walking segments.

2.3.4 Data Processing and Analysis

Two customized Matlab programs (2013 version) were used to analyze the data. The recorded data consisted of acceleration in 3 planes. Using the first Matlab program, the data were filtered using a six order Butterworth coefficient with a low pass cut off frequency of 10 Hz, and were sampled at 100 Hz. A plot of the acceleration signals with respect to time was generated (Figure 2.4 & 2.5).

The following steps were followed to analyse the recorded data:

1. The data corresponding to the start and end of each walking segment were identified manually using the time points and entered into an Excel spreadsheet.
2. This Excel spreadsheet was used in conjunction with the second Matlab program to obtain the variance of accelerations from head, neck, and trunk in the ML, AP, and V directions.
3. The RMS of the acceleration was then calculated by taking the square root of the variance.
4. The RMS of all variances were used for statistical analysis because they were found to be more normally distributed than the variances.

In addition, the walking velocity was calculated for each walking segment using the following formula:

$$Velocity = Distance/Time$$

The distance was 30 m for all segments except the street crossing segment, which was 16.8 m. Time was calculated by identifying the data corresponding to the start and end of each walking segment. This provided two readings representing the number of samples at two points in time. By using the following formula we were able to obtain the time.

Time = Number of samples (End - Start) / Sampling rate

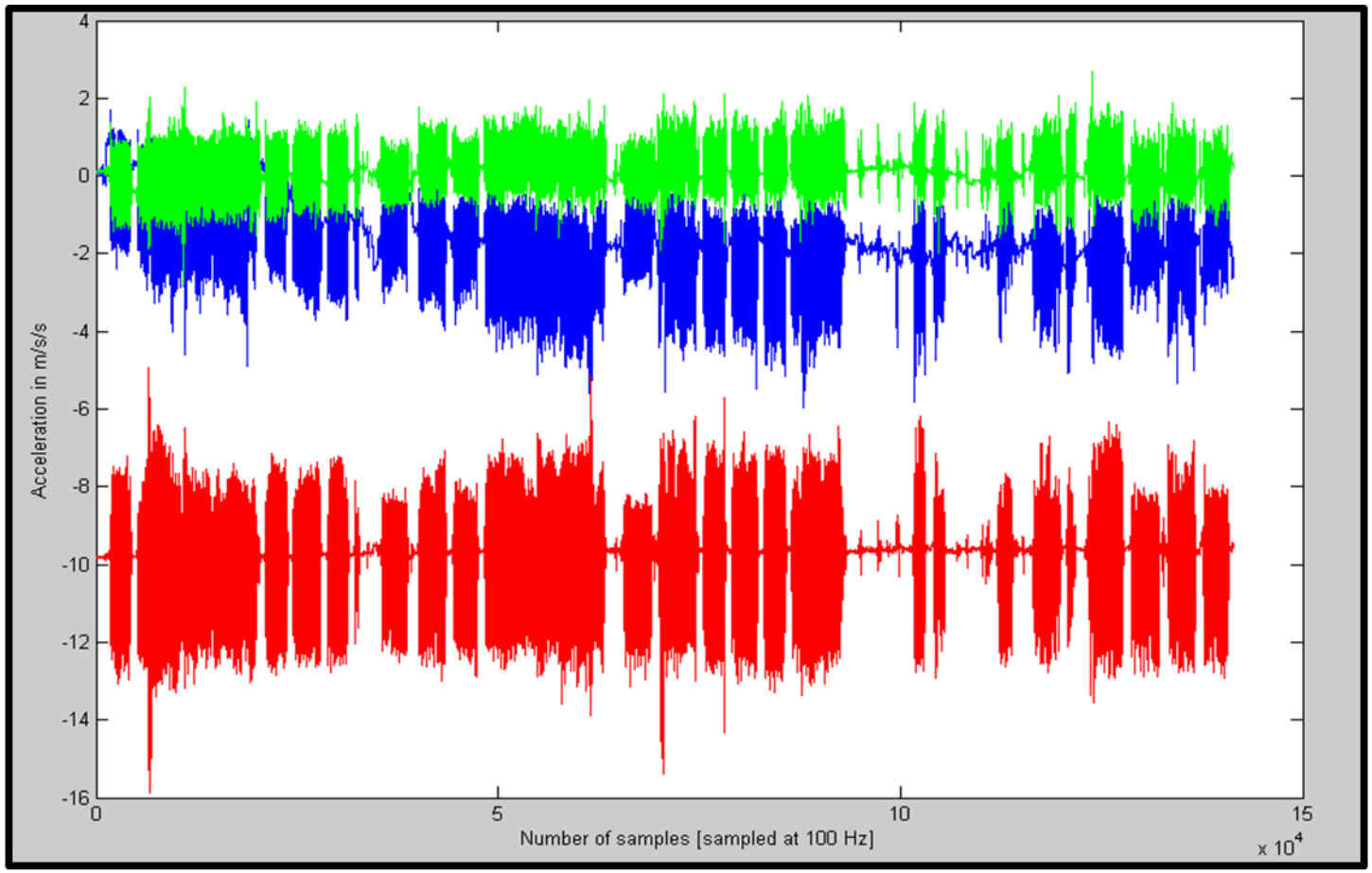

Figure 2.4. Acceleration pattern during walking for a single subject, blue (AP), green (ML), Red (V).

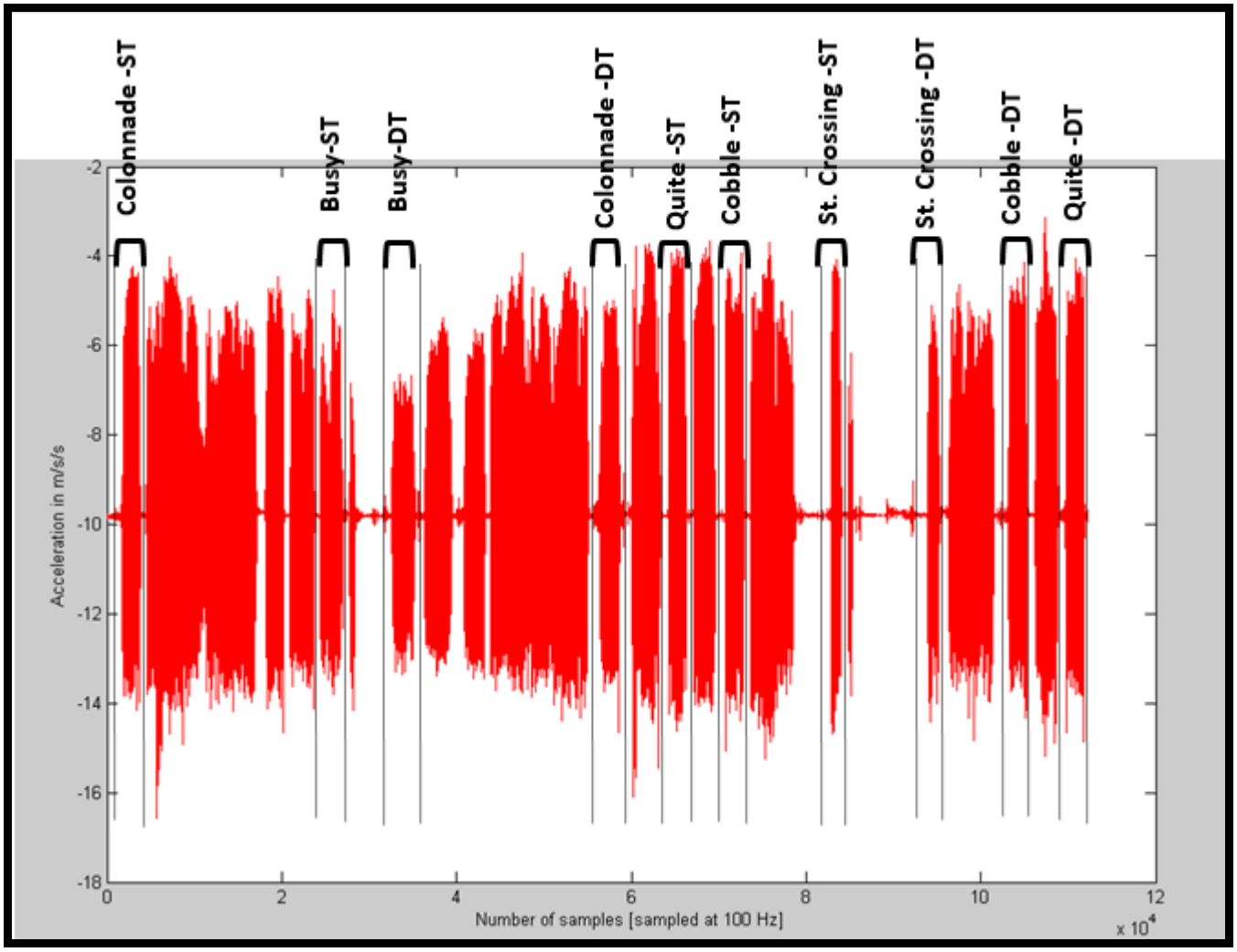

Figure 2.5. Manual identification of the start and end of each walking segment.

2.4 Behavioural Assessment of the Dys-Executive Syndrome Test Battery (BADs)

The BADs (Wilson et al., 1996) is a cognitive test that assesses the skills and abilities required to effectively carry out activities of daily living such as organizing, planning, temporal judgment, problem solving, attention, cognitive flexibility, and adjustment. This makes the BADs superior to other available cognitive tests that focus on the assessment of single aspects of cognitive functions. Moreover, it has the advantage of being easy to administer with minimal training, and can be completed within 30-40 min. It has six subtests, described as follows.

2.4.1 Rule Shift Cards: Identify Preservative and Mental Flexibility

A booklet of 21 spiral bound non-picture playing cards is used. The playing cards are turned one at a time and the participant is asked to say “Yes” or “No” for each card according to a rule. The rules are written in an A4 sheet and will be visible for the participant during the test. The first rule is “*Say Yes to Red, No to Black*”. The second rule is “*Say Yes if the card is the same colour as previous one, otherwise say No*”. The response and the time are noted for both trials and the participants is scored according to the second trial only in a score from (0-4).

2.4.2 Action Program: Assess Ability to Implement a Solution to a Practical Problem

The material in (Figure 2.6) was presented to the participants as shown. The following instruction was given:

"If you look at the bottom of this tube you will see a small cork. Your task is to get the cork out of the tube. You can use any of these things (indicate equipment) to help you. However, you must not lift this up (indicate main assembly), nor this (indicate beaker) nor this (indicate the tall tube), and you cannot touch this (indicate lid) with your fingers. Now go ahead and try to get the cork out of the tube."

If, after 2 minutes, the participants were unable to make progress, one clue was given to enable completion of the task. The score was calculated using a scale (0-4) according to the number of stages completed independently.

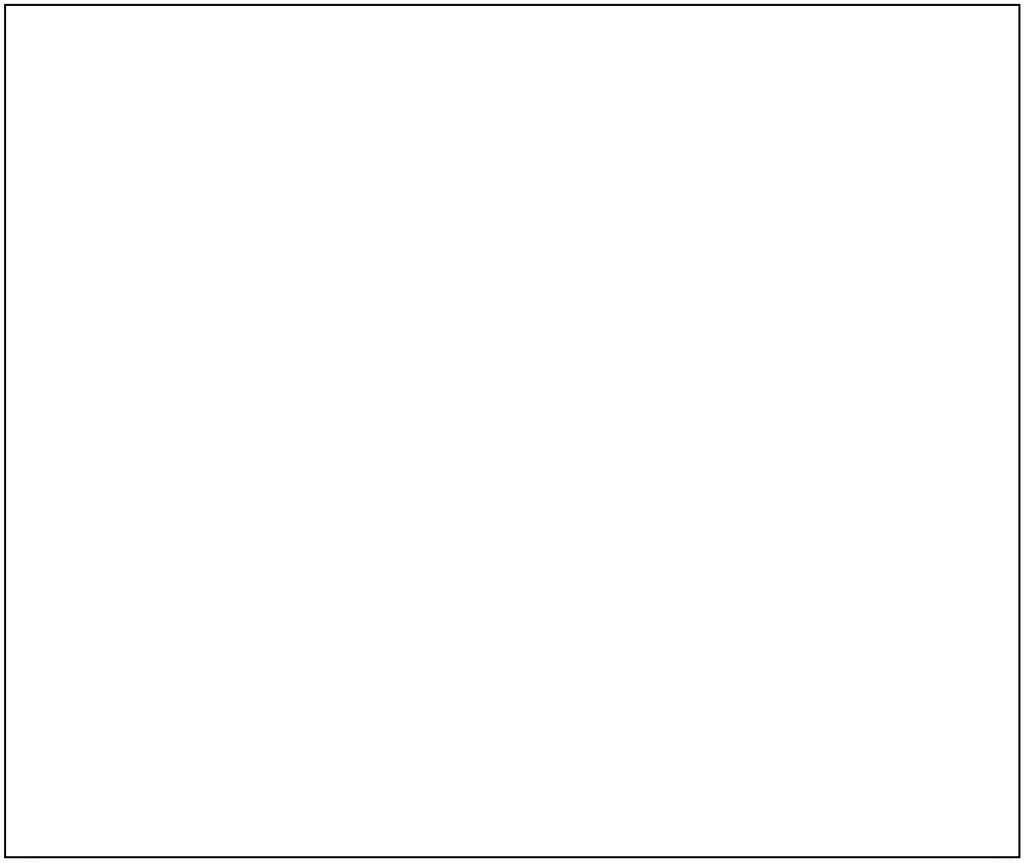

Figure 2.6. Action program test materials.

2.4.3 Key Search Test: Assesses Ability to Plan a Strategy to Solve a Problem

The participant was then presented with the response sheet (Figure 2.7). The following instructions were given to the participant:

"*I want you to imagine that this square is a large field. Somewhere in this field you have lost your keys. You do not know exactly where you have lost them because you have been all over the field, all you know is that they are somewhere in the field.*"

After a short pause to make sure the participant grasped the above instructions, the tester was instructed to say:

"*Starting from this dot, I want you to draw a line with the pen to show me where you would walk to search the field to make absolutely certain that you would find your keys no matter where they were.*"

The test was timed and scored according to certain criteria, including the starting point, the finishing point, making continuous line, making parallel lines, and making an effort to cover the whole area. The score was calculated using a scale (0-4).

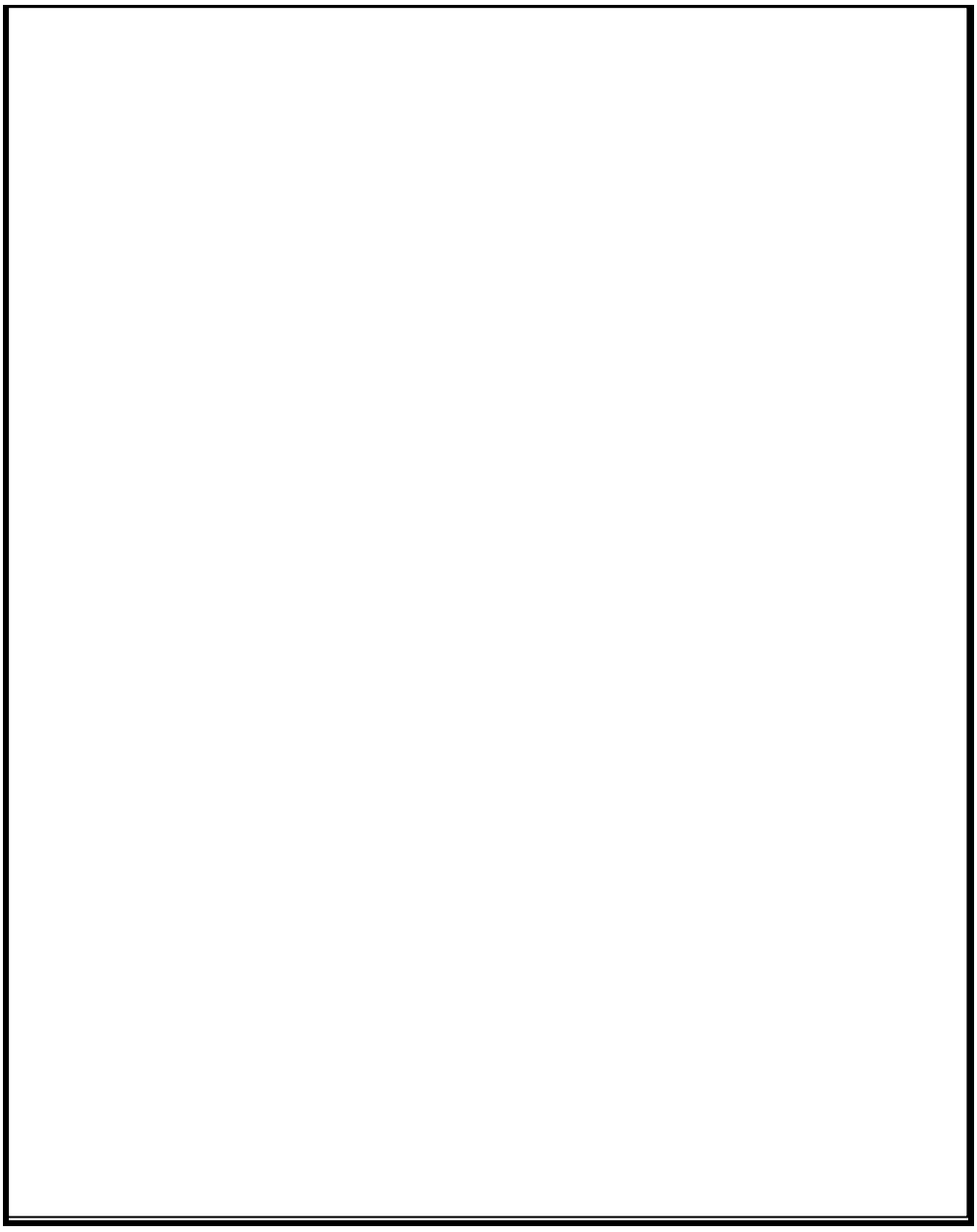

Figure 2.7. Key search test.

2.4.4 Temporal Judgment: Judgment and Abstract Thinking

The participant was asked to estimate how long the following items take:

1. How long does it take to complete a routine dental check-up?
2. How long do most dogs live for?
3. How long does it take a window cleaner to clean the windows of an average sized house?
4. How long does it take to blow a party balloon?

2.4.5 Zoo Map: Assess Ability to Independently Formulate and Implement a Plan and to Follow a Pre-formulated Plan

Sub-test 1:

The participant was presented with a copy of "Version 1: Zoo Map," (Figure 2.8). The following instruction was given:

"Here is a map of a zoo. Your task is to plan a route around the zoo to visit all the places listed in the instructions (indicate). You will be drawing a line to show me how you are planning to go from one place to another place and I will give you a different coloured pen after you have visited each place. It is not part of the test, it simply reminds me of the order in which you visited the places when I look at the map later."

Testers then read the instructions in the zoo map for the participant.

After finishing sub-test 1, the zoo map was taken away by the tester.

Sub-test 2:

The participant was presented with a copy of “Version 2: Zoo Map” (Figure 2.9). The following instruction was given:

“The next day you go back to the zoo for another visit but this time the instructions have changed. Could you just read aloud this second set of instructions please?”

Both sub-tests were timed and the final score was calculated based on the performance in both Version 1 and Version 2 sub-tests.

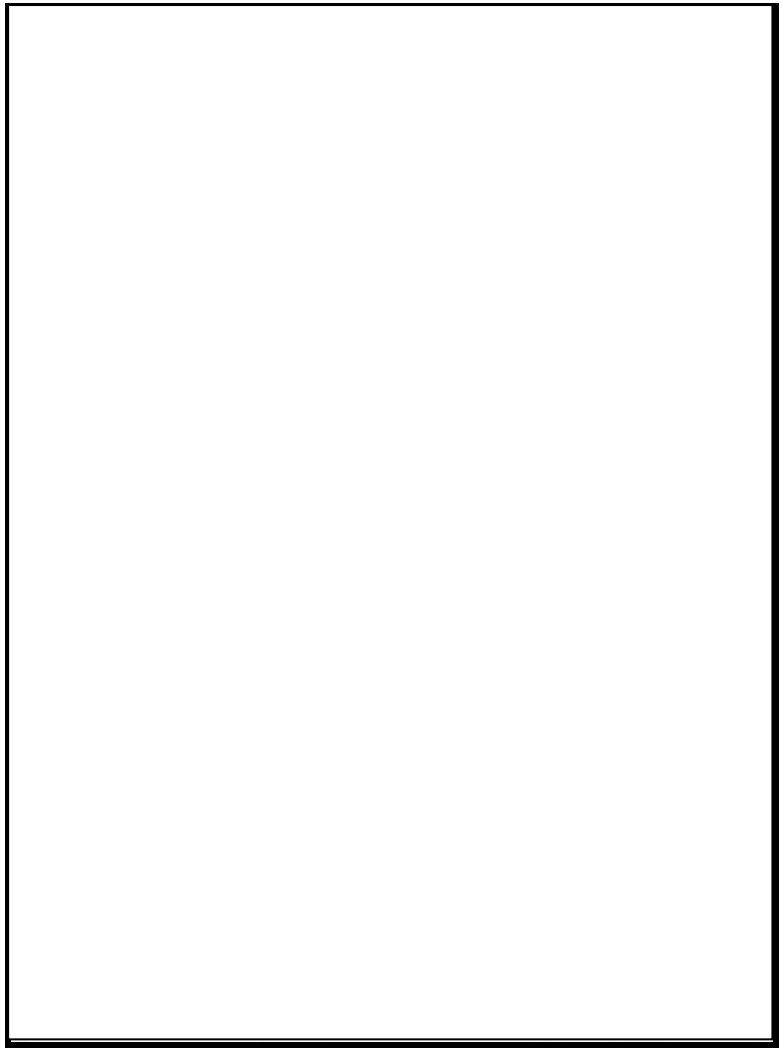

Figure 2.8. The zoo map, Version 1.

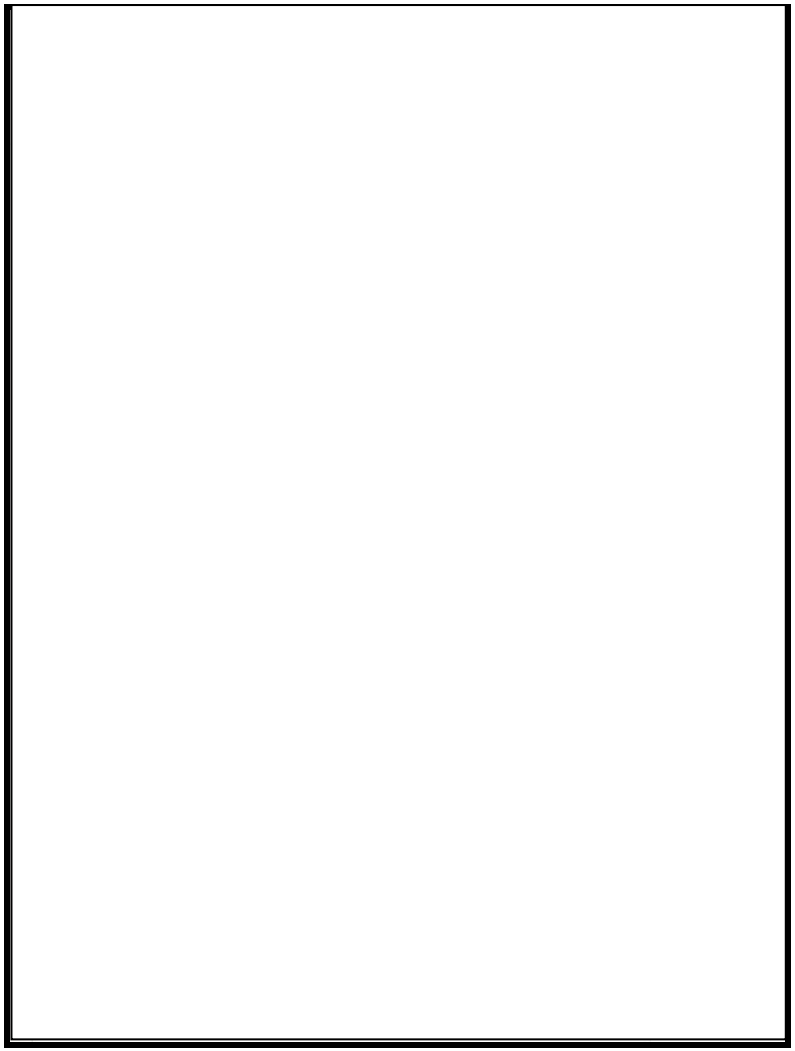

Figure 2.9. The zoo map, Version 2.

2.4.6 Modified Six Elements: Assess the Ability to Manage Time

In this test we used a tape recorder, four spiral booklets, two booklets with pictures, two with arithmetic problems, a paper, a pencil, and an eraser. The materials were arranged as per Figure 2.10. The participant had ten minutes to perform three kinds of tasks. The first task involved describing events. The second involved writing down (on paper) the names of some pictures shown on cards. The third involved solving some simple arithmetic problems shown on cards, and again writing the answers down on paper. Each of these three tasks is divided into two parts, Part A and Part B.

The following instruction was given to the participants:

"*During the next 10 minutes, I would like you to try to complete at least some of each of the six individual parts. There is no way that you will be able to complete everything in just ten minutes. The most important thing then, is not to try to complete any one task, but to make sure you have a go at completing at least some of all six parts. However, there is one rule that you must obey: you cannot move on to the second part of a task immediately after you have attempted the first part of the same, and of course you cannot do the first part of the task immediately after the second part of the same task.*"

The score was calculated based on the number of tasks attempted and whether the rule was broken or not.

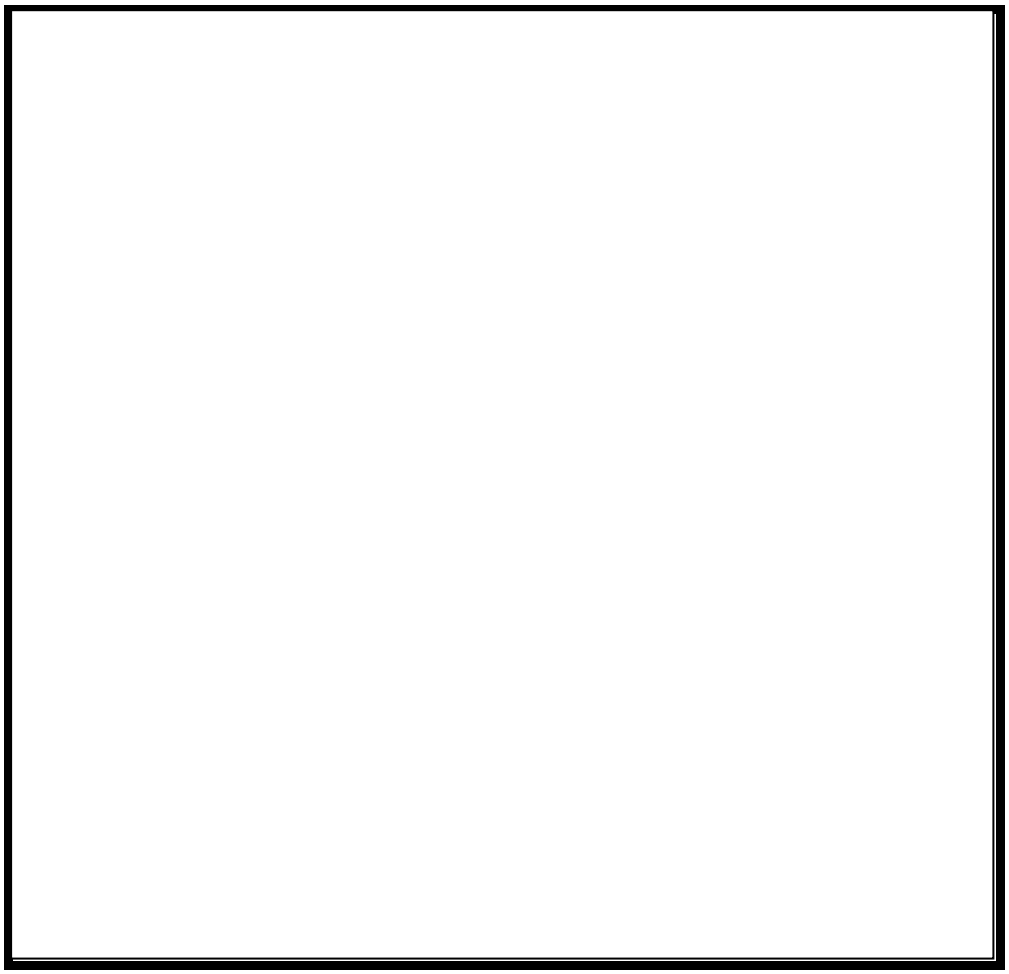

Figure 2.10. Modified six elements test materials and set up.

Each BADs test was scored on a scale from 0 to 4. The profile score was the sum of the individual test score. The maximum profile score was 24. The profile score categorized participants into one of 7 domains ranging from impaired to very superior. The mean profile score in healthy control adults was 18.5, corresponding to a standardised score of 100. To eliminate the effect of age, the standardised score was adjusted for 3 different age groups: 1) 40 or less; 2) 41 to 65; and 3) 65 to 87 years old (Table 2.2).

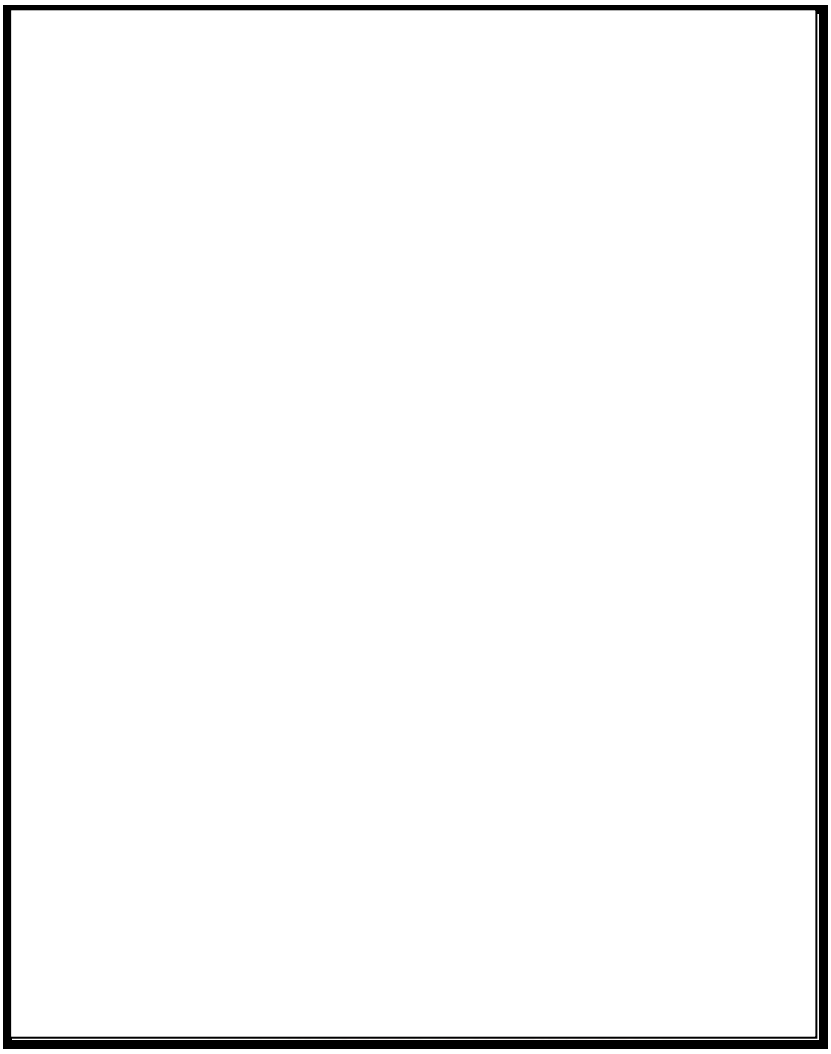

Table 2.2. Conversion of BADs profile score into standardised score and classification of test performance by age.

CHAPTER 3

The Effect of Dual Cognitive Tasking on Dynamic Balance in Young and Old Healthy Adults: A Pilot Study

3.1 Introduction

Maintaining balance while walking was considered to be an automatic process that requires minimal attentional input. However, recent evidence suggests that postural stability requires cognitive and sensory inputs (Woollacott and Shumway-Cook, 2002).

The ageing process is associated with decreased functional capacity and changes in sensory systems such as vision, vestibular and proprioceptive systems, a decrease in muscle strength, and a slowing of information processing (Maki and McIlroy, 2003). Aging has a great impact on posture and balance. This is reflected in the decreased walking velocity and increased double support time of older adults (Prince et al., 1997). At the same time, older adults are reported to have significantly reduced dual tasking ability while performing postural, stepping, and normal walking tasks (Maylor and Wing, 1996, Shumway-Cook et al., 1997, Alexander et al., 2005, Lundin-Olsson et al., 1997). This is reflected as an increase in postural instability, reduced walking velocity, increased stride-to-stride variability, and even with the tendency to discontinue walking while talking. The decline in performance under dual tasking conditions is linked to deficits in executive function and attention which are common with increasing age (Redfern et al., 2001). Moreover, as the complexity of either the motor or the cognitive task increases, the dependence

on executive functions becomes more significant, which can have the consequence of revealing minor gait dysfunction (Ble et al., 2005).

The addition of a cognitive task while performing a balance task might compromise older adults' balance capabilities and exposing them to the risk of fall. Since multitasking is normal in contemporary life, rather than being an exception, older adults might be exposed to the risk of fall in many everyday situations.

To our knowledge, no previous study has investigated the effect of dual tasking on functional gait assessment measures and on dynamic balance while walking in an outdoor environment where multitasking is compulsory and not optional.

In this study, we investigated the effect of dual tasking on the FGA and on free outdoor walking velocity and body stability in young and old healthy adults. Furthermore, a cognitive assessment was carried out using the dys-executive syndrome tests battery (BADs). Participants' performance in dual tasking was correlated with their performance in neuropsychological tests.

We hypothesised that dual tasking would adversely affects the dynamic balance in healthy older adults compared with young adults, and that this would correlate with their performance in the executive function tests.

The study may aid in the understanding of balance strategies used by older adults engaged in a dual tasking paradigm. It may also give insight into the risk

of falling in specified populations; in particular, it will address whether it is underestimated in healthy older adult engaged in dual tasking conditions.

3.2 Materials and Methods

3.2.1 Questionnaires

All participants completed the following questionnaires (Section 2.1 of Chapter 2 provided details of each).

- The Dizziness Handicap Inventory (DHI) (Jacobson and Newman, 1990).
- The Situational Vertigo Questionnaire (SVQ) (Guerraz et al., 2001).
- The Activities of Balance Confidence Scale (ABC)(Powell and Myers, 1995).
- The Vertigo Symptom Scale (VSS) (Yardley et al., 1992).
- The Vestibular Disorders Activities of Daily Living Scale (VD-ADL) (Cohen and Kimball, 2000).
- The Hospital Anxiety and Depression Scale (HAD) (Zigmond and Snaith, 1983).

3.2.2 Indoor Gait Assessment

All participants performed the Timed Up and Go test (TUG) (Podsiadlo and Richardson, 1991) and the Functional Gait Assessment (Wrisley et al., 2004) under single and dual task conditions. The testing protocol was detailed in the Section 2.2.

3.2.3 Outdoor Gait Assessment

All participants completed an urban walking session around London Bridge area under single and dual task conditions. The testing protocol was detailed in Section 2.3.

3.2.4 Behavioural Assessment of Dys-Executive Syndrome Test Battery (BADs) (Wilson et al., 1996)

All participants had a cognitive assessment using the BADs test battery. The details of the battery were outlined in Section 2.4.

3.2.5 Statistical Analysis

Statistical Analysis was performed using SPSS Version 22 (SPSS Inc, Chicago USA). The data was presented as mean ± standard deviation. Significance for all tested variables was assumed if $p<0.05$.

Two-way ANOVA was used to analyse TUG scores, determine the effect of study groups and gender on participants' score, and whether there was an interaction between independent variables. FGA scores were analysed using two-way mixed ANOVA. The independent variables were the study group (2 levels) and the testing condition (4 levels: single, motor, cognitive numeracy, and cognitive literacy). The walking velocity data were analysed using three-way mixed ANOVA with the following independent variables: 1) study groups (two levels); 2) walking conditions (two levels: single and dual); 3) walking segments (five levels: colonnade, busy, quiet, cobble, and street crossing).

Significant main effects and any significant two-way interactions between independent variables were presented.

The 9 RMS acceleration outcomes were considered separately: head, neck, and truck. Each outcome had 3 directions: ML, AP, and V. We used a mixed-effects regression analysis with the subject as the random factor. For all models, velocity was adjusted for by including this variable as a covariate. We had 1 between subjects' factor: Group (2 levels) and 2 within subject factors: segment (5 levels). At each level we had data for 2 conditions (single and dual). All 2 way interactions were investigated, i.e., group*condition, group*segment, and segment*condition. We used the quiet segment as a base line segment when exploring the condition*segment interaction in more detail and a Bonferroni adjustment was made to account for multiple comparisons.

The same approach was considered with the 3 Trunk Attenuation Rate (TAR) outcomes. The TAR was calculated for ML, AP and V acceleration direction using the following formula (Mazza et al., 2008) :

$$TAR\ (\%) = 100\ X\ (1 - Head\ RMS/\ Trunk\ RMS)$$

A higher TAR (%) indicated greater efficacy in attenuation of acceleration towards the head.

The Mann Whitney U test was used to assess between groups difference in BADs scores and all questionnaire scores.

3.3 Results

3.3.1 Participants

Participants were assigned to two age groups: Group 1, Young (20-59); and Group 2, Old (60-80) (Table 3.1).

All participants had a negative history for diagnosis of vestibular disorder, history of ear pathology, vertigo/balance impairments, and were free from neurological and musculoskeletal pathology or injury.

Groups		Number	Mean	SD	Gender
Young	20-59	28	38.67	12.72	M (13) , F (15)
Old	60-80	13	69.15	5.74	M (5) , F (8)

Table 3.1: Participant demographics.

3.3.2 Questionnaires

There was no significant difference in questionnaire scores between study groups (Table 3.2).

Questionnaire	Young		Old		P Value
	Mean	SD	Mean	SD	
ABC Total Score	98.75	1.54	95.43	6.43	.151
HAD Depression Score	.85	1.69	1.38	2.18	.186
HAD Anxiety Score	3.25	2.86	4.00	2.91	.382
SVQ Score	.14	.26	.08	.11	.989
VD-ADL Functional Score	12.00	.00	13.00	3.60	.709
VD-ADL Ambulation Score	9.00	.00	10.15	2.73	.249
VD-ADL Instrumental Score	7.25	1.53	7.46	.96	.285
VSS Vestibular Score	.39	1.06	.84	1.67	.324
VSS Somatic Anxiety Score	2.03	2.70	3.00	2.91	.260
DHI Total	.50	1.50	1.53	3.57	.515
DHI Emotional Score	.00	.00	.30	1.10	.709
DHI Functional Score	.00	.00	.61	1.26	.149
DHI Physical Score	.50	1.50	.61	1.50	.836

Table 3.2. Mean and SD of questionnaire scores of study participants.

3.3.3 Indoor Gait Assessment

3.3.3.1 Time Up and Go (TUG)

The TUG score increased from the young group (7.58 ± 1.32) to the old age group (10.30 ± 1.77) with a significant main effect of study groups, F (1, 37) = 30.694, p=.001, η_p^2=.453. (Figure 3.1). However, there was a non-significant main effect of gender on the TUG score, F (1, 37) = 0.601, p = .443, and no significant interaction effect between age and gender on the TUG score, F (1, 37) = 1.078, p = .306. This indicates that both male and female genders were affected similarly by age factor.

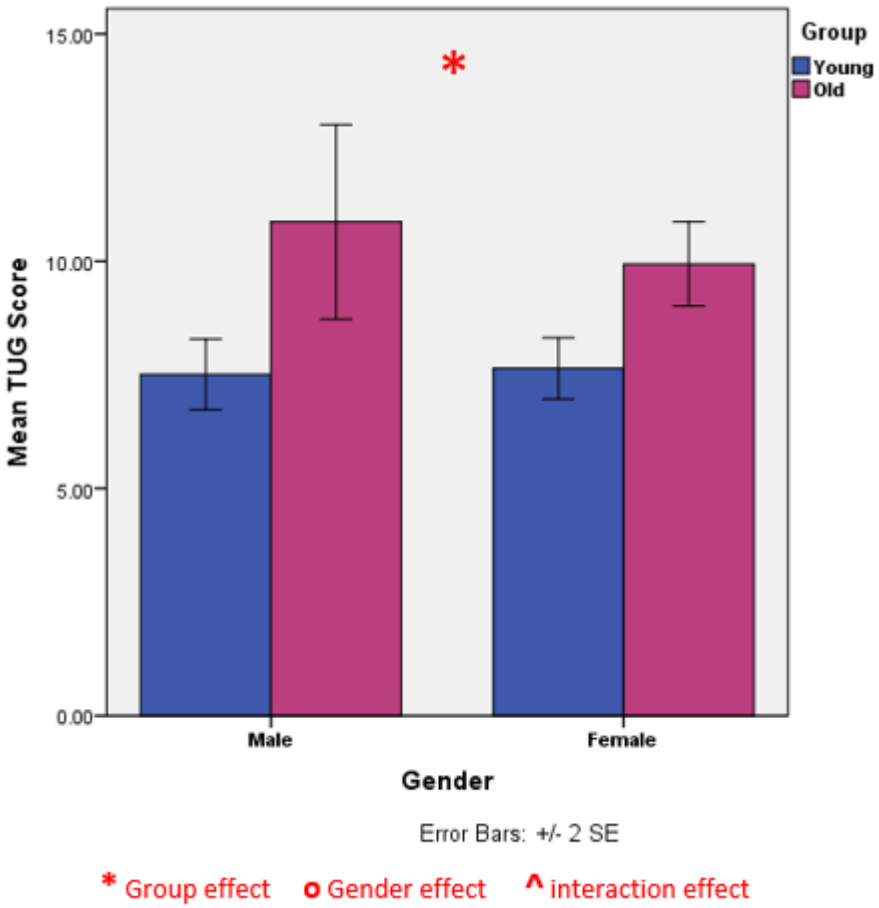

Figure 3.1. TUG Score for study groups.

3.3.3.2 Functional Gait Assessment (FGA)

a. FGA Scores

FGA score was significantly affected by the study group, F (1, 39) = 6.244, p = .017, η_p^2=.138 and by testing condition F (1.717, 66.955) = 68.595, p < .001, η_p^2=.638. There was no significant interaction between study groups and testing condition F (1.717, 66.955) = 1.248, p = .290.

As seen in Table 3.3 and Figure 3.2, FGA scores were lower in the old age group compared to the young age group, and lower under dual task conditions compared with the single task condition. Pairwise comparisons using Bonferroni adjustment revealed that FGA scores under dual tasking conditions including motor, cognitive numeracy, and cognitive literacy were significantly lower than FGA scores under single tasking condition, with the following p-values (respectively): .016, .001, and 001. In addition, there was no significant difference between the two cognitive task conditions, with a p-value of .171. The percentage of study participants with a total FGA score of 22 or less was calculated. It is clear that (as shown in Table 3.3) the risk of fall using the FGA scoring criteria was higher in the older group, especially with the addition of cognitive tasking.

	Young			Old		
	Mean	SD	Risk of Fall (%)	Mean	SD	Risk of Fall (%)
FGA-S	27.57	2.18	0%	26.08	3.0	7.7%
FGA-M	27.14	2.27	3.6%	25.08	3.33	7.7%
FGA-N	23.46	3.36	32.1%	20.62	3.22	76.9%
FGA-L	24.11	4.07	35.7%	21.31	3.38	61.5%

Table 3.3. Mean, SD, and fall risk of FGA scores in the two study groups. The risk of fall was calculated as the percentage of participants who had a total score of 22 or less as suggested by Wrisley and Kumar (2010).

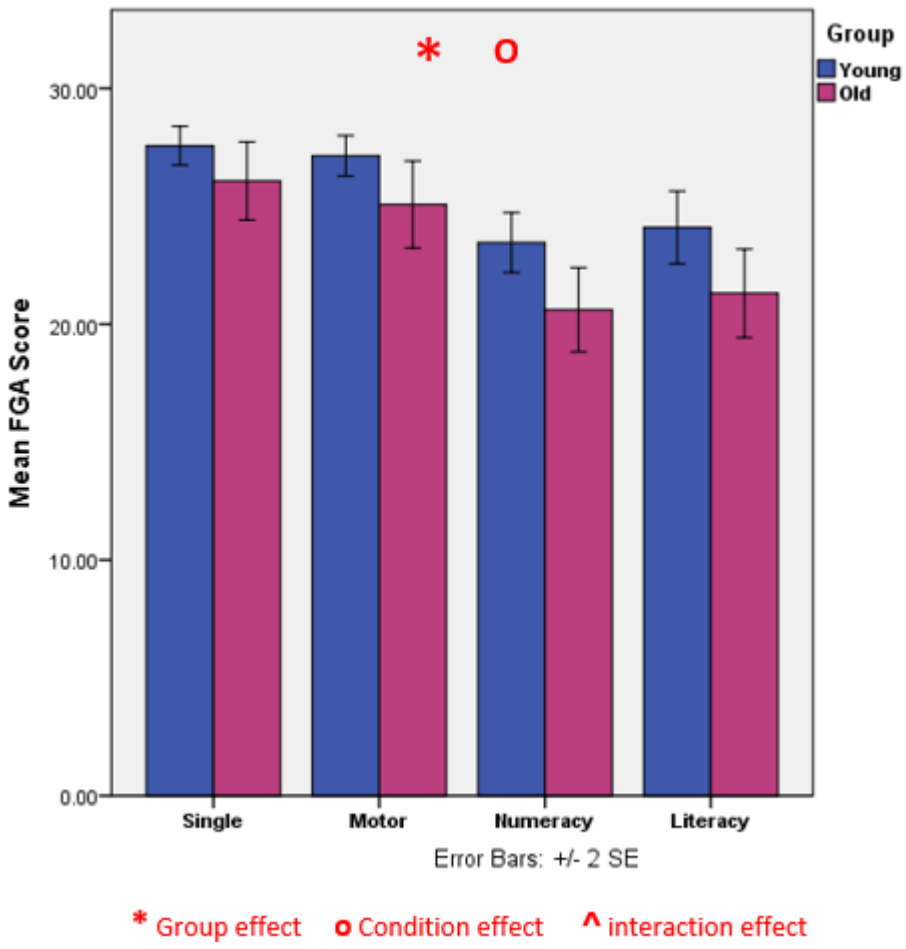

Figure 3.2. FGA scores in study groups.

b. Cognitive Task Scores

The number of responses for cognitive numeracy and literacy tasks during FGA testing did not show significant differences between the young and old groups, with t (16) = -2.111, p = .051) for numeracy and t (16) = -1.154, p = .265) for literacy tasks, respectively. In addition, the error rate was the same in both study groups with no significant difference for numeracy (U = 35.000, z = -.445, p = .696) or literacy tasks (U = 35.500, z = -.400, p = .696).

3.3.4 Outdoor Walking

3.3.4.1 Walking Velocity

Walking velocity was significantly affected by the study groups, F (1, 39) = 8.006, p = .007, η_p^2=.170, and by walking segments, F (2.510, 97.891) = 17.388, p<.001, η_p^2=.308. However, there was no significant effect of walking condition, F (1, 39) = 3.460, p = .070, and no recorded significant interaction between the independent variables.

This indicates that the old age group walked significantly more slowly compared with the young age group (Figure 3.3 and Table 3.4), and that walking velocity was affected by the type of walking environment that was presented. Pairwise comparisons with Bonferroni adjustment for the walking segments revealed that walking velocity at the colonnade, busy, and cobble segments were significantly reduced compared with the walking velocity of the quiet (p=.009, .013, .010) and street crossing segments (p= .016, .015, .019) respectively (Figure 3.4). In addition, there was no significant difference between the walking velocities in the colonnade, busy, and cobble segments, and no difference between the

quiet and street crossing segments. Though the study condition effect did not reach statistical significance, walking velocity was reduced under dual tasking compared with single tasking, and the p-value was borderline (this may be attributable to the small number of participants in the study).

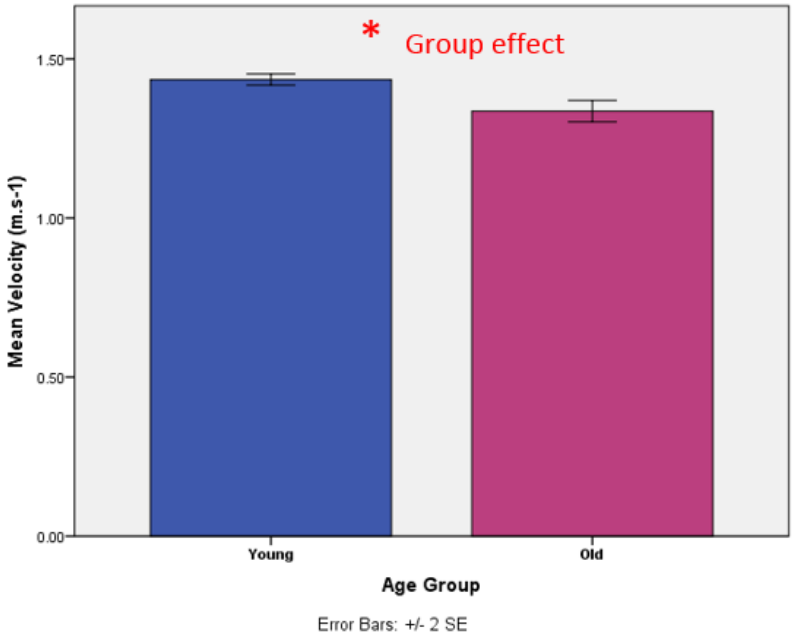

Figure 3.3. Walking velocity in the study groups.

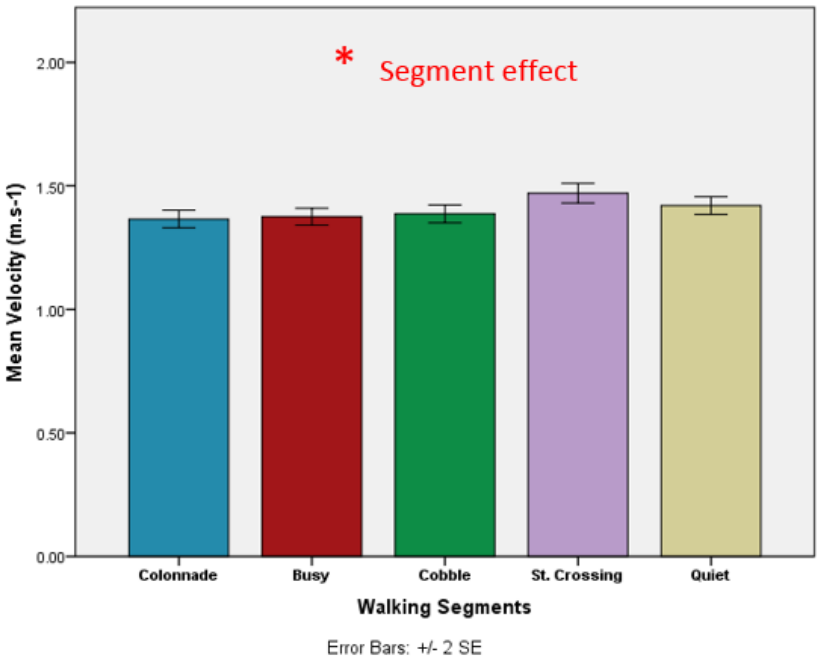

Figure 3.4. Walking velocity in various walking segments.

Age Group	Condition	Segment	Mean	Std. Error	95% Confidence Interval	
					Lower Bound	Upper Bound
Young	**Single**	Colonnade	1.449	.029	1.391	1.508
		Busy	1.426	.028	1.368	1.483
		Cobble	1.439	.029	1.380	1.498
		St.Crossing	1.560	.031	1.497	1.624
		Quiet	1.481	.030	1.420	1.542
	Dual	Colonnade	1.345	.027	1.291	1.399
		Busy	1.384	.028	1.328	1.441
		Cobble	1.395	.031	1.332	1.458
		St.Crossing	1.468	.032	1.403	1.532
		Quiet	1.402	.030	1.341	1.463
Old	**Single**	Colonnade	1.338	.042	1.252	1.424
		Busy	1.304	.042	1.220	1.388
		Cobble	1.342	.043	1.255	1.428
		St.Crossing	1.401	.046	1.308	1.495
		Quiet	1.397	.044	1.308	1.486
	Dual	Colonnade	1.254	.039	1.175	1.334
		Busy	1.315	.041	1.232	1.399
		Cobble	1.303	.046	1.211	1.396
		St.Crossing	1.354	.047	1.259	1.449
		Quiet	1.351	.044	1.261	1.441

Table 3.4. Mean, SE and 95% CI of walking velocity in the study groups.

3.3.4.2 Acceleration

a. Trunk Acceleration

There was a significant group effect on ML acceleration only, but not in the AP or V directions. In addition, there was a significant walking conditions and walking segments effect in all acceleration directions. Table 3.5 summarises all related statistics and p-values.

The ML trunk acceleration was significantly reduced in the older age group compared with the young age group (as shown in Figure 3.5**)**. In addition, with dual tasking, accelerations were significantly reduced compared with the corresponding values under single task walking (Figure 3.6). The effect of walking segment on acceleration was very clear in the colonnade and busy segments where acceleration was reduced in all directions relative to the other three walking segments (Figure 3.7).

Trunk Acceleration			Coef.	SE	Z	P
Group effect	**ML**		-.245	.113	-2.18	.030
	AP		-.125	.031	-1.00	.318
	V		-.165	.044	-1.31	.189
Condition Effect	**ML**		-.125	.025	-4.84	.001
	AP		-.235	.031	-7.46	.001
	V		-.176	.044	-4.03	.001
Segment Effect	**Colonnade**	**ML**	-.255	.029	-8.79	.001
		AP	-.328	.035	-9.37	.001
		V	-.250	.046	-5.34	.001
	Busy	**ML**	.252	.029	-8.67	.001
		AP	-.347	.035	-9.87	.001
		V	-.383	.047	-18.17	.001

Table 3.5. Result of a mixed effects regression analysis on Trunk acceleration.

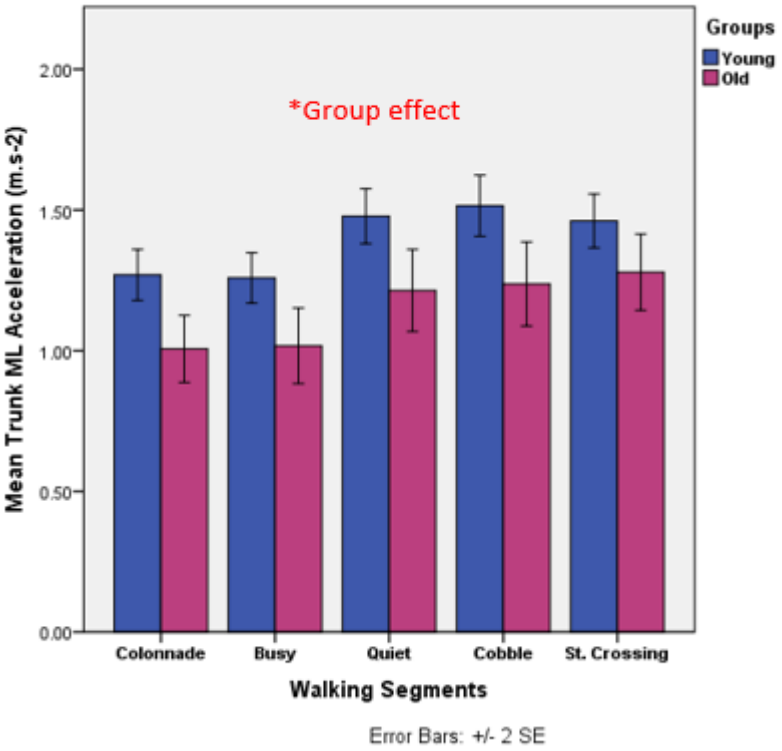

Figure 3.5. ML trunk acceleration in young and older age groups.

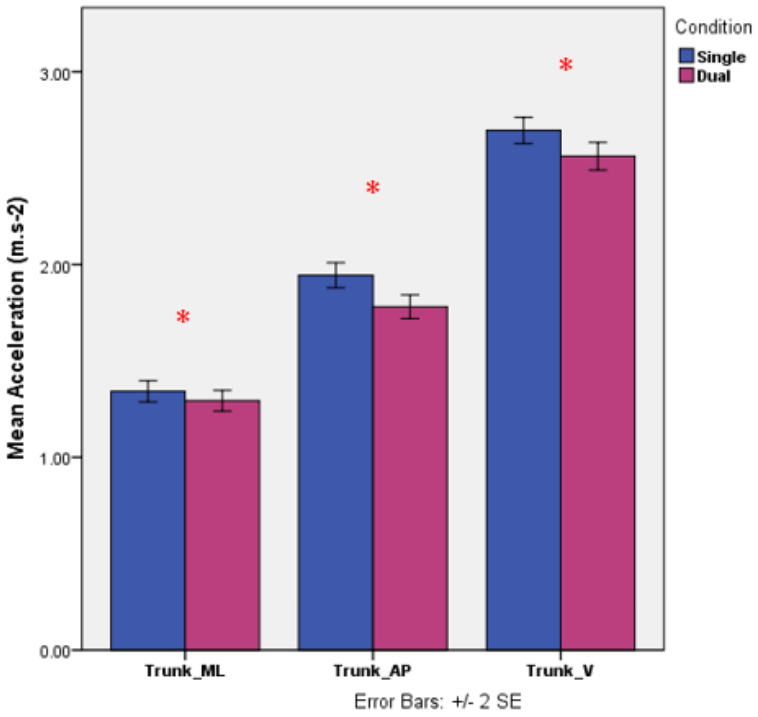

Figure 3.6. The effect of walking conditions on trunk acceleration in the ML, AP, and V directions.

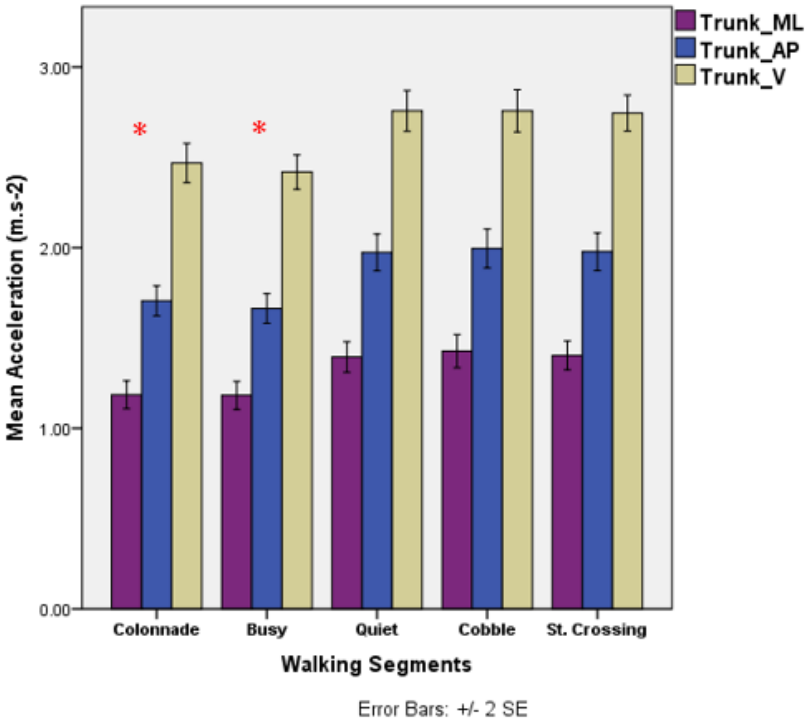

Figure 3.7. Effect of walking segments on Trunk acceleration in ML, AP, and V directions.

b. Neck Acceleration

There was no significant study group effect in all acceleration directions. However, there was a significant effect of walking condition in the ML (β=.046, SE=.017, Z=2.66, P=.008), AP (β=-.299, SE=.060, Z=-5.00, P=.000), and V directions (β=-.301, SE=.051, Z=-5.97, P=.001). The effect of walking segment was significant in all acceleration directions in the colonnade (ML: β=-.158, SE=.027, Z=-5.89, P=.001), (AP: β=-.300, SE=.060, Z=-5.05, P=.001), (V: β=-.261, SE=.052, Z=-4.98, P=.001) and in the busy segment (ML: β=-.161, SE=.027, Z=-6.01, P=.001), (AP: β=-.357, SE=.060, Z=-5.98, P=.001), (V: β=-.385, SE=.053, Z=-7.32, P=.001). Figure 3.8 shows the decrease in acceleration with dual tasking and Figure 3.9 the shows decrease in accelerations in the colonnade and busy segments relative to other segments.

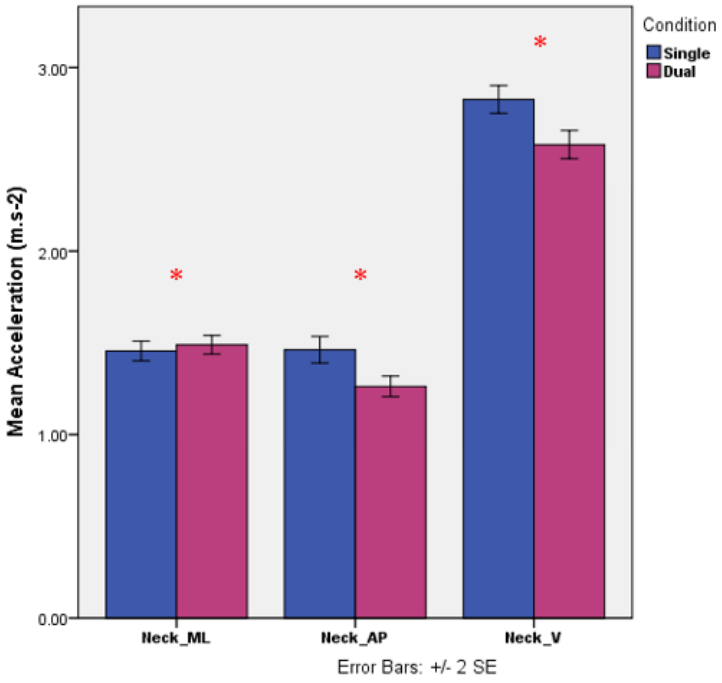

Figure 3.8. The effect of walking condition on neck acceleration in the ML, AP, and V directions.

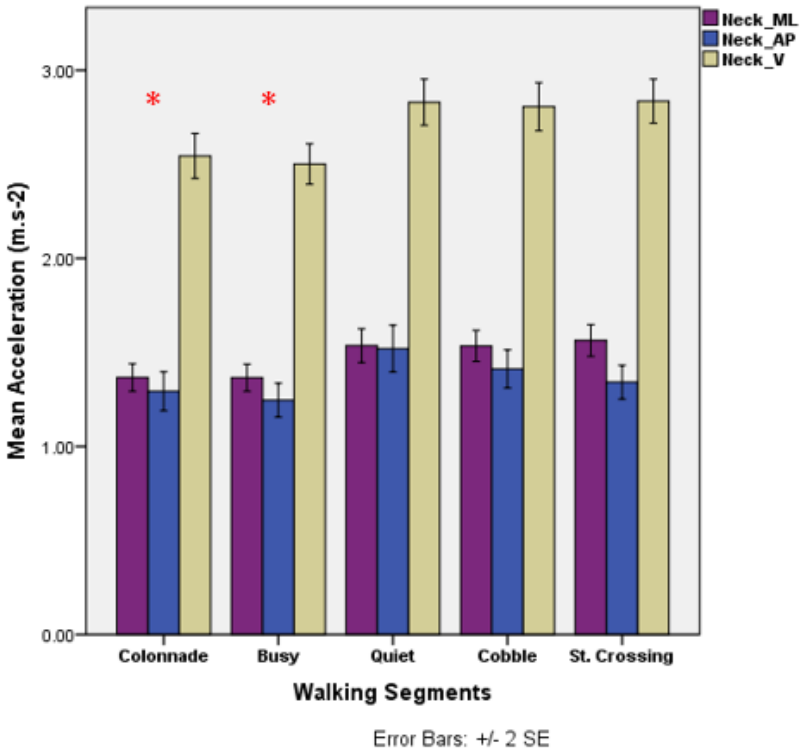

Figure 3.9. Effect of walking segments on neck acceleration in ML, AP, and V directions.

c. Head Acceleration

At the head level there was no significant effect of study group for any acceleration directions. Moreover, the effect of the walking condition was significant only on acceleration in the AP (β=-.068, SE=.014, Z=-4.93, P=.001) and V directions (β=-.211, SE=.044, Z=-4.77, P=.001). Figure 3.10 shows the reduction in acceleration under dual tasking condition. In addition, there was a significant walking segment effect in all acceleration directions as indicated in Figure 3.11, which shows the reduction in acceleration in the colonnade (ML: β=-.130, SE=.027, Z=-4.54, P=.001), (AP: β=-.150, SE=.021, Z=-6.88, P=.001), (V: β=-.229, SE=.046, Z=-4.93, P=.001) and in the busy walking segments (ML: β=-.106, SE=.028, Z=-3.81, P=.001), (AP: β=-.151, SE=.021, Z=-7.13, P=.001), (V: β=-.369, SE=.046, Z=-7.88, P=.001).

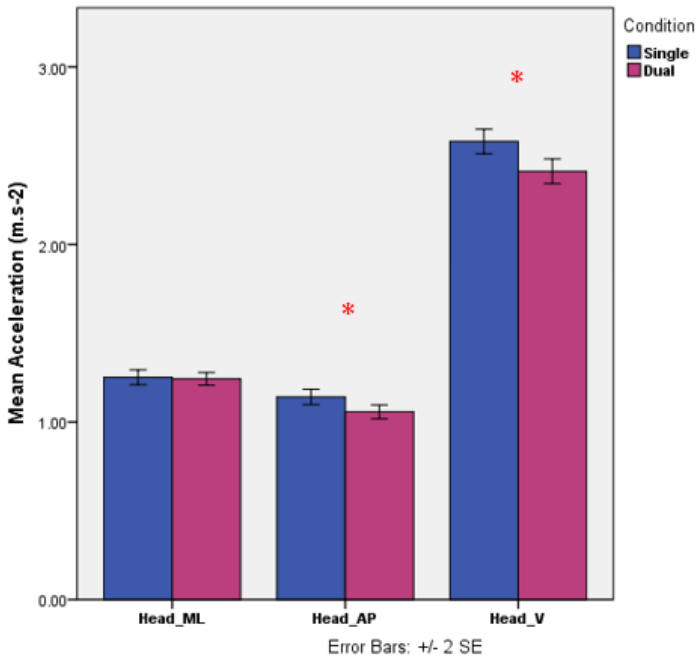

Figure 3.10. The effect of walking condition on head acceleration in the ML, AP, and V directions.

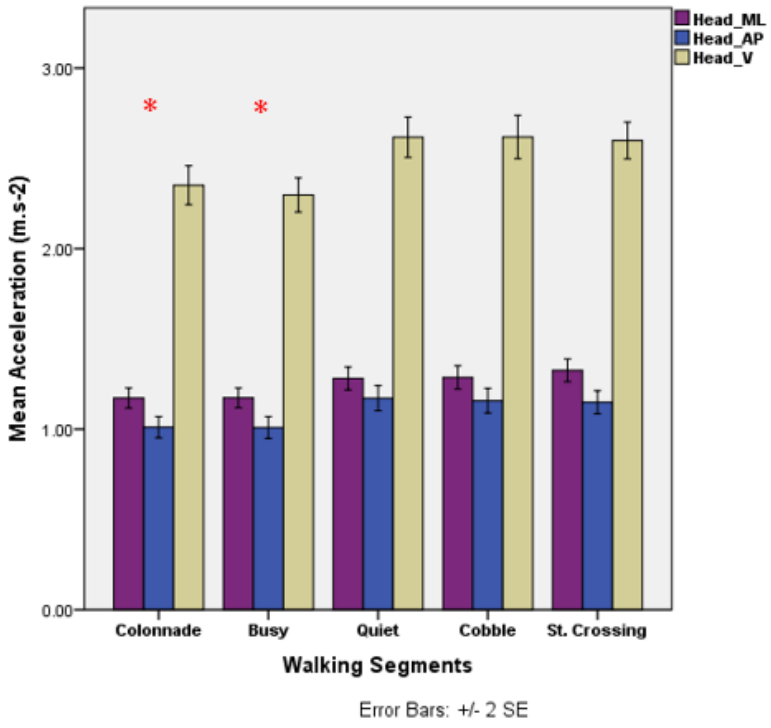

Figure 3.11. The effect of walking segments on head acceleration in ML, AP, and V directions.

3.3.4.3 Trunk Attenuation Rate (TAR)

The trunk attenuation rate was not significantly affected by study groups in all three acceleration directions. Moreover, the TAR in the V direction was significantly affected by walking condition (β=1.31, SE=.225, Z=5.84, P=.001). In the ML direction, TAR was significantly affected by walking condition (β=-6.19, SE=2.85, Z=-2.17, P=.030), walking segments in the colonnade (β=-8.07, SE=2.97, Z=-2.72, P=.007), and in the busy segment (β=-9.54, SE=2.98, Z=-3.20, P=.001). There was a significant interaction between walking segments and walking conditions which was obvious in the cobble segment (β=10.04, SE=4.00, Z=2.51, P=.012).

Based on the above findings and as illustrated in Figures 3.12 and 3.13, we found that the TAR in the AP direction was least affected by study group, walking condition, and segment. This reflects the fact that participants were most stable in this direction. Moreover, we noticed that the TAR in the vertical direction was improving with dual tasking. This finding can be explained by the compensatory reduction in the walking velocity of study participants. In the ML direction, we noticed that, though the group effect didn't reach significant levels, the TAR was adversely affected in older healthy adults compared with young healthy adults, and was more compromised by dual tasking. This indicates that the older group was least stable in the ML direction. Nonetheless, this finding didn't reach the level of statistical significance. This fact may be attributed to the small sample size used in the study.

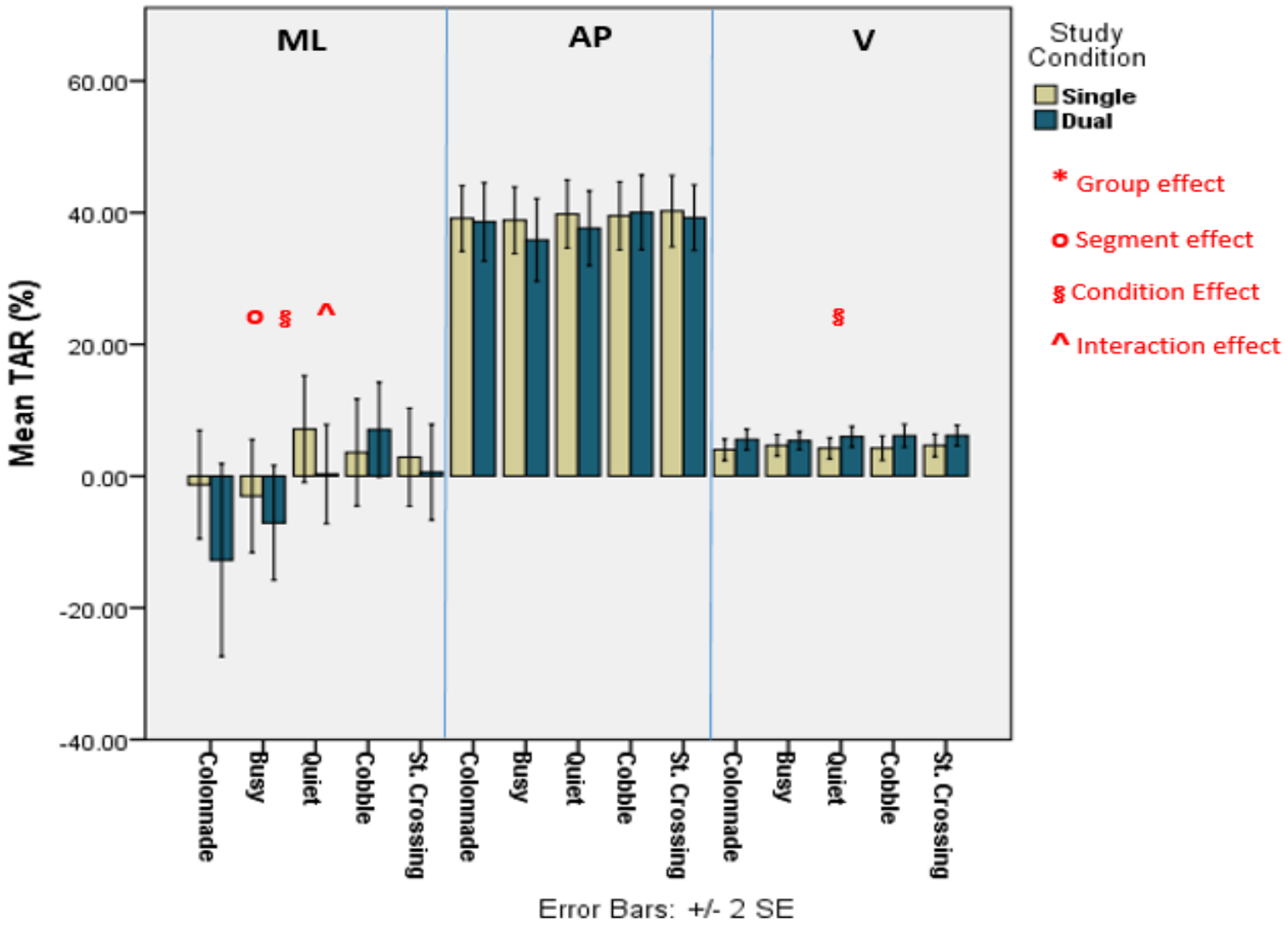

Figure 3.12. TAR among walking segments under single and dual tasking.

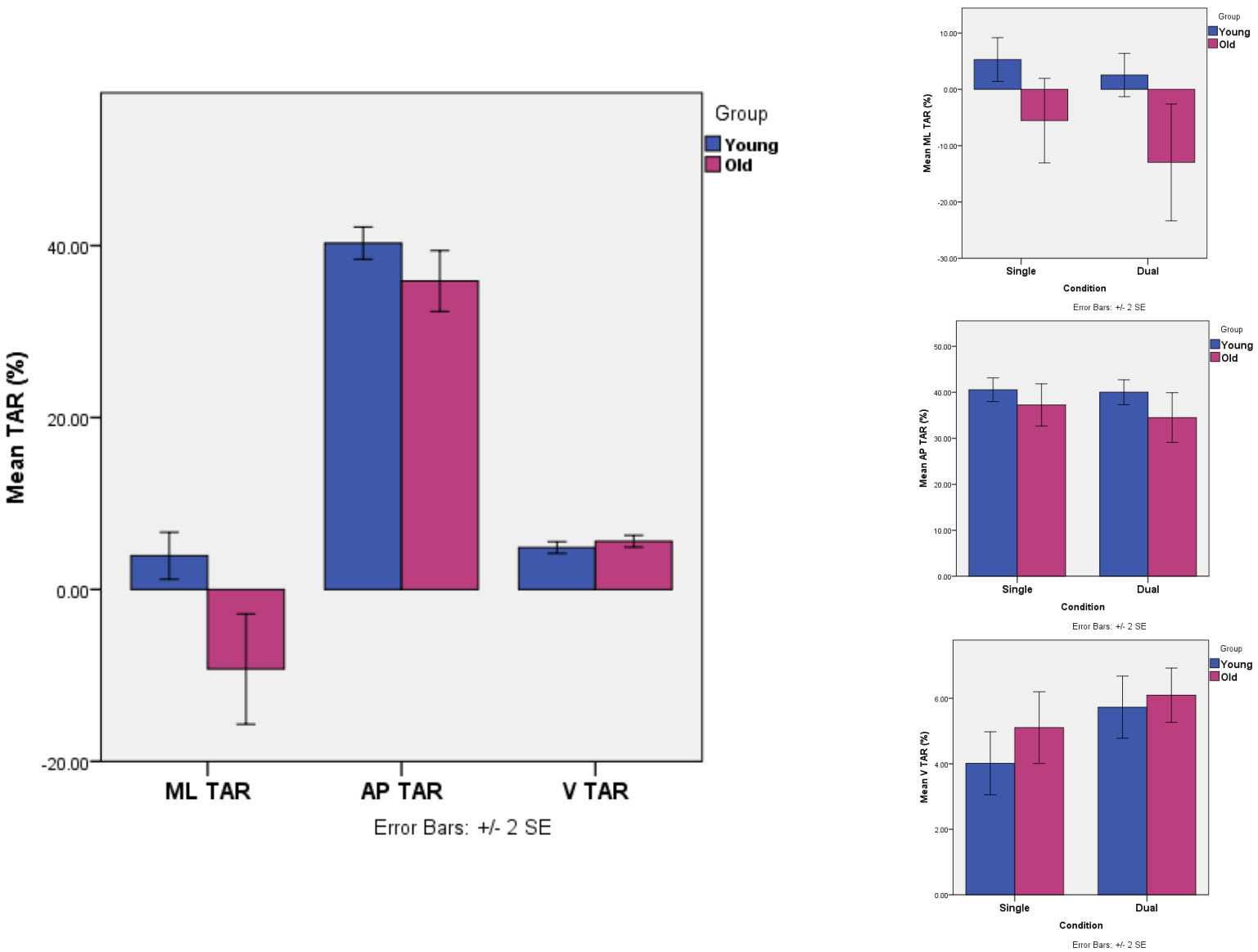

Figure 3.13. TAR among study groups and study conditions.

3.3.4.4 Cognitive Task Scores

The response rate, the error rate, and the percentage of correct answers were calculated for each walking segment and compared between study groups. The scores did not show any significant difference between study groups (Tables 3.6 and 3.7).

Group		Mean	SD	p
Colonnade_response	Young	13.00	5.55	.573
	Old	14.15	6.64	
Busy_response	Young	12.80	3.95	.366
	Old	14.00	3.55	
Quiet_response	Young	14.84	5.72	.346
	Old	16.92	7.54	
Cobble_response	Young	13.28	5.27	.559
	Old	12.23	5.05	
Street crossing_response	Young	7.68	2.80	.726
	Old	8.00	2.30	

Table 3.6. Response rate in all walking segments for both groups.

Group		Mean	SD	p
Colonnade_error	Young	.68	1.21	.516
	Old	1.00	1.77	
Busy_error	Young	.64	1.15	.517
	Old	.38	1.12	
Quiet_error	Young	1.12	2.87	.852
	Old	1.30	2.98	
Cobble_error	Young	.56	1.44	.243
	Old	.07	.27	
Street crossing_error	Young	.16	.37	.486
	Old	.07	.27	

Table 3.7. Error rate in all walking segments for both groups.

3.3.5 Behavioural Assessment of Dys-Executive Syndrome Test Battery (BADs)

The distribution of BADs score classification in study groups did not differ significantly, as per the Chi Square Test, $\chi^2(4) = 3.091$, $p = .543$ (Figure 3.14) Total Profile score (U=119.5, Z=-1.766, =.080), total standardized score (U=119.5, Z=-1.766, =.080), and age corrected score (U=209.5, Z=.758, =.463) did not differ significantly between study groups (Figure 3.15).

Comparing the performance between study groups for each sub-test showed no statistically significant difference between study groups (Figure 3.16).

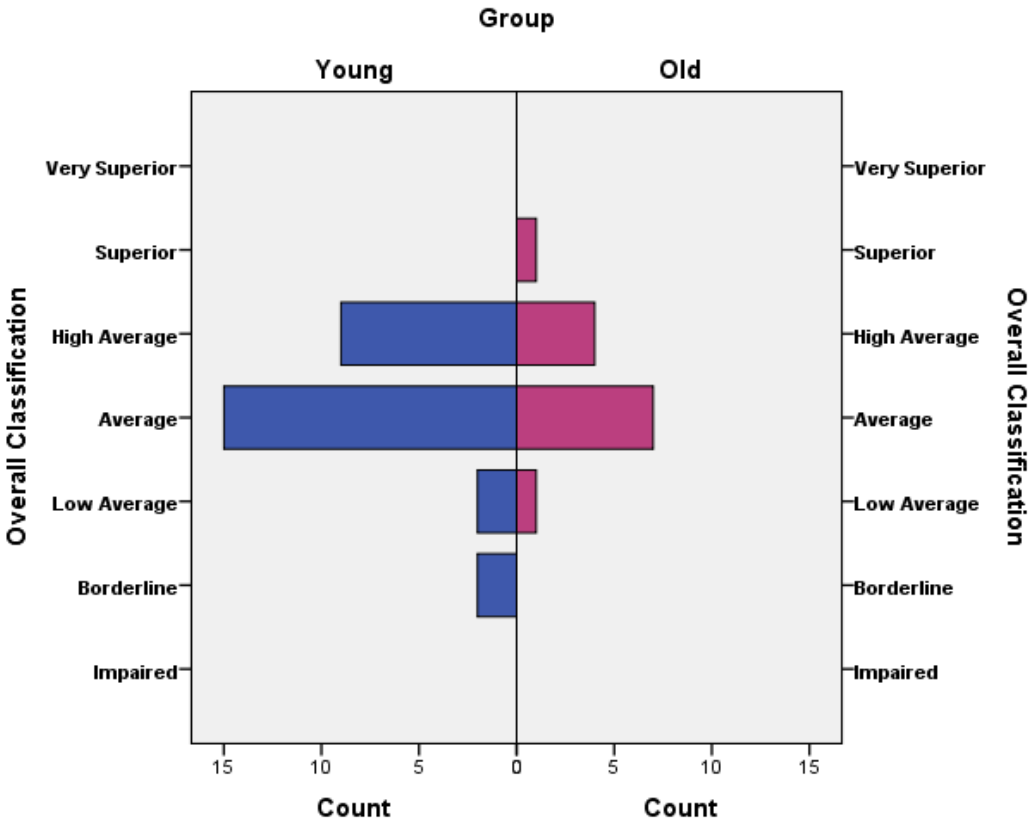

Figure 3.14. Distribution of BADs overall classification in young and old groups.

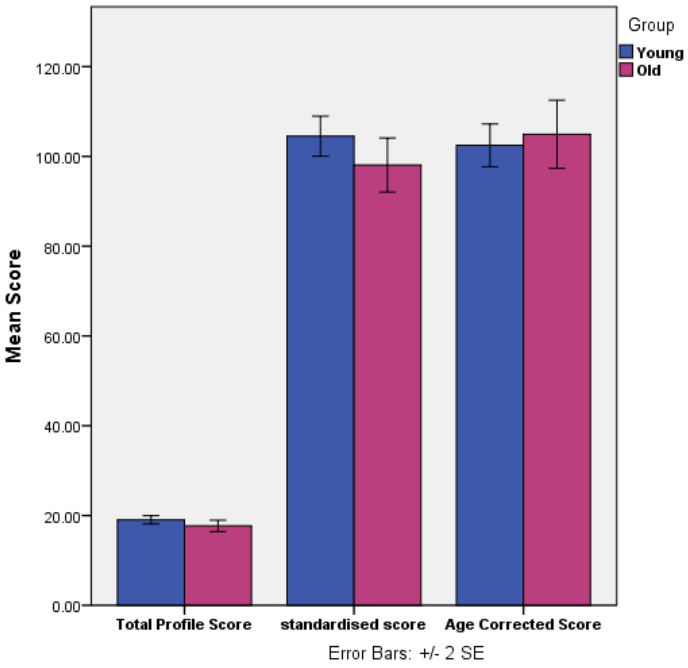

Figure 3.15. Mean BADs total scores for study groups.

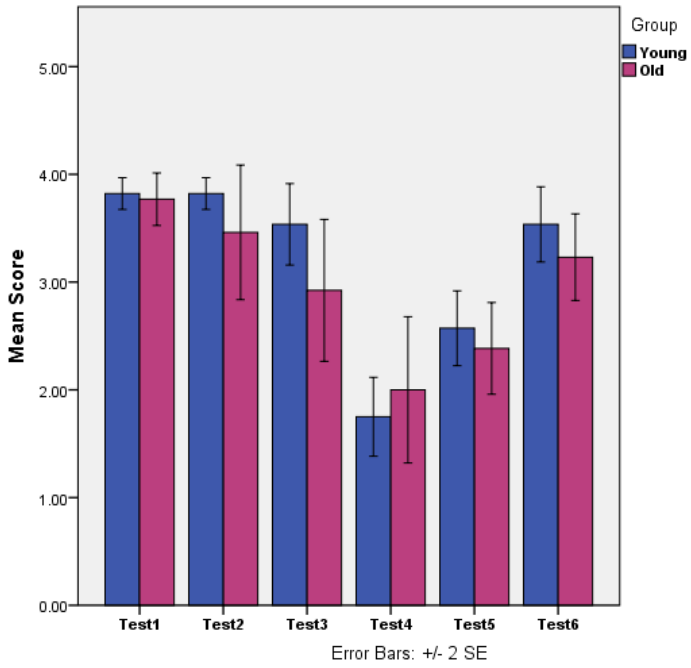

Figure 3.16. BADs sub-test scores.

3.3.6 Correlation

For the old group, there were significant correlations between the BADs total profile score and the FGA under single task condition (r=.621, p=.023) and ABC questionnaire score (r=.570, p=.042). In addition, age-corrected BADs scores for older healthy adults correlated with FGA-single (r=.647, p=.017) and FGA-motor (r=.654, p=.015).

BADs sub-scores in test 3 (the “key search test”) correlated significantly with walking velocity under dual tasking conditions in the busy (r=.580, p=.038), quiet (r=.605, p=.028), and cobble segments (r=.756, p=.003).

The young group did not show any significant correlation between BADs scores with walking velocity or acceleration.

3.4 Discussion

In this study, we evaluated the effect of dual tasking on balance control during an indoor and outdoor gait assessment task conducted by young and old healthy adults. TUG and FGA assessments were used indoors, while the outdoor task involved walking on a pre-set route around the London Bridge area, where participants were exposed to five different urban environments. Three tri-axial accelerometers were attached to the head, neck, and trunk. Walking velocity and acceleration in the ML, AP, and V directions were measured. Cognitive evaluation was conducted using BADs. Results showed that, for dual cognitive tasking, both groups had significantly reduced FGA scores, though the old group showed a higher fall risk with cognitive dual tasking. In addition, trunk ML RMS acceleration was significantly reduced in the old group compared with the young group. Performance in BADs tests were the same for both groups.

3.4.1 Effect of Single Tasking

This study is the first to investigate the effect of outdoor environments on walking velocity and body acceleration in healthy adult populations. To our knowledge, all previous studies have been carried out in indoor laboratories. The main result of our pilot study is that the velocity of older healthy adults is significantly reduced compared with young adults. Moreover, the walking environment has a significant effect on the velocity adopted by study participants. Our results show a significant reduction of walking velocity in the colonnade, busy, and cobble segments, compared with walking velocity in the quiet or street crossing segments. The reduction of velocity in these segments suggests that these environments may hinder participants by exposing them to many challenges, such as visual contrast flooring in the colonnade, crowds in

the busy segment, and an uneven walking surface in the cobble segment. Although the same effect was achieved by both study groups in outdoor segments, the reduction in velocity was more significant in the older adult group. This could be due to the increase in visual sensitivity experienced by older adults in busy visual environments compared with young adults (Borger et al., 1999, Sundermier et al., 1996). Alternatively, it may be due to the decreased functional capacity associated with the aging process, which involves changes in the sensory system (i.e., vision, vestibular, and proprioceptive) and the motor system (i.e., decrease in muscle strength) (Maki and McIlroy, 2003).

Comparison of the walking velocity of both study groups for all walking segments with age correspondent meta-analytic reference values (Bohannon and Williams Andrews, 2011) confirmed the previously reported inverse relationship between age and walking velocity. On the other hand, the mean walking velocity in the street crossing segment for both groups under both walking conditions was above 1.2 m/s, which is the minimum walking velocity required for safe pedestrian crossing both internationally and in the UK (Asher et al., 2012). This finding for the old group should be viewed with care due to the number and type of participants; our older adults are very physically and mentally active.

These results differ from Kavanagh et al. (2004, 2005), who found no evidence of significant difference in gait velocity between young and elderly while performing straight-line walking along a 20 m walkway. Despite the fact that these studies and our study had limited numbers of healthy old adults, the discrepancy in findings could be due to fact that our study was carried out in an

urban, less predictable, and thus more challenging environment, while the other two studies took place in conventional laboratories. Our walking segments, showing significant differences in walking velocities, had the advantage of exposing participants to busy visual surroundings and uneven walking surfaces that are not available in a controlled laboratory setting. In the studies reported by Kavanagh et al., participants were simply instructed to focus on a target at the end of a walkway.

In addition, we found that the old group had lower RMS accelerations compared with the young group in all walking segments, body levels, and acceleration directions. However, by removing the effect of the velocity we found that trunk ML RMS acceleration was significantly reduced in the old group compared with the young group. The present finding appears consistent with other research which found that lateral stability is challenging in older adults during both walking and standing tasks (Hilliard et al., 2008, Maki et al., 1994, McClenaghan et al., 1996, Park et al., 2014).

Menz et al. (2003) reported similar findings in his old group. This reduction in magnitude of acceleration may be attributed to a reduction in walking speed, suggesting that older people adopt a slower speed to keep the magnitude of head and pelvis acceleration at a tolerable level. This perhaps suggests that older subjects may have some difficulty in attenuating head accelerations when walking at a fast pace.

TAR results suggest that TAR was most effective in the AP direction and least effective in the V direction, without a significant study group effect. These findings are consistent with those of Kavanagh et al. (2004) and Winter (1991),

indicating that the trunk does not play a major role as a shock absorbent in the vertical direction, though it does in attenuating AP acceleration at the level of the head. ML TAR was reduced in the older adult group compared with the young group, but did not reach a significant level. This finding must be viewed with care and re-examined using a larger and more heterogeneous sample size. In addition, the ML TAR was significantly affected by walking segments: it was significantly reduced in the colonnade and busy segments.

For the indoor assessment, the TUG score was significantly higher in the old age group relative to the young group, however the old group score did not reach the cut-off point of 13.5 s used to predict falls in community dwelling adults as investigated by Shumway-Cook et al. (2000). In addition, our study found that gender had no significant effect on TUG score, consistent with the finding reported by Kamide et al. (2011).

The FGA score under the single task condition was consistent with reference values provided by Walker et al. (2007) for each age group, and above the cut-off value for predicting falls in the elderly (Wrisley and Kumar, 2010).

3.4.2 Effect of Dual Tasking

The FGA scores were significantly reduced in the older age group compared with the healthy adult group. The addition of a secondary task led to a significant reduction in FGA scores in both groups, however, old group FGA scores were below the cut-off scores used to predict falls in community older adults (Wrisley and Kumar, 2010). Moreover, we found no significant difference between FGA scores under the two cognitive tasking conditions used. In the

young age group, FGA scores under cognitive task conditions were comparable to the functional abilities of a two decades older participant, as indicated in reference values provided by Walker et al. (2007). In the older group, the addition of cognitive tasks tended to increase fall risk. The fact that our older group were healthy and active allowed us to speculate that having a larger and more heterogeneous group of older adults might reveal a higher risk of fall under dual task conditions. The current finding is in agreement with Maylor and Wing (1996) who showed that postural stability is increasingly affected by the addition of a cognitive task in older age groups, and with Beauchet et al. (2005), who found that mean stride time in older adults increased significantly when they walked and performed an arithmetic or verbal fluency task compared with when they were only walking.

On the other hand, the outdoor walking velocity was reduced with dual tasking in both study groups, but this effect didn't reach the level of significance. This pilot study has been unable to demonstrate that older adults are affected significantly more by dual tasking than young adults, as reported by (Beauchet et al., 2003, Hollman et al., 2007, Lundin-Olsson et al., 1997). In Lundin-Olsson et al. (1997), talking was used as a secondary task to walking in residents in sheltered accommodation. Patients had an average age of 80 years and had been diagnosed with dementia, depression, or previous stroke. The study protocol used cannot establish whether the effect of dual tasking is due to the effect of aging or the effect of impaired cognitive abilities in study participants. In Hollman et al. (2007), older adults walked more slowly than younger and middle-aged adults in the normal and dual walking conditions. The cognitive task used was backwards spelling of words while walking, a task considerably

harder than our numeracy and literacy tasks. In addition, the mean age of older adults was 81 ± 5 years, older than that used in our study: 69.15 ± 5.74. However, cognitive performance in dual task walking did not differ significantly between groups, consistent with our study findings. Beauchet et al. (2003) found an increase in stride-to-stride variability during dual tasking in older adults only. Their older group average age was 83 ± 7.7, older than the older group average of this study, while the dual tasking was counting backwards. In addition, walking velocity was not used as a measuring parameter of stability. On the other hand, Springer et al. (2006) showed that, despite the fact that walking velocity reduced with dual tasking in both young and older groups, elderly non-fallers and young adults maintained a stable gait under all dual-task conditions, with no difference in gait variability between the two groups.

The discrepancy between our study findings and that of previous studies can be attributed to many factors. These factors include: a) the limited number of participants in our pilot study; b) participants' age and inclusion criteria used; and c) methodological differences in the types of dual tasks used.

In dual tasking, acceleration at the trunk and neck levels was reduced significantly in the ML, AP, and V directions, and in the AP and V directions at the head level. Moreover, the trunk attenuation rate (TAR) in the ML direction was significantly reduced under dual tasking conditions. Although the group effect was not significant, we found that ML TAR was reduced in the older group and was significantly worsened by the addition of dual tasking. These findings are in accord with previous research undertaken by Asai et al. (2013) and Doi et al. (2011), who reported that TAR in the ML direction was significantly reduced in healthy older adults with the addition of dual tasks. The fact that our result

didn't reach the level of significance could be attributed to the limited number of participants in our older adults group.

3.4.3 Cognitive Abilities and Dual Tasking

Our results showed no significant difference in the cognitive assessment test battery between the old and young group. In addition, the response to the cognitive tasks did not show significant difference in the response rate or error rate either during FGA or during the outdoor walking tasks.

The observed reduction in FGA scores with dual tasking indicates that the performance of cognitively demanding tasks has a destabilising effect, potentially placing participants (especially the old group) at greater risk of falling. This is consistent with the findings of Yogev-Seligmann et al. (2010), who report that in dual taking situations involving motor and cognitive tasks, older participants who are not given any prioritization instructions will give more attention to cognitive tasks over the balance task. This is in contrast with the "posture first strategy", in which all attention is directed toward maintaining balance and preventing falls.

The effect of dual tasking results in decreased walking velocity in the urban environment, a mechanism adopted by both groups to compensate for the attention demanding cognitive task. Moreover, medio-lateral trunk stability was affected in the older group, as indicated by the reduction in the trunk attenuation rate.

3.5 Conclusion

As far as we know, no previous study has used the dual task paradigm to investigate its potential effect on FGA scores or dynamic balance during walking activities in an outdoor environment. The findings of this pilot study indicate that the addition of a cognitive task compromised the dynamic balance of older adults when carrying out FGA and free walking in an outdoor environment. Further studies with a larger sample size and a heterogeneous group of older adults will need to be undertaken to further verify some important (albeit statistically insignificant) observations. This study's findings may aid in the assessment of old adults who may overestimate their ability to function independently, unless assessed in a situation that resembles real world conditions.

CHAPTER 4.

The Effect of Cognitive Dual Tasking on Functional Gait Assessment in Patients with Peripheral Vestibular Disorders

4.1 Introduction

There is growing research interest on the relationship between cognitive deficits and gait disorders. This relationship has been investigated via dual tasking methodologies in healthy people (Pellecchia, 2003, Siu and Woollacott, 2007, Woollacott and Shumway-Cook, 2002), as well as in patient groups including stroke sufferers (Plummer-D'Amato et al., 2008), patients with dementia (Allali et al., 2007), and patients with Parkinson's disease (O'Shea et al., 2002).

Studies examining the effect of cognitive tasks on balance performance in patients with vestibular disorders compared with healthy subjects have mainly assessed posture while standing on a fixed and a sway-referenced floor (Redfern et al., 2004, Yardley et al., 2001), while studies assessing dynamic balance-cognitive interactions in vestibular patients are very limited (Bessot et al., 2012, Nascimbeni et al., 2010, Roberts et al., 2011). Moreover, none of these studies used neuropsychological measures to assess cognitive abilities in patients with vestibular dysfunction.

Vestibular patients may have cognitive deficits, such as decreased concentration, auditory short term and spatial memory deficits, and difficulties with multitasking (Hanes and McCollum, 2006). The addition of a cognitive task when performing a balance task will result in greater attentional demands and the need to be capable of flexibly dividing attention between two tasks. The

dependence on executive functions becomes more significant as the complexity of either the motor or the cognitive task increases (Ble et al., 2005); this may reveal minor gait dysfunction even in healthy subjects. Inability to flexibly divide attention could be one important factor contributing to imbalance during gait and fall; this has been noted in older adults (Shumway-Cook et al., 1997, Siu et al., 2009).

To our knowledge, no previous study has used a dual tasking paradigm while carrying out functional gait assessment (FGA), and no study has assessed the relationship between patient performance in dual tasking with performance in neuropsychological tests.

In this study, FGA was conducted with and without a secondary motor and a secondary cognitive task, in order to investigate the effect of dual tasking on dynamic balance as reflected by FGA scores in patients diagnosed with unilateral peripheral vestibular disorders and age-matched controls. Furthermore, a cognitive assessment was carried out using the BADs, in order to assess whether baseline cognitive performance correlated with FGA scores.

We hypothesized that the addition of a secondary task would adversely affect the performance of the UVD patients when compared with healthy age-matched controls.

The information obtained from this study may provide insight into dual task interference with postural stability during walking (a situation commonly encountered in everyday life) and its effect on postural strategy used, cognitive performance, and fall risk. Findings could be used to modify patient rehabilitation programmes currently in use.

4.2 Materials and Methods

4.2.1 Participants

Patients diagnosed with a peripheral vestibular disorder were recruited from the Department of Neuro-otology at the National Hospital for Neurology and Neurosurgery (NHNN), Queen Square, London. The patients were diagnosed by consultants on the basis of their clinical history and neuro-otological findings. An invitation letter with the study information sheet was sent to the patients, and was followed by a phone call to confirm whether they wished to participate. Healthy controls were staff and students King's College, Neuro-otology staff, and the UVD patients' friends and relatives. A consent form was signed by each participant at the beginning of the assessment session.

The inclusion criteria were:

- 18-80 years old;
- History of vertigo and/or imbalance and presence of a peripheral vestibular deficit with a significant canal paresis CP of 8% or more in observational caloric (duration parameter) or at least 20% in videonystagmography-VNG recorded caloric and/or C-VEMP abnormality as reflected by either absent response or amplitude asymmetry of 37% or more (as per departmental normative data);
- ndependently walking in the community.

The exclusion criteria were:

- Patients who had a neurological condition other than vertigo, an unstable medical condition (e.g., uncontrolled diabetes or hypertension), acute orthopaedic injury, severe visual impairment which may affect their balance, dementia or clinical depression with a score >15 on the depression part of HADs.

4.2.2 Questionnaires

The following questionnaires were used. Refer to Section 2.1 for the details of each questionnaire.

- The Dizziness Handicap Inventory (DHI) (Jacobson and Newman, 1990)).
- The Situational Vertigo Questionnaire (SVQ) (Guerraz et al., 2001) .
- The Activities of Balance Confidence Scale (ABC) (Powell and Myers, 1995).
- The Vertigo Symptom Scale (VSS) (Yardley et al., 1992).
- The Vestibular Disorders Activities of Daily Living Scale (VD-ADL) (Cohen and Kimball, 2000).
- The Hospital Anxiety and Depression Scale (HAD) (Zigmond and Snaith, 1983).

4.2.3 Indoor Gait Assessment

All participants completed the Timed Up and Go (TUG) test and the Functional Gait Assessment under single and dual task conditions. The testing protocol is detailed in Section 2.2.

4.2.4 Behavioural Assessment of Dys-Executive Syndrome Test Battery (BADs)

All participants received cognitive assessment using the BADs tests battery. The details of the battery are outlined in Section 2.4.

4.2.5 Statistical Analysis

Statistical analysis was performed using SPSS Version 22 (SPSS Inc, Chicago USA). The data were presented as mean ± standard deviation. Significance for all tested variables was assumed if $p<0.05$.

The Mann Whitney U test was used to assess between groups difference in all questionnaire scores and BADs scores. Two-way ANOVA was used to analyse TUG scores and to determine the effect of study groups and gender on participant scores, and to determine whether there was an interaction between the independent variables.. FGA scores were analysed using two-way mixed ANOVA. The independent variables were the study group (2 levels) and the testing condition (4 levels: single, motor, cognitive numeracy, and cognitive literacy).

The effect size was calculated using Pearson's rho (Field A 2009) for Mann Whitney U test.

$$r = \frac{z}{\sqrt{N}}$$

z = Test statistic

N = Number of participants

4.3 Results

4.3.1 Participant Demographics

A total of 37 participants were tested. Two were excluded from analysis (1 had facioscapulohumeral muscular dystrophy (FSHD) and 1 had benign intracranial hypertension), and one decided to withdraw in the middle of a testing session for no obvious reason.

A total of 34 UVD (13 male, 21 female) were thus included in the analysis. The mean age was 55.32 years (SD 12.94; range 26-74).

The control group had a total of 34 age-matched healthy participants (15 male, 19 female) with a mean age of 53.32 (SD 15.63; range 26-79). There was no significant difference between the mean age for both groups (p=0.542).

The aetiology of unilateral vestibulopathy in the patient group is summarized in Table 4.1.

Vestibular Neuritis	18
Labyrinthitis	2
Head Trauma	2
Ramsay Hunt Syndrome	1
Vascular	1
Vestibular Schwannoma (under observation, surgical intervention not required).	10

Table 4.1. Aetiology of UVD in patient group.

4.3.2 Questionnaires

There was a significant difference in all questionnaire scores between vestibular patients and the control group ($p<0.01$), as shown in Table 4.2.

Questionnaire	UVD		Control		p-value	r-value
	Mean	SD	Mean	SD		
ABC Total Score	64.41	21.35	97.38	4.38	**0.001**	**.77**
HAD Depression Score	7.15	4.34	1.20	1.98	**0.001**	**-.72**
HAD Anxiety Score	8.94	5.01	3.5	2.97	**0.001**	**-.55**
SVQ Score	1.62	.92	.14	.24	**0.001**	**-.80**
VD-ADL Functional Score	42.42	23.09	12.40	2.23	**0.001**	**-.86**
VD-ADL Ambulation Score	26.84	11.88	9.44	1.74	**0.001**	**-.85**
VD-ADL Instrumental Score	21.30	11.89	7.38	1.49	**0.001**	**-.75**
VSS Vestibular Score	20.78	19.95	.58	1.37	**0.001**	**-.82**
VSS Somatic Anxiety Score	18.71	9.59	2.59	2.92	**0.001**	**-.78**
DHI Total	50.40	26.55	1.00	2.60	**0.001**	**-.87**
DHI Emotional Score	15.46	9.85	.12	.70	**0.001**	**-.86**
DHI Functional Score	18.31	10.53	.24	.83	**0.001**	**-.85**
DHI Physical Score	16.93	7.08	.65	1.61	**0.001**	**-.87**

Table 4.2. Mean and SD of questionnaire scores for UVD and control group.

4.3.3 Indoor Walking Tasks

4.3.3.1 Timed Up and Go (TUG)

The TUG score was significantly higher in the UVD (*M* = 11.25, *SD* = 2.44) than in the control group (*M* = 8.83, *SD* = 1.84), with a significant main effect of study group, F (1, 64) = 21.459, p=.001, η_p^2=0.251 (Figure 4.1). However, there was a non-significant main effect of gender on TUG score, F (1, 64) = 0.128, p=0.722, and no significant interaction effect between study group and gender on TUG score, (1, 64) = 0.490, p=0.486.

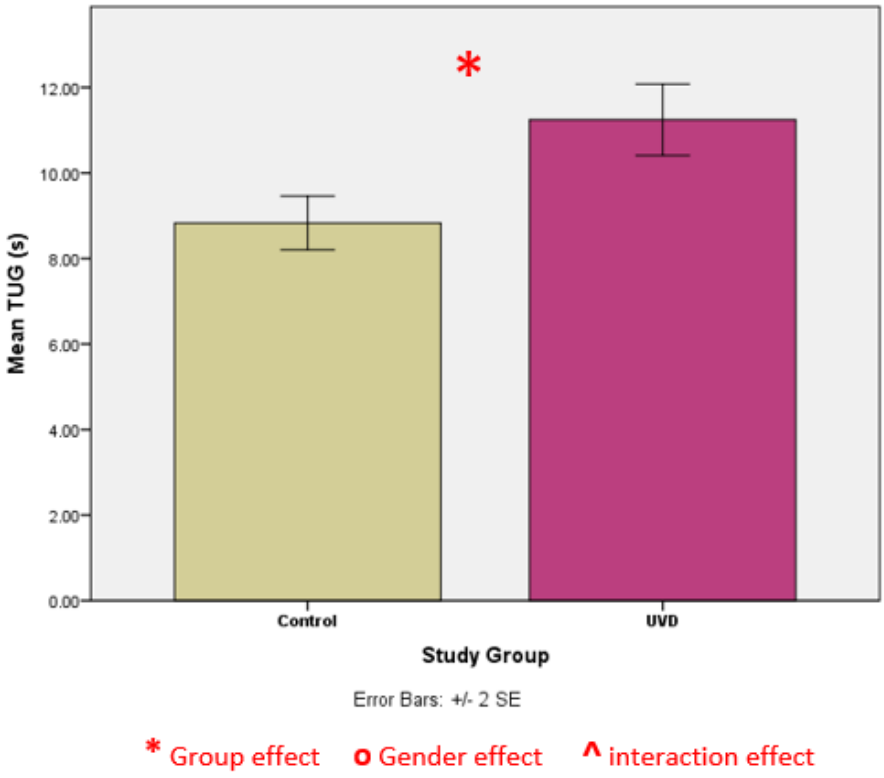

Figure 4.1. Mean TUG score in UVD and control groups.

4.3.3.2 Functional Gait assessment (FGA)

The UVD group had lower FGA scores under all FGA testing conditions compared with the control group, with a significant group effect, F (1, 66) = 30.186, p=0.001, η_p^2 =0.314, and a significant effect of testing conditions, F (2.29, 151.439) = 129.721, p=0.0001, η_p^2= 0.663. However, there was no significant interaction between testing conditions and study groups, F (2.295, 151.439) = 0.953, p=0.398. Post-hoc comparison using Bonferroni adjustment showed that FGA-Numeracy and FGA-Literacy scores were significantly reduced compared with FGA-Single & FGA-Motor with p-values <.0001 as shown in Figure 4.2 and Table 4.3.

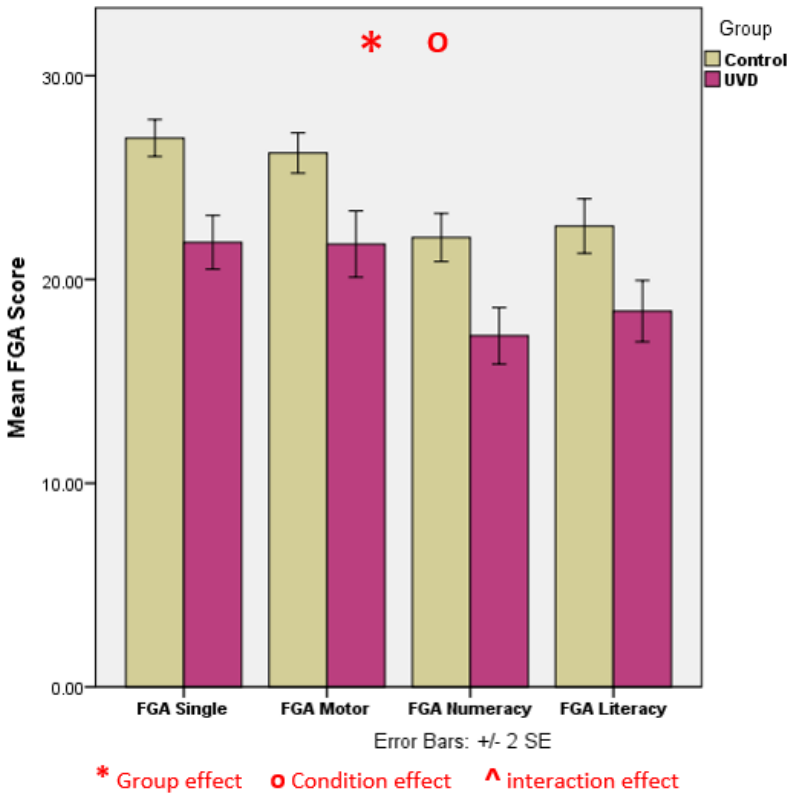

Figure 4.2. Mean FGA scores in UVD and control groups.

	UVD			Control		
	Mean	**SD**	Fall Risk (%)	**Mean**	**SD**	Fall Risk (%)
FGA-S	21.85	3.9	55.9%	26.88	2.65	2.9%
FGA-M	21.52	4.6	55.9%	26.15	2.90	5.9%
FGA-N	17.15	4.07	100%	21.94	3.43	52.9%
FGA-L	18.21	4.25	88.2%	22.61	3.40	50.0%

Table 4.3. Mean, SD, and fall risk from FGA scores in the two study groups. The risk of fall was calculated as a percentage of participants who had a total score of 22 or less as suggested by Wrisley and Kumar (2010)

In addition, the percentage of participants who had a high risk of fall was calculated for each study group under each FGA testing condition. This was based on a total FGA score of 22 or less, as suggested by Wrisley and Kumar (2010). The result showed that the risk of fall was significantly higher for UVD participants compared with their control group under all testing conditions. In addition, it was higher under cognitive tasking conditions compared with single or motor conditions within each study group (Table 4.3).

Furthermore, we compared FGA scores between young patients under 60 years diagnosed with peripheral vestibular disorders with an age-matched control, and healthy older adults above the age of 60 from Chapter 3. The result showed that, though the young UVD had a significantly higher fall risk than the older group under FGA single and motor conditions, both groups had a similar risk of fall under dual cognitive tasking conditions (Table 4.4).

	UVD (<60) n=20			Control (<60) n=20			Old (>60) n= 13		
	Mean	SD	Risk of Fall (%)	Mean	SD	Risk of Fall (%)	Mean	SD	Risk of Fall (%)
FGA-S	22.65	3.78	50%	27.56	2.35	0%	26.08	3.0	7.7%
FGA-M	22.60	5.01	50%	27.05	2.35	5%	25.08	3.33	7.7%
FGA-N	17.90	3.83	100%	23.05	3.40	15%	20.62	3.22	76.9%
FGA-L	18.85	4.56	85%	23.60	4.07	20%	21.31	3.38	61.5%

Table 4.4. FGA scores in the young UVD group vs. controls vs. older healthy participants under various FGA testing conditions. The risk of fall was calculated as the percentage of participants with a total score of 22 or less, as suggested by Wrisley and Kumar (2010).

4.3.3.3 Cognitive task scores during FGA

The number of responses for numeracy and literacy tasks during FGA testing did not show a significant difference between UVD (N: 30 ± 11.8/ L: 54.24±14.8) and the control group (N: 34.5 ± 14.05 / L: 51.39 ± 13.65).

The number of errors for numeracy and literacy tasks during FGA did not show a significant difference between UVD (N: 3.7 ± 4.37 / L: 4.6 ± 4.04) and the control group (N: 3.79 ± 2.74 / L: 4.67 ± 4.63).

4.3.4 Behavioural Assessment of Dys-Executive Syndrome Test Battery (BADs)

The distribution of BADs score classifications in both study groups did not differ significantly, χ^2 (6) = 8.574, *p* = .199 (Figure 4.3).

Total profile score, total standardized score, and age corrected score did not show significant differences between study groups. However, comparing the performance between the study groups in each sub-test shows that the UVD group had a statistically significant lower score in Test 1 (*U* = 918.0, *z* = 4.655, *p* = .0005, r=.56), Test 2 (*U* = 544.5, *z* = 2.266, *p* = .023, r=.30), and Test 3 compared with the control group (*U* = 799.5, *z* = 2.844, *p* = .004, r=.35) (Figure 4.4).

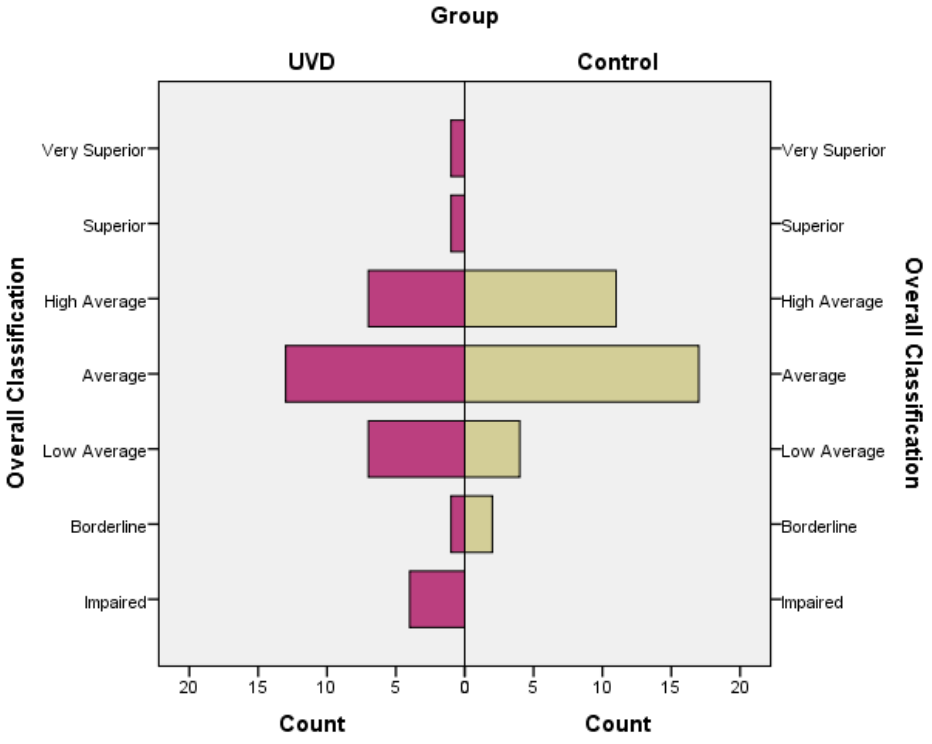

Figure 4.3. Distribution of BADs overall classification in UVD and control groups.

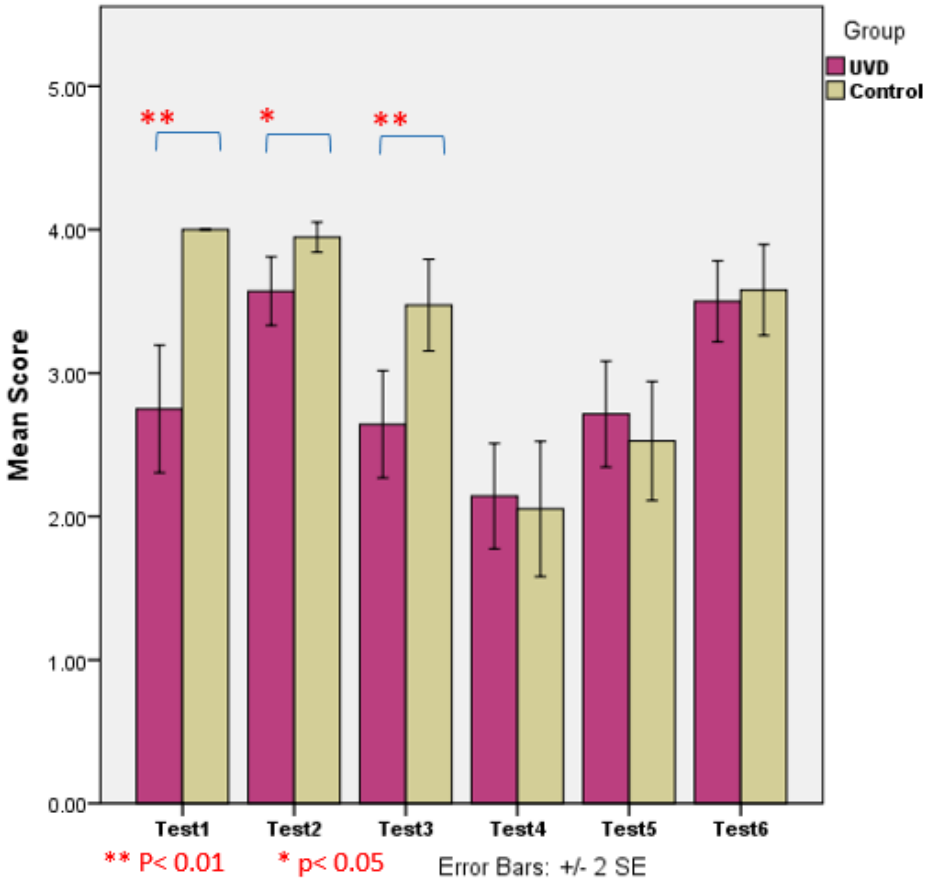

Figure 4.4. BADs tests battery scores for UVD and control groups.

4.3.5 Correlation

The UVD group showed the following significant correlations between the various questionnaires used in the study, and between ABC questionnaires and FGA under dual task conditions. The details of these correlation are as follows.

A decrease in ABC score was significantly associated with increased HAD-Depression score (r=-.412, p=.017), HAD-Anxiety score (r=-.524, p=.002), SVQ Score (r=-.678, p=.000), VD-ADL Functional (r=-.624, p=.000), VD-ADL Ambulation (r=-731, p=.000), VD-ADL Instrumental (r=-.648, p=.000), VSS Vestibular (r=-.648, p=.000), VSS-Somatic (r=-.434, p=.013), DHI-Total (r=-.706, p=.000), DHI-Emotional (r=-.638, p=.000), DHI-Functional (r=-.705, p=.000), and DHI-Physical (r=-613, p=.000).

In addition, a decrease in ABC score was significantly associated with decrease in FGA-Motor Score (r=.430, p=.012), FGA-Numeracy Score (r=.478, p=.030), and FGA- Literacy Score (r=.494, p=.003).

An increase in TUG score was significantly correlated with decrease in FGA-single score (r=-.497, p=.003), FGA-Motor Score (r=-.694, p=.000), FGA-Numeracy Score (r=-.513, p=.002), and FGA-Literacy Score (r=-.563, p=.001).

BADs total scores or sub-scores did not correlate significantly with any functional gait assessment scores.

4.4 Discussion

The present study was designed to determine the effect of dual tasking on postural control and gait while carrying out indoor gait assessment tasks in participants diagnosed with unilateral peripheral vestibular disorders and age-matched healthy controls. In addition, the impact of cognitive ability on FGA performance was assessed by correlating FGA scores with BADs test outcomes. Results indicate that FGA total scores were significantly reduced with the addition of cognitive tasks compared with FGA scores for a single task. Cognitive scores were significantly lower in three BADs sub-tests. However, no correlation was noted between FGA scores and various BADs scores.

4.4.1 Effect of Single Tasking

The TUG score was significantly higher in the UVD group compared with the control group and reached the cut-off point recommended by Whitney et al., (2004) for patients with vestibular disorders. The cut-off value of 11.1 s had a sensitivity of 80% compared with 48% if 13.5 s was used instead. Previous studies in UVD patients reported TUG scores to be 19.5 s Gill-Body et al. (2000) while Whitney et al. (2004), reported an average score of 12 s. The mean age of patients in previous studies was 60 years and 62.5 years for Whitney et al. (2004) and Gill-Body et al. (2000) respectively, which is older than the mean for the present study. Moreover, none of our patients used an assistive device during the test, while this was not mentioned clearly in previous studies. The FGA score under single task condition was significantly reduced in the UVD group compared with the control group, and was comparable to the score proposed by Wrisley and Kumar (2010) for predicting falls in older adults.

Considering the findings of TUG and FGA scores as well as the ABC score suggests that our UVD patients may be at risk of fall.

4.4.2 Effect of Dual Tasking

The UVD group had significantly lower FGA scores under all dual task conditions compared with the control group. However, for dual cognitive tasking, UVD scores were significantly below the cut off values used by Wrisley and Kumar (2010) to predict falls in older adults, while control group scores were borderline at this cut-off value. This may indicate that dual tasking interference exerts the same effect on UVD patients as well as healthy controls, though the UVD group had a significantly increased fall risk with the addition of cognitive tasks. This means that our UVD group, who might be at risk of falls as reflected by FGA single task score, is exposed to a higher risk of fall with the addition of cognitive tasks.

The addition of a motor task did not affect the FGA score significantly compared with the cognitive tasks. This may be due to insufficient challenge in the motor task of carrying a cup of water, which suggests that such a task does not require a great amount of attention to interfere with various competing gait tasks. Cognitive numeracy and literacy tasks resulted in lower scores for both groups. The number of responses and errors for numeracy and literacy tasks during FGA did not show a significant difference between the UVD and control groups. Based on these findings we can conclude that that neither group applied the “posture first” strategy, with a clinically significant gait impairment and higher risk of fall noted in the UVD group under dual tasking conditions.

In contrast, when we compared young patients diagnosed with unilateral peripheral vestibular disorders with their healthy aged-matched control and older healthy adults, no significant difference was found between the young UVD group and the older healthy adults group in FGA scores under dual cognitive tasking conditions. This suggests that, despite having normal FGA scores under single and motor task conditions, older healthy adults had a significantly higher risk of fall in the dual cognitive tasking conditions. This indicates that both groups applied a posture second strategy that increased participants' risk of fall and injury.

To our knowledge, no previous study has used the FGA in a dual tasking paradigm. Hence, we compared our results with other studies that carried out different balance and cognitive tasks. Our finding of reduced FGA scores under dual cognitive tasking is in accordance with a previous study by Roberts et al. (2011), in which the vestibular group had significantly slower walking velocity compared with controls under dual task walking with eyes open or closed, though within each group walking while performing a cognitive task was significantly slower than walking without the addition of the cognitive challenge. However, the authors did not document responses to cognitive task scores. Research by Bessot et al. (2012) also accords with our findings, demonstrating that patients with bilateral vestibular loss have a slower gait speed in dual tasking, and a higher reduction in gait speed from single to dual tasking, but no difference in cognitive performance compared with healthy controls in single and dual task conditions.

In contrast, a study by Nascimbeni et al. (2010) showed that both the UVD and the control group had a more conservative gait during dual tasking, with no

significant difference in gait parameters such as foot contact (FC), swing (Sw), double support (DS), stride time (ST), and coefficient of stride time variance (CV). In cognitive tasks, only the UVD group showed a significant decline in performance when moving from single to dual task conditions. This suggests that their patient group adopted a balance-first strategy. The discrepancy between our findings and those of Nascimbeni et al. (2010) may be attributable to the fact that their patients received vestibular rehabilitation following neuronitis, while ours did not receive rehabilitation.

Redfern et al. (2004) reported normal postural responses in UVD patients showing impairment in cognitive task performance. Yardley et al. (2001) found that vestibular patients prioritize posture over cognitive tasks, leading to an increase in mental task response time and a reduction in the accuracy of mental tasks, though both vestibular patients and controls were affected. Both of these studies, however, involved postural tasks rather than dynamic balance tasks, as in our study. In addition, the patients in Redfern et al. (2004) were functionally fully compensated and asymptomatic.

Inconsistencies with the findings of previous research may be due to the different primary motor and secondary cognitive tasks used, and the type of instructions given to participants regarding whether to prioritize balance or cognitive tasks in the different studies. In our study, no-prioritization instructions were given. Participants were asked to complete both tasks to the best of their ability.

4.4.3 Cognitive Abilities and Dual Tasking

Damage to the vestibular system has been linked to cognitive impairment as suggested by animal studies (Russell et al., 2003, Stackman et al., 2002, Wallace et al., 2002) and a neuroimaging study (Brandt et al., 2005) proposing that patients with bilateral vestibular nerves had atrophy of the hippocampus correlating with spatial memory deficits. Therefore, many studies have used a dual task model to indirectly evaluate executive function. However, there are also many neuropsychological tests, such as the Weschler Memory Scale (WMS) and the Digit Span Test (a part of the Weschler Intelligence Test) that have been developed to assess memory and attention, respectively. Recently, computerized versions of the Morris water maze task have been used to assess spatial memory (Schautzer et al., 2003). However, all these tests are designed to exclusively assess one executive function at a time, while the BADs test battery is designed to assess a range of cognitive abilities that are utilised in many everyday activities (Norris and Tate, 2000, Wilson et al., 1996). Our results show that UVD group performance in Test 1 (Rule Shift Cards), Test 2 (Action Programme), and Test 3 (Key Search) was significantly lower than in the control group. This reveals that UVD patients have lower cognitive flexibility, and lower novel problem solving and planning abilities. These skills are necessary to be able to navigate safely, especially in challenging and unpredictable environments. Rule Shift Cards is a test of cognitive flexibility, which is required to be able to compare ongoing actions in the environment with body static and dynamic posture to facilitate decision making and flexible behaviour in adjusting bodily response accordingly. Impaired mental flexibly may affect the ability to adjust gait and posture, increasing the chance of fall and injury. In contrast, Action Programme and Key Search test the ability to

identify and organize elements in order to develop plans and undertake actions. A deficit in problem solving and planning abilities may affect decisions that need to be made when walking in a complex environment, such as finding one's way in a new setting, or performing an action to avoid an obstacle. The impairment of such skills may be the cause of decreased balancing ability during dual tasking, and having a significantly increased risk of fall.

The lack of a significant difference for dual task total response and error scores between study groups (despite having reduced BADs scores in three subtests) can be supported by the findings of Risey and Briner (1990). Risey and Briner provided evidence that patients with peripheral vestibular lesions performed normally on all arithmetic/counting tests, and that only patients with central vestibular lesions were likely to make arithmetic errors. Moreover, in Hufner et al. (2007), patients with unilateral vestibular neurectomy did not demonstrate hippocampal atrophy, as identified by Brandt et al. (2005) in their group of patients with bilateral vestibulopathy. These findings may indicate that the presence of one normally-functioning labyrinth may help preserve the critical volume of the hippocampus required to maintain performance in relatively simple arithmetic and numerical tasks.

Studies using neuropsychological measures to assess cognitive abilities in vestibular patients are very limited. In a study by Schautzer et al. (2003), 10 patients with bilateral vestibular loss as a result of NF2 had to complete a computerized virtual water maze task. Only 50% of patients could directly navigate to the hidden platform on the screen, compared with 100% of controls. This result may reflect deficits in memorising spatial locations for patients with bilateral vestibular dysfunction. Gizzi et al. (2003) used the Neurobehavioral

Symptom Inventory to measure a range of neurological and psychological symptoms in 200 patients with balance disorders. The results showed that cognitive complaints were more common in dizzy patients with a history of brain trauma. There was no significant correlation between the diagnosis of vestibular dysfunction and the frequency of cognitive complaints.

In contrast with Schautzer et al. (2003), our cohort of vestibular patients had unilateral peripheral disorders. Moreover, the study by Gizzi et al. (2003) gathered epidemiological data using the Neurobehavioral Symptom Inventory, rather than a cognitive test.

4.5 Conclusion

Dual tasking interferes with postural stability during various tasks of functional gait assessment (FGA), with cognitive tasks prioritized over balance in patients with a unilateral peripheral vestibular disorder, as well as in normal controls. This suggests that patients are at higher risk of fall in multitasking situations commonly encountered in everyday life. Cognitive impairment in patients diagnosed with peripheral vestibular disorders (as reflected in impaired mental flexibility and planning ability) may lead to inappropriate shifting of attention in dual task situations, and may increase the risk of fall and injuries. This finding could be used to inform the development of existing patient rehabilitation programmes.

CHAPTER 5.

The Effects of Dual Cognitive Tasking on Free Walking in Patients with a Peripheral Vestibular Disorder

5.1 Introduction

A normal cyclical gait movement produces oscillations that travel from the lower limbs toward the trunk and the head (Kavanagh 2006). Normally, the trunk acts as a low-pass filter that attenuates these oscillations and minimizes their transmission to the head. This mechanism provides a stable platform at the level of the head that is crucial to ensure proper processing of visual and vestibular information required for body and gaze stability. This process of maintaining balance control during dynamic locomotion can be challenging for vestibular patients. Compared with healthy individuals, patients with vestibular disorders are reported to have reduced trunk movement in the yaw axis (Lang et al., 2013) and to have a higher level of head movement while walking (Mamoto et al., 2002).

Despite the fact that gait disorders associated with loss of sensory input may be less obvious than those resulting from musculoskeletal or cerebellar disorders (Nutt et al., 1993), their impact on patients' daily activities and quality of life is of paramount importance (Mira, 2008). Patients with vestibular disorders adopt more conservative gait patterns characterised by reduced walking velocity (Bessot et al., 2012, Borel et al., 2004, Glasauer et al., 1994, Kim et al., 2014, Mamoto et al., 2002, Roberts et al., 2011) and experience unsteadiness while walking. This puts them at high risk of falls and injuries (Herdman et al., 2000). Moreover, previous studies suggest that the presence of an underlying

vestibular pathology increases the attentional demand required to control postural and dynamic balance.

To date, gait assessment studies in vestibular patients have been carried out only in indoor controlled laboratories. These setting fail to expose patients to unexpected challenges they may encounter in everyday life.

In this study we used an accelerometer device to assess gait in patients with peripheral vestibular disorders. Patients were asked to walk in an outdoor pre-set route that exposed them to five different environments. The assessment was performed with and without a concurrent cognitive task. We hypothesised that the trunk's function as a low-pass filter attenuating acceleration as it passes to upper body segments would be impaired in patients with vestibular disorders, and that the addition of a cognitive task would further compromise this function.

The objectives of this study were: (1) to determine how patients diagnosed with a peripheral vestibular disorder navigate in an outdoor environment; (2) to examine the effect of adding a secondary cognitive task on dynamic balance.

5.2 Materials and Methods

5.2.1 Participants

Participants from the previous study (Chapter 4) completed the outdoor assessment protocol.

5.2.2 Outdoor Gait Assessment

All participants performed the assessments outlined in Section 2.3.

5.2.3 Statistical Analysis

Statistical Analysis was performed using SPSS Version 22 (SPSS Inc, Chicago, USA). The data was presented as mean ± standard deviation. Significance for all tested variables was assumed if $p<0.05$.

The walking velocity data were analysed using three-way mixed ANOVA with the following independent variables: 1) study groups (two levels); 2) walking conditions (two levels: single and dual); 3) walking segments (five levels: colonnade, busy, quiet, cobble, and street crossing). Significant main effects and any significant two-way interactions between independent variables were presented.

The 9 RMS acceleration outcomes (head, neck, and trunk) were considered separately, and each had 3 directions (ML, AP, and V). We used a mixed-effects regression analysis with subject as the random factor. For all models, velocity was adjusted for by including this variable as a covariate. There was one between-subject factor: group (two levels). There were two within-subject

factors: segment (five levels), and each level had data for 2 conditions (single and dual). All two-way interactions were investigated, i.e., group*condition, group*segment, and segment*condition. We used segment level 3 (the quiet segment) as a baseline segment for exploring the condition*segment interaction in more detail. A Bonferroni adjustment was made to account for multiple comparisons.

The same approach was considered for the 3 Trunk Attenuation Rate (TAR) outcomes.

The TAR was calculated for ML, AP, and V acceleration direction using the following formula (Mira, 2008):

$$TAR\ (\%) = 100\ X\ (1 - Head\ RMS/\ Trunk\ RMS)$$

The higher the TAR (%), the more effective the attenuation of acceleration was toward the head.

5.3 Results

5.3.1. Participants Demographic

A total of 33 UVD participants (12 male, 21 female) were included in the analysis. The mean age was 56.21 years (SD 12.04; range 26-74). The control group had a total of 33 age-matched healthy participants (15 male, 18 female) with a mean age of 54.15 (SD 15.10; range 26-77). There was no significant difference between the mean age for the two groups (p=0.542). Patient diagnoses and inclusion criteria are described in Section 4.3.1.

5.3.2 Outdoor Walking

5.3.2.1 Walking Velocity

Walking velocity was significantly affected by study group, F (1, 64) = 24.176, p=.001, η_p^2=.274, walking condition, F (1, 64) = 93.214, p= .001, η_p^2=.593 & walking segments, F (3.278, 209.802) =29.421, p=.001, η_p^2=.315. In addition, there was a significant interaction between walking conditions and groups, F (1, 64) = 7.108, p=.010, η_p^2=.100, and between walking conditions and walking segments F (3.567, 228.271) = 3.193, p=.018, η_p^2=.048.

This result suggests that patients diagnosed with unilateral peripheral vestibular disorders walk significantly more slowly than age-matched control (Figure 5.1). This is so despite the fact that both groups walked significantly more slowly under dual tasking conditions. The significant group-condition interaction reflects the fact that the patient group was more heavily affected by dual tasking and hence walked at a significantly slower pace during dual tasking (Figure 5.2).

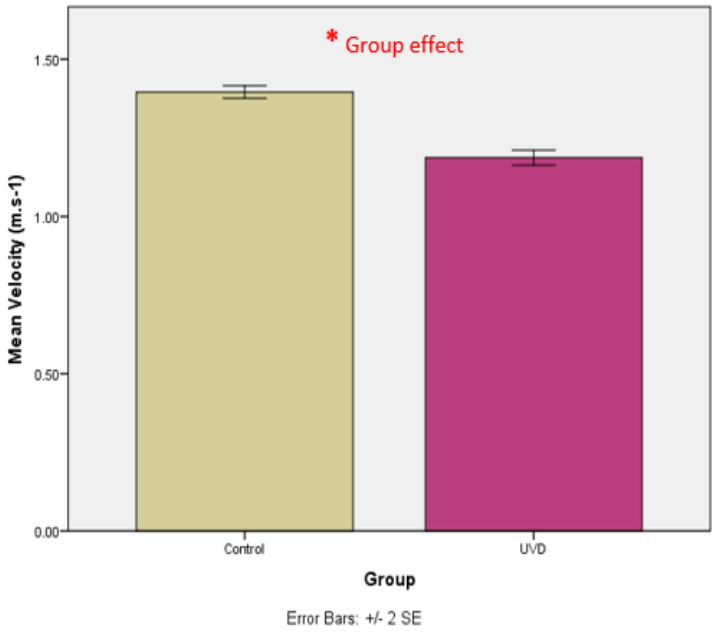

Figure 5.1. Effect of study groups on walking velocity.

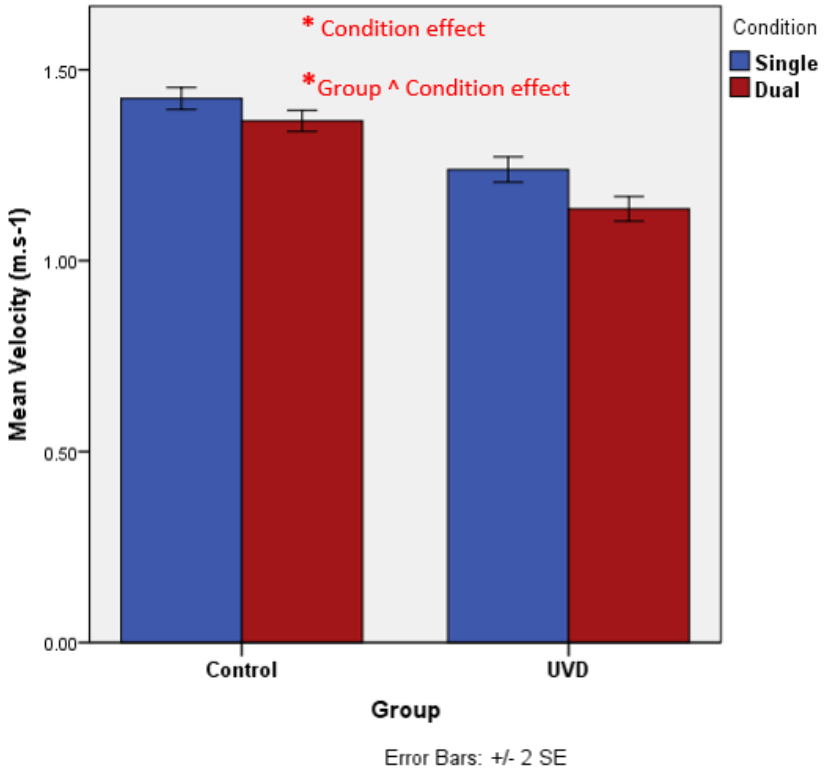

Figure 5.2. Effect of condition and group-condition interaction on walking velocity.

The significantly effect of walking segments (Figure 5.3) was followed by pairwise comparisons with Bonferroni adjustment. The analysis revealed that walking velocity at the colonnade, busy, and cobble segments were significantly reduced compared with the walking velocity of the quiet (p=.001, .001, .001) and street crossing segments (p= .001, .001, .001). In addition, there was no significant difference between the walking velocities of these three segments (i.e., colonnade, busy, and cobble) and walking velocity at the street crossing segment was significantly higher than walking velocity for all other segments, with a p-value of <.05. Figure 5.4 shows that walking velocity in the colonnade segment was the most affected by the addition of the cognitive task. This could be attributed to the increased visual sensitivity to the chalkboard flooring of this segment. Table 5.1 summarises the mean walking velocity for both study groups under various testing conditions and walking segments.

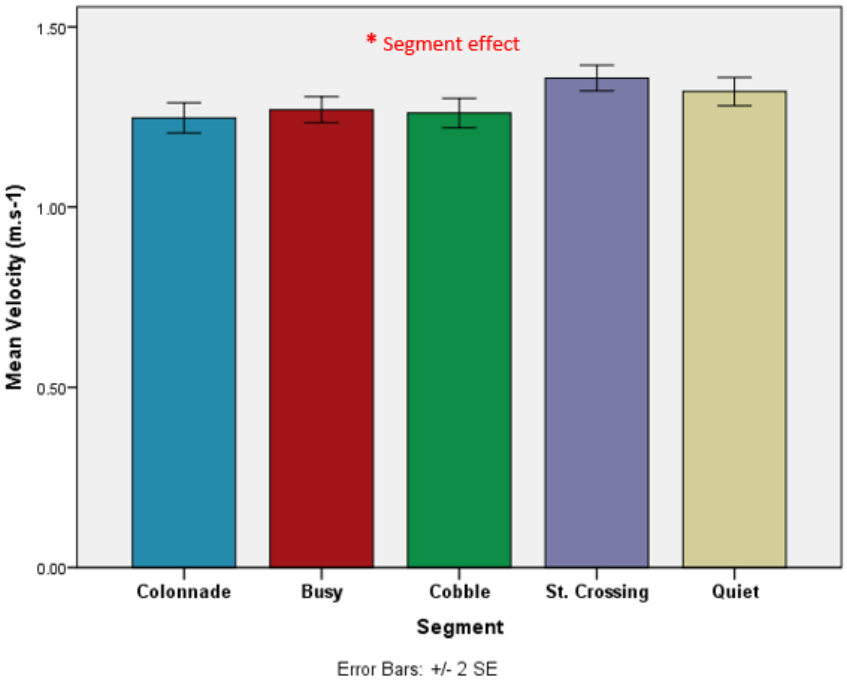

Figure 5.3 Effect of walking segments on walking velocity.

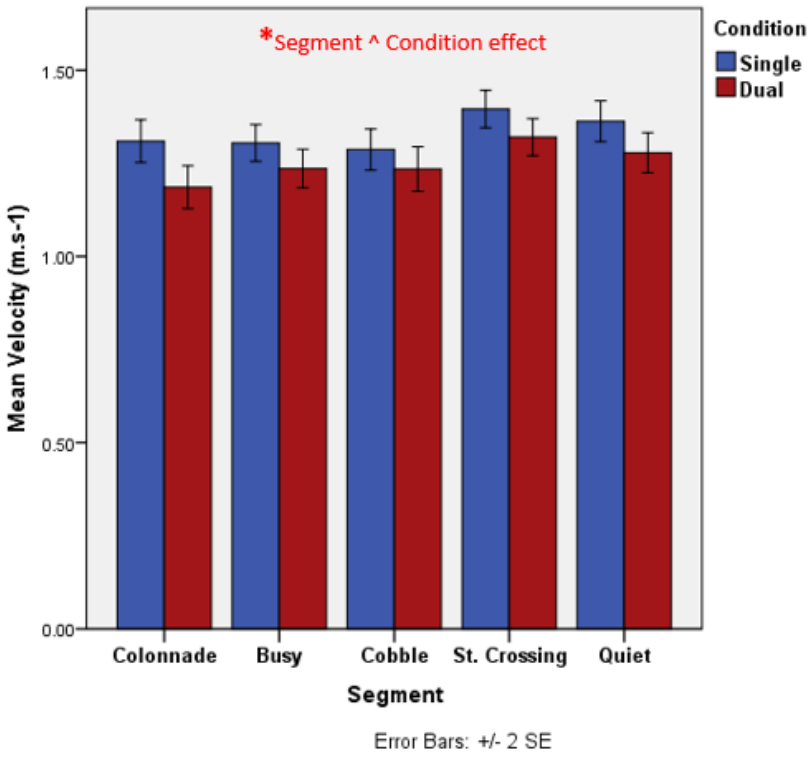

Figure 5.4. Interaction effect of walking segments and conditions on walking velocity.

Group	Condition	Segment	Mean	Std. Error	95% Confidence Interval	
					Lower Bound	Upper Bound
Control	Single	Colonnade	1.406	.037	1.331	1.480
		Busy	1.383	.032	1.319	1.448
		Cobble	1.403	.034	1.336	1.470
		St. Crossing	1.473	.033	1.406	1.540
		Quiet	1.459	.035	1.389	1.530
	Dual	Colonnade	1.304	.035	1.233	1.374
		Busy	1.355	.030	1.294	1.415
		Cobble	1.368	.035	1.297	1.438
		St. Crossing	1.422	.031	1.361	1.483
		Quiet	1.383	.034	1.316	1.450
UVD	Single	Colonnade	1.213	.037	1.138	1.287
		Busy	1.226	.032	1.161	1.290
		Cobble	1.171	.034	1.104	1.239
		St. Crossing	1.319	.033	1.252	1.385
		Quiet	1.266	.035	1.195	1.336
	Dual	Colonnade	1.068	.035	.997	1.139
		Busy	1.117	.030	1.056	1.177
		Cobble	1.102	.035	1.031	1.172
		St. Crossing	1.219	.031	1.158	1.280
		Quiet	1.173	.034	1.106	1.240

Table 5.1. Summary of mean walking velocity for both study groups under different walking conditions and segments.

5.3.2.2 Acceleration

a. Trunk Acceleration

Trunk acceleration was significantly affected by study group in the AP and V directions. In addition, acceleration was significantly affected by walking conditions and walking segments in all acceleration directions. Table 5.2 summarizes all related statistics and p-values.

Trunk acceleration was significantly reduced in patients diagnosed with peripheral vestibular disorders in all directions, though this was significant only in the AP and V directions (Figure 5.5). Moreover, with dual tasking, accelerations were significantly reduced in all acceleration directions (Figure 5.6). The effect of walking segment on acceleration was reflected as a significant reduction of acceleration in the colonnade and busy segments, where acceleration was reduced in all directions relative to the other three walking segments (Figure 5.7).

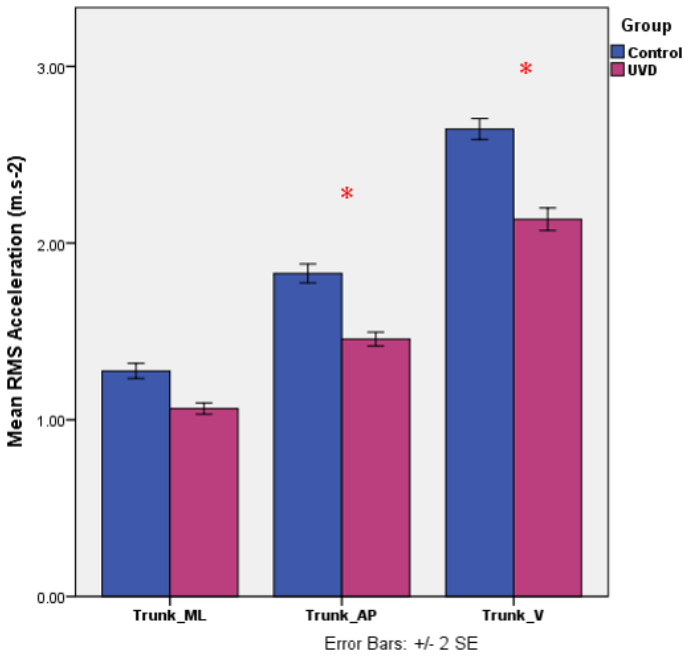

Figure 5.5. Trunk acceleration in UVD and control groups.

Trunk Acceleration			Coef.	SE	Z	P
Group effect	**AP**		.188	.073	2.59	.010
	V		.157	.071	2.19	.028
Condition effect	**ML**		-.095	.018	-5.08	.001
	AP		-.158	.019	-8.18	.001
	V		-.097	.027	-3.55	.001
Segment effect	**Colonnade**	**ML**	-.184	.019	-9.56	.001
		AP	-.230	.026	-9.29	.001
		V	-.132	.032	-4.51	.001
	Busy	**ML**	-.175	.019	-9.07	.001
		AP	-.245	.022	-10.89	.001
		V	-.260	.030	-8.81	.001

Table 5.2. Result of a mixed effects regression analysis on Trunk acceleration.

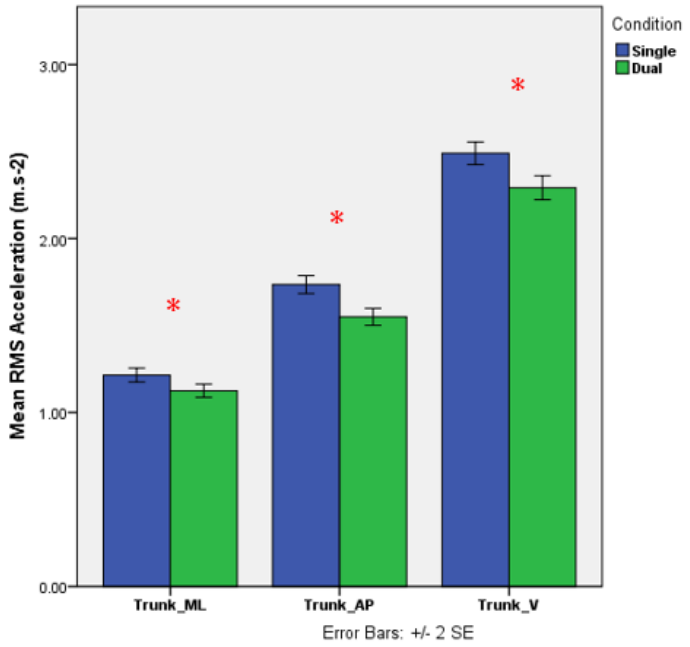

Figure 5.6. The effect of walking condition on Trunk acceleration in the ML, AP, and V directions.

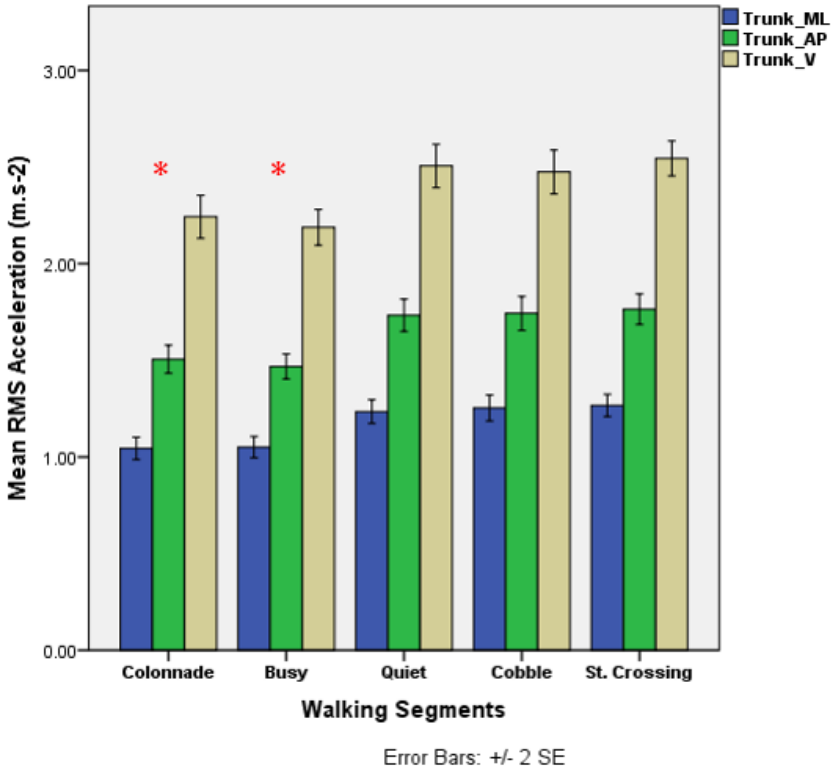

Figure 5.7. The effect of walking segments on Trunk acceleration in ML, AP, and V directions.

b. Neck Acceleration

At the neck level, there was a significant study group effect in the V direction Figure 5.8. Additionally, acceleration was significantly affected by dual tasking which, resulting in a statistically significant reduction of acceleration in the AP and V directions. The effect of walking segment was significant for all acceleration directions in the colonnade and the busy segment. Table 5.3 summarizes all related statistics and p-values.

Figure 3.9 shows the decrease in acceleration with dual tasking and Figure 3.10 shows the decrease in acceleration in the colonnade and busy segment relative to other segments.

In addition, there was a significant condition-segment interaction. This was noted in the colonnade segment in ML acceleration direction (β=.122, SE=.033, Z=3.61, P=.001) and AP β=.191, SE=.062, Z=3.06, P=.002). ML acceleration at the neck level in the colonnade segment was higher under the dual tasking condition compared with the single tasking condition, while all other segments showed lower acceleration under the dual tasking condition. Moreover, the AP acceleration at the colonnade segment showed the lowest mean acceleration difference between walking conditions when compared with all other walking segments.

Trunk Acceleration			Coef.	SE	Z	P
Group effect	**V**		.231	.072	3.20	.001
Condition effect	**AP**		-.259	.044	-5.78	.001
	V		-.190	.03	-6.21	.001
Segment effect	**Colonnade**	**ML**	-.178	.024	-7.13	.001
		AP	-.280	.044	-6.29	.001
		V	-.135	.034	-4.04	.001
	Busy	**ML**	-.293	.044	-6.58	.001
		AP	-.293	.044	-6.58	.001
		V	-.254	.038	-7.53	.001

Table 5.3. Result of a mixed effects regression analysis on Neck acceleration.

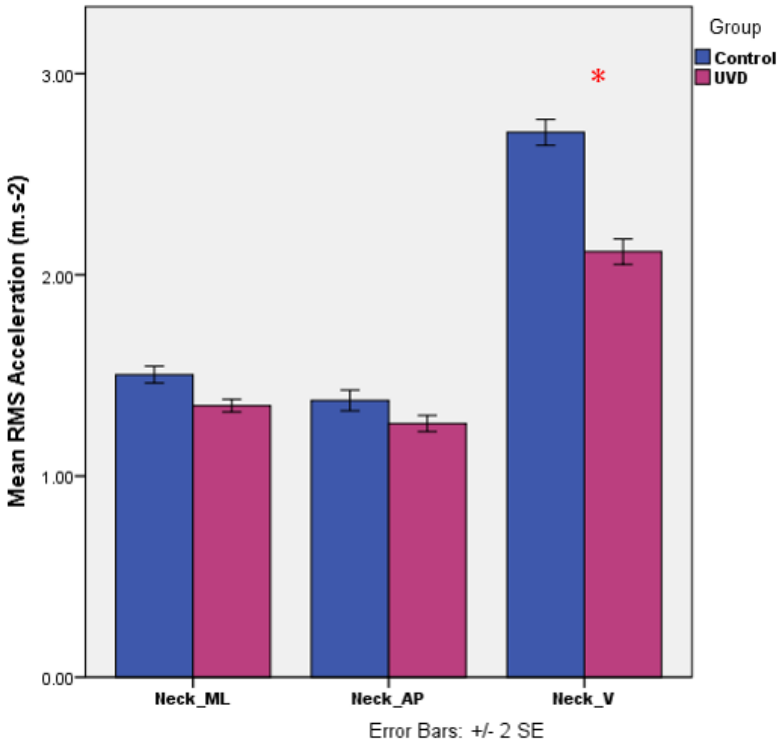

Figure 5.8. Neck acceleration in UVD and control groups.

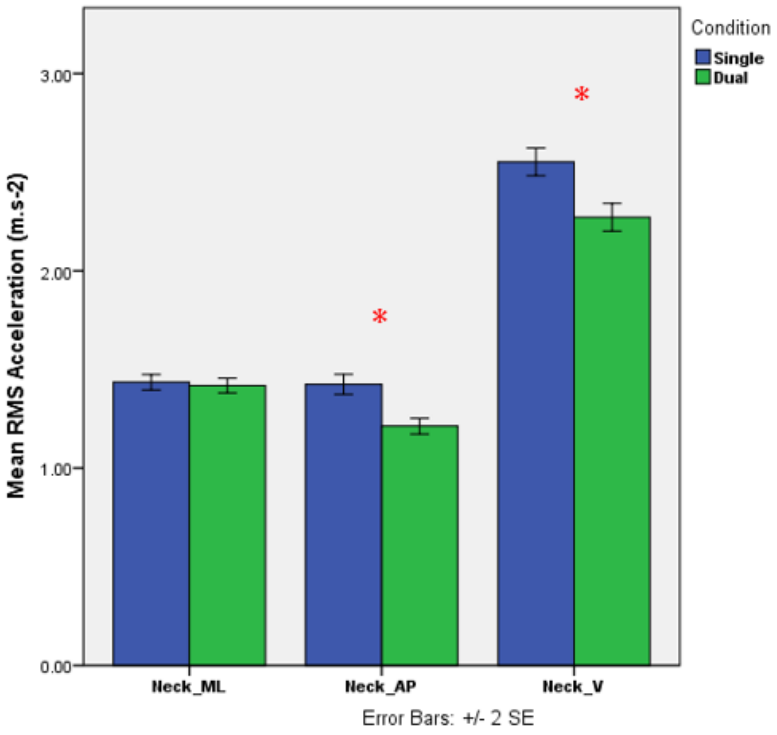

Figure 5.9. The effect of walking condition on Neck acceleration in the ML, AP, and V directions.

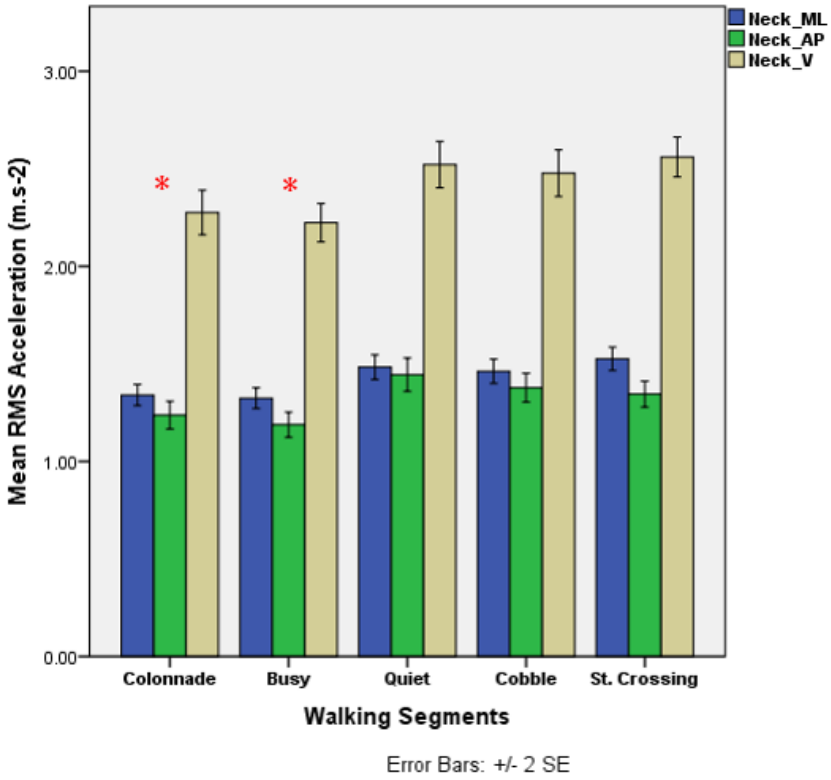

Figure 5.10. Effect of walking segments on Neck acceleration in ML, AP, and V directions.

c. Head Acceleration

There was a significant study group effect in the AP and V acceleration directions (Figure 5.11). Moreover, the effect of the walking condition was significant in all acceleration directions. Figure 5.12 shows the reduction in acceleration under dual tasking conditions. In addition, there was a significant walking segment effect in all acceleration directions as indicated in Figure 3.13, which shows the reduction in acceleration in the colonnade and the busy walking segments. Table 5.4 summarizes all related statistics and p-values.

In addition, there was a significant condition-segment interaction. This was noted in the colonnade segment in the ML direction (β=.098, SE=.025, Z=3.86, P=.001). The ML acceleration at the head level showed the least mean acceleration difference between single and dual walking conditions compared with all other walking segments.

Trunk Acceleration			Coef.	SE	Z	P
Group effect	**AP**		.102	.050	2.10	.036
	V		.167	.063	2.63	.008
Condition effect	**ML**		-.047	.018	-2.60	.009
	AP		-.063	.001	-6.38	.001
	V		-.120	.027	-4.56	.001
Segment effect	**Colonnade**	**ML**	-.128	.018	-6.98	.001
		AP	-.130	.020	-6.40	.001
		V	-.121	.028	-4.26	.001
	Busy	**ML**	-.107	.018	-5.83	.001
		AP	-.131	.020	-6.42	.001
		V	-.246	.028	-8.65	.001

Table 5.4. Results of a mixed effects regression analysis on Head acceleration.

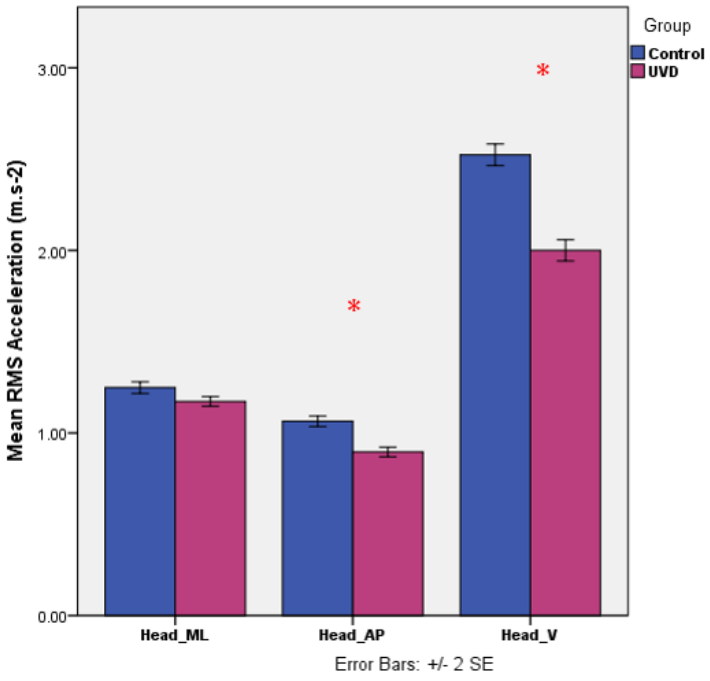

Figure 5.11. Head acceleration in UVD and control groups.

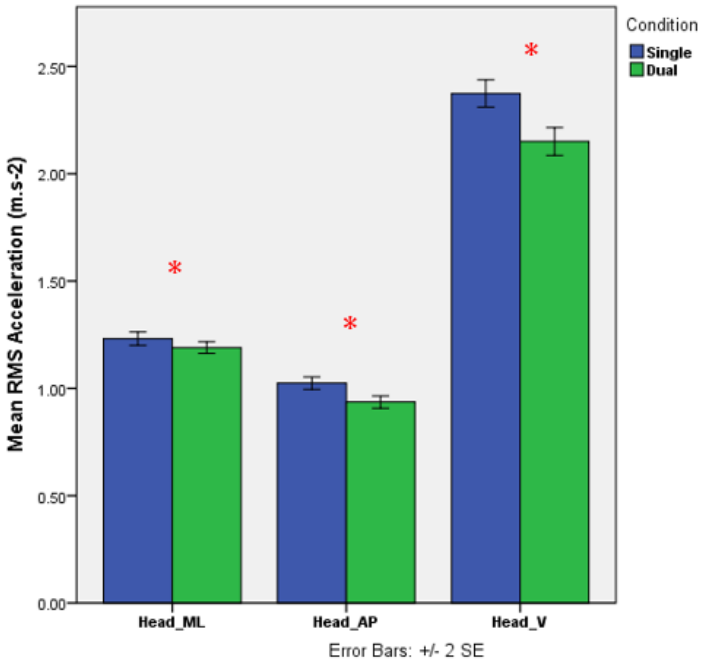

Figure 5.12. The effect of walking condition on Head acceleration in the ML, AP, and V directions.

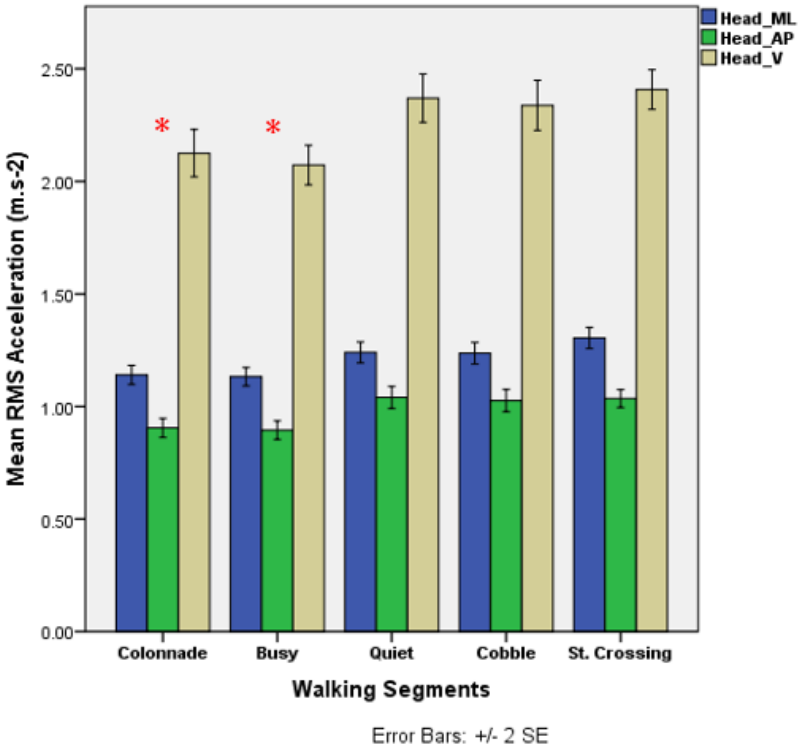

Figure 5.13. Effect of walking segments on Head acceleration in ML, AP, and V directions.

5.3.2.3 Trunk Attenuation Rate (TAR)

The trunk attenuation rate was not significantly affected by study groups in all three acceleration directions. However, there was a significant effect for walking segment, showing a significant reduction in TAR in the ML direction in the busy (β=3.70, SE=1.77, Z=2.08, P=.038) and street crossing segments (β=5.68, SE=1.78, Z=3.18, P=.001). Furthermore, the TAR was significantly affected by walking conditions in the ML (β=9.30, SE=1.80, Z=5.18, P=.0001) and V (β=1.38, SE=0.371, Z=3.73, P=.0001) directions. As Figure 5.14 illustrates, the ML TAR was significantly reduced under dual tasking conditions in the colonnade (β=-7.02, SE=2.51, Z=-2.80, P=.005) and busy segments (β=-21.11, SE=2.50, Z=-8.42, P=.001) compared with other segments. In addition. The AP TAR was significantly reduced in the colonnade (β=5.00, SE=2.30, Z=2.17, P=.030) and busy segments (β=-12.32, SE=2.30, Z=-5.40, P=.001).

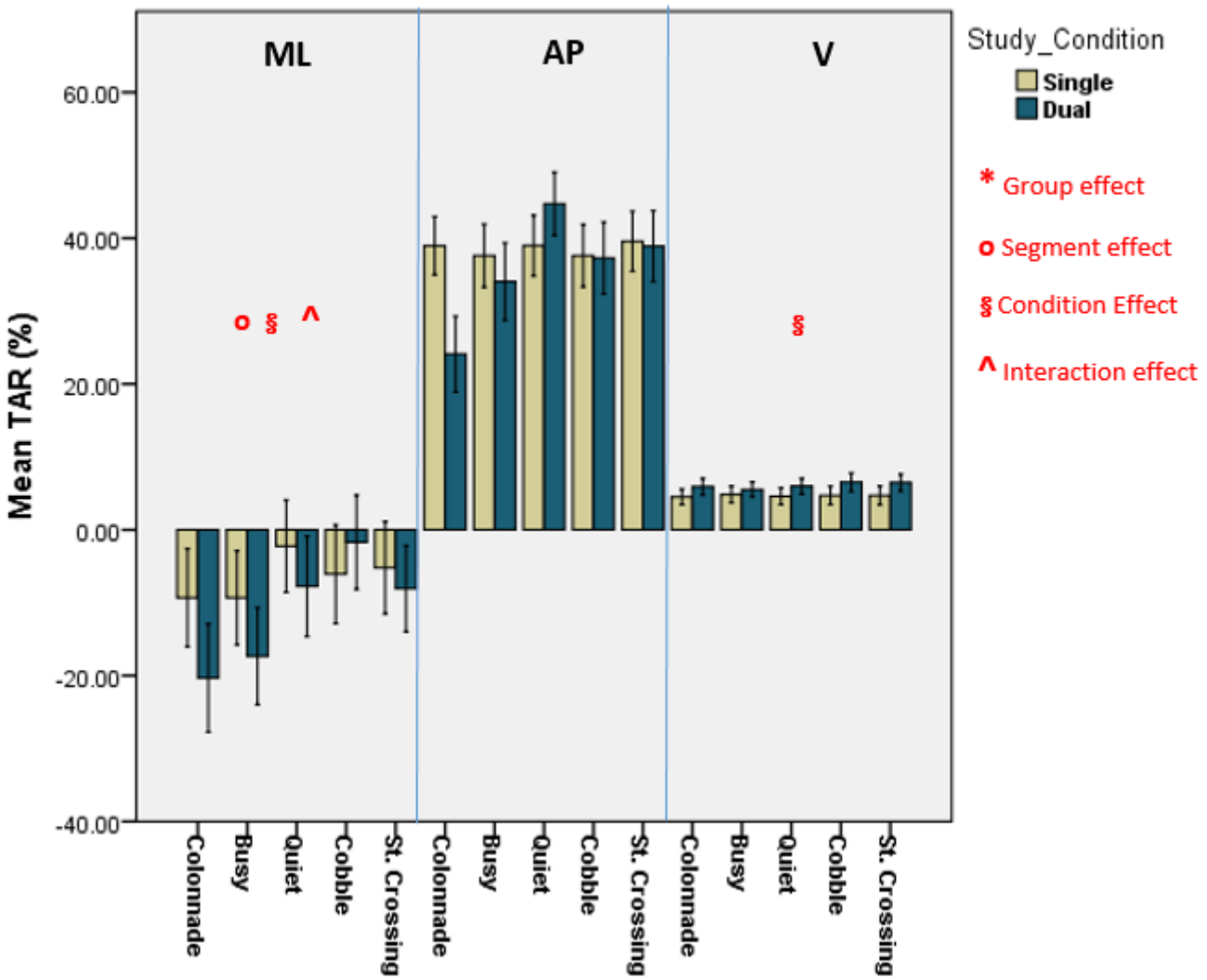

Figure 5.14. TAR among walking segments under single and dual tasking.

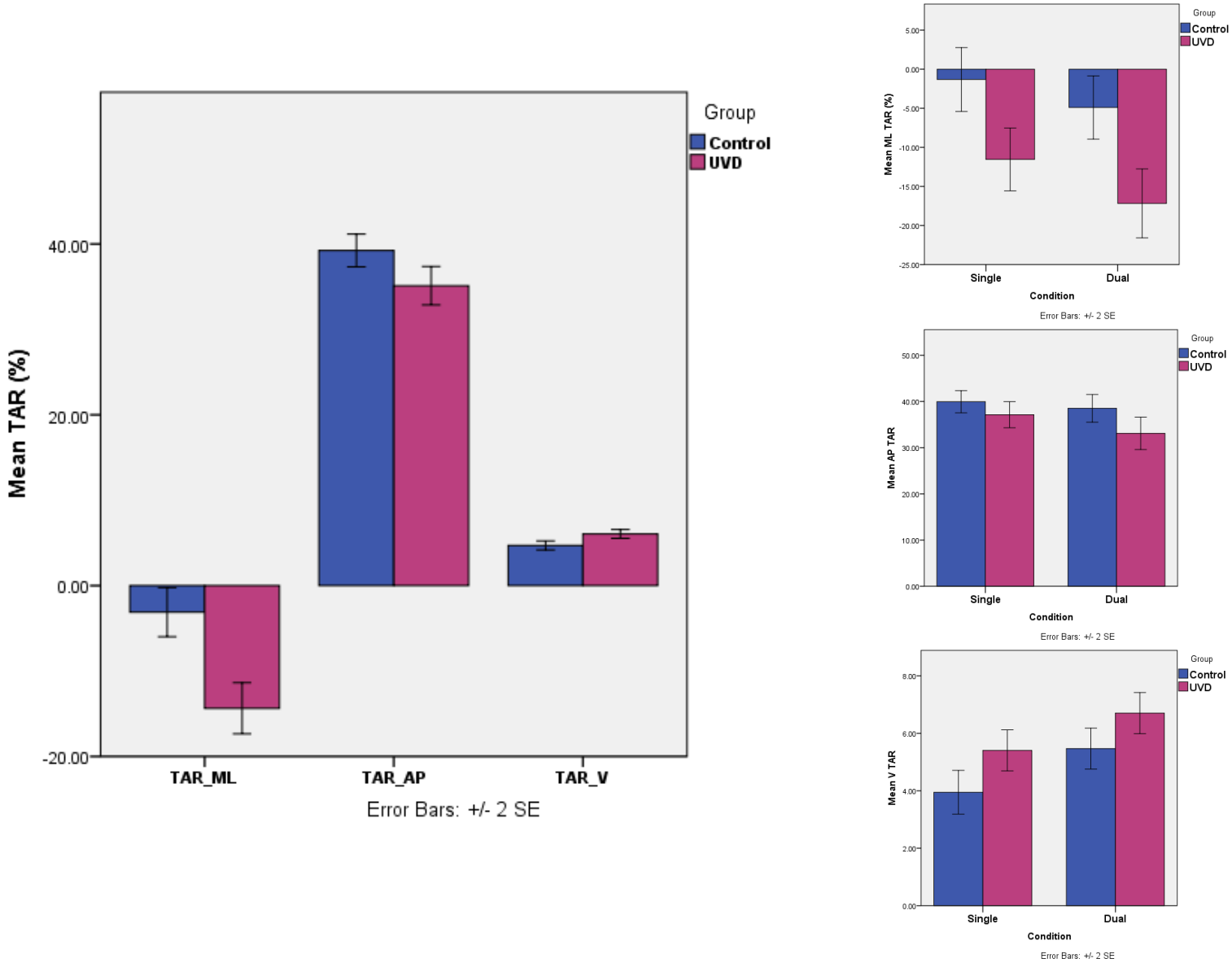

Figure 5.15. TAR among study groups and study conditions.

In summary, the results of the acceleration and trunk attenuation rate (TAR) show that acceleration was significantly reduced under dual tasking in all directions and was significantly affected by walking segments. The lowest accelerations were noted in the colonnade and the busy segments. Additionally, acceleration was significantly reduced in the patient group in only the AP and V directions, while remaining high in the ML direction.

We can infer from the overall results of the outdoor walking test that, as patients diagnosed with vestibular disorder adopt a conservative gait by reducing their walking velocity, there will be a significant consequent reduction in trunk AP and V accelerations. However, this was not the case in the ML direction, since acceleration remained high. This shows that patients showed higher values of trunk acceleration in the ML direction despite their compensatory strategy of walking at a lower speed. This may indicate that they are less stable in the ML direction. This possibility receives further support through the findings of the TAR that, although lacking statistical significance between study groups, nonetheless shows a clear trend of decreasing TAR in the ML direction (Figure 5.15).

5.3.2.4 Cognitive Task Scores

The response rate, the error rate, and the percentage of correct answers were calculated for each walking segment and compared between study groups.

The percentage of correct answers was significantly reduced in UVD compared to controls in the cobble (U=717.5, z=2.829, p=.005, r=.35) and street crossing (U=682, z=2.248, p=.025, r=.28) segments. The response rate for each walking segment did not show any significant differences between study groups. The error rate tended to be higher for UVD in all walking segments except the quiet segment, though it was significantly higher in only the cobble (p=.027, r=.30) and street crossing segments (p=.021, r=.31).

5.4 Discussion

This study aimed to determine the effect of dual tasking during urban walking in patients diagnosed with unilateral peripheral vestibular disorders versus an age-matched control group. Walking velocity and acceleration at the head, neck, and trunk levels were measured across five different environments. Walking velocity and acceleration TAR were compared between study groups under both single and dual task conditions.

5.4.1 Walking Velocity

This is the first study to assess dual tasking effect on locomotion in a real life outdoor setting. We found that walking velocity in patients diagnosed with vestibular disorders was significantly reduced compared with healthy controls. Similar findings have been reported in Kim et al. (2014), Glasauer et al. (1994), and Borel et al. (2004), all of which show that UVD patients' gait patterns are characterized by slower walking velocity compared with controls, under both open and closed eye visual conditions, and at preferred and fast locomotion speeds. This was mainly explained by the reduction in both step length and step frequency. The main difference between the previous work in the literature and our study is the fact that ours is the first to report this effect in outdoor settings in which patients are exposed to different real life environments. All previous studies were carried out in conventional laboratories in which the environment was controlled and walking distance was comparatively short. In our study we had five walking segments. Each segment was 30 meters in length, apart from the street crossing segment which was 16.8 meters. We found that different urban environments had different impacts on walking velocity. In our study, walking velocity was significantly reduced in the

colonnade, busy, and cobble segments compared with walking velocity in the quiet or street crossing segments. This means that the aforementioned segments exposed participants to challenges that impose a reduction of their walking velocity in order to maintain dynamic balance. This may be due to the fact that these segments exposed participants to challenges such as visual contrasts, crowdedness, and uneven flooring. Patients diagnosed with peripheral vestibular disorders reported increased visual sensitivity to visual motions, crowds, and busy visual surroundings, which may have led to the exacerbation of symptoms (Bronstein, 1995). Consequently, it is expected that such patients would adopt a conservative gait strategy by reducing walking velocity, especially with the addition of a secondary cognitive task. This slower gait strategy adopted by patients might increase the efficiency of acceleration attenuation by the trunk, consequently increasing the stability at the level of the head (Kavanagh et al., 2006).

Moreover, we examined the effect of dual tasking on dynamic balance, an evolving subject in reference to patients with vestibular disorders. Despite the fact that both study groups had a slower walking pace under dual tasking conditions compared with the single tasking condition, the effect was significantly greater in the patient group, as reflected in the significant group-condition interaction. Our finding seems to be consistent with research by Roberts et al. (2011) who reported that patients with vestibular disorders walk significantly more slowly than controls, especially when performing cognitive tasks. Our finding is further supported by Bessot et al. (2012) who reported a slower gait speed with dual tasking in patients with bilateral vestibular loss.

However, the findings of the current study do not support the previous research of Nascimbeni et al. (2010) whose UVD and control groups both presented with more conservative gait during dual tasking, with no statistical significant difference in gait parameters. The discrepancy between our findings and those of Nascimbeni et al. (2010) may be attributable to the fact that their patients received vestibular rehabilitation following neuronitis, while the patients in the present study were chronic sufferers who did not receive any rehabilitation.

Comparing the walking velocity of our participants in both study groups with the reference values of self-selected gait speed reported in Bohannon (1997) and Bohannon and Williams Andrews (2011) suggests that the mean gait speed of the UVD was reduced with dual tasking, while the control group had similar mean velocity compared with their reference values. However, the UVD walking velocity in the street crossing segment was more than or equal to 1.2 meters per second, this being the pace required to safely cross pedestrian crossing lines according to UK and international standards (Asher et al., 2012). This reflects the fact that our UVD group can still cross the street safely despite their chronic symptoms. However, to the limited number of participants and the stringent criteria used, we cannot generalize this finding for the entire population of chronically dizzy patients.

5.4.2 Walking Acceleration

Very little was found in the literature on the use of the accelerometer device to study dynamic balance in patients with vestibular disorders. Therefore, we compared our findings with other studies that used the accelerometer device in

subjects with balance impairment due to other aetiologies. Studies conducted in elderly adults were also included due to the reported effect of aging processes on dynamic balance. This effect was attributed to changes in sensory systems including the visual, vestibular, and proprioceptive, in the musculoskeletal system (e.g., reduced muscle strength and slowing contraction) and in the nervous system (e.g., slowing nerve conduction and slower information processing, cf. Maki and McIlroy, 2003).

Through analysing RMS acceleration, we found that the vertical and anterio-posterior RMS accelerations were significantly reduced at the trunk level as well as the head level in the patient group compared with the control group, indicating that patients were stable in these two directions. On the other hand, no significant reduction in medio-lateral acceleration was noted between the studied groups. This might point to the fact that the patient group is less stable in this direction. Moreover, the addition of a dual cognitive task resulted in a significant reduction of acceleration in all directions in both study groups, reflecting the fact that this is a compensatory mechanism for maintaining dynamic stability. This strategy was observed as a significant reduction in acceleration while participants were walking in two of the urban environments, i.e., the colonnade and the busy segment, where the acceleration at the level of the head, neck, and trunk were significantly reduced in all acceleration directions.

This finding is inconsistent with that of Wilhelmsen et al. (2010) who show that patients with unilateral vestibular disorder had larger RMS accelerations in the lower trunk than the upper trunk. We found that the acceleration value was

reduced at the level of the head compared with the trunk and neck in the AP and V directions while acceleration was significantly increased at the neck in the ML direction. This discrepancy may be attributed to many factors: (1) we used three tri-axial accelerometers at the head, neck, and trunk levels, while Wilhelmsen et al. only used two accelerometers devices at the lower and upper trunk; (2) our study had an outdoor setting with a total walking distance of 136 m for each walking condition while the testing conducted by Wilhelmsen et al. was conducted in a laboratory with an 8.5 m long walking distance; and (3) Wilhelmsen et al. did not utilise a control group and there was no consistency during testing, such that some patients completed the walking task barefoot and others with shoes.

In general, our results show that RMS acceleration was reduced in the UVD group compared with the control group at all body levels and in all directions. This is consistent with the findings of Menz et al. (2003), in which older subjects had decreased walking velocity and acceleration in all directions compared with young subjects. However, this reduction in acceleration was significant only in the AP and V directions, indicating that ML remained high in the patient group. Moreover, using the trunk attenuation rate (TAR, see Mazza et al., 2008), we found that, though TAR was not significantly affected by study group in any acceleration direction, the ML TAR showed a decreasing trend in the patient group and under dual tasking conditions. Additionally, only the ML and V TAR were affected by dual tasking, indicating that the TAR was most effective in the AP direction.

Our findings in the UVD group support the findings of Mazza et al. (2008), who found that older women had higher ML accelerations at the head compared with the trunk. This was further supported by Vardaxis (2005) who reported that the older group had significantly higher ML acceleration at the head compared with the pelvis under both normal and fast walking speed conditions. Moreover, our findings are in partial agreement with Doi et al. (2011), who report that TAR in the ML direction was significantly reduced in healthy older adults with the addition of dual tasks. However, in contrast to our findings, TAR in the AP direction was not affected by dual tasking. This may be due to the difference in the type of study participants or cognitive task used.

Asai et al. (2013) demonstrated that an attentionally demanding task significantly decreases TAR in the ML direction in both young and old healthy adults, without affecting TAR in the V and AP directions. They suggested that the control of the trunk in the ML direction may be strongly associated with attention. This finding is similar to that of O'Connor and Kuo (2009), who suggest that maintenance of stability in the ML direction requires an active control, when compared with the AP direction.

The medio-lateral acceleration is also affected in Parkinson's patients and hemiplegic patients. Lowry et al. (2009) demonstrated that Parkinson's patients had decreased walking stability in medial-lateral and anterior-posterior planes as reflected by lower harmonic ratios. Moreover, Sekine et al. (2013) showed that ML accelerations in hemiplegic patients significantly deviated from the common value of healthy subjects.

This instability in the ML direction as reflected by increases in RMS acceleration or reduction in TAR or harmonic rations has been linked to a predisposition to fall (Park et al., 2014).

5.4.3 Cognitive Tasks

Performance in cognitive tasks was significantly reduced in the UVD group during outdoor walking in the cobble and street crossing segments. This finding differs to the finding presented in Chapter 4, in which cognitive tasks of the UVD score were similar to the control group during FGA testing. This could be explained by the fact that being in an urban environment exposes patients to real daily life situations which may increase the attentional demands required to navigate safely. This will decrease the attentional capacity allocated to carrying out a secondary cognitive task. In addition, the urban environment offers a greater challenge over a more uniform indoor laboratory setting. This may be the rationale behind using a “posture first” strategy in the outdoor environment over and against the “posture second” strategy adopted in a relatively controlled atmosphere such as a laboratory.

5.5 Conclusion

This is the first study to assess dynamic balance in outdoor environments, i.e., those in which patients with vestibular disorders report most of their symptoms. Few studies have investigated the effect of vestibular dysfunction on head and trunk stability. This is a major limitation, as head stability is fundamental for processing visual and vestibular information, and consequently for static and dynamic stability.

The current study showed that UVD patients adopt a more conservative gait strategy by reducing gait velocity as a compensatory mechanism to reduce acceleration at the level of the head. This is necessary to provide a stable platform at the head level, crucial for processing various visual and vestibular stimuli. Our findings suggest that patients diagnosed with peripheral vestibular disorders are less stable in the medio-lateral direction. This increases their risk of fall and exposes them to the danger of serious injuries, including hip fracture. Cognitive task performance was significantly reduced in the UVD group during outdoor but not indoor assessment, indicating that exposure to an urban environment increases attentional demands for navigating safely, when compared with indoor tasks. These findings could be used to modify vestibular rehabilitation programmes currently in use by addressing the impairment in lateral stability and the detrimental effect of dual tasking on dynamic balance.

CHAPTER 6 Discussion

The results of each experiment were discussed at the end of each chapter. This discussion provides a summary of all findings and a general discussion of the project as a whole.

6.1 Background of the Project

Vestibular dysfunction affects 30% of the UK population by the age of 65 (Roydhouse, 1974) and 35.4% of the United States population by the age of 40 (Agrawal et al., 2009). It has been reported that the prevalence of vestibular disorders increases with age (Agrawal et al., 2009, Sheldon, 1955).

Vestibular dysfunction has been found to have a negative effect on quality of life and activities of daily living (Bronstein, 2004, Guerraz et al., 2001, Jacobson and Newman, 1990). It may result in postural and gait problems and, consequently, falls. The chance of incurring a fall is eightfold for those with vestibular disorders compared with a healthy population (Agrawal et al., 2009, Cavanaugh et al., 2005, Herdman et al., 2000, Marchetti et al., 2008).

Many changes in gait parameters have been noted in people with a vestibular disorder, including increased base of support, stride time, veering from the gait path, and decreased step length and walking velocity (Borel et al., 2004, Cohen, 2000, Glasauer et al., 1994, Kim et al., 2014, Krebs et al., 2002, Mamoto et al., 2002, Perring and Summers, 2007, Tucker et al., 1998).

Moreover, people with vestibular disorders may have an impaired vestibulo-ocular reflex gain which makes head movement very disturbing through provoking gaze instability (Schubert et al., 2002).

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To overcome this, patients usually will adopt a more conservative gait strategy by reducing gait velocity. This consequently reduces acceleration at the level of the head and helps in maintaining gaze stability (Mamoto et al., 2002).

Adopting this mechanism enables maintenance of head stability during many walking tasks, however, voluntary head movement is unavoidable in many daily living activities such as crossing the street, looking around to navigate through a busy or challenging environment, or even simply responding to auditory signals. These everyday dynamic movements exacerbate dizziness and unsteadiness and can lead to falls and activity restrictions which adversely affect quality of life and have psychological consequences (Mira, 2008).

On the other hand, maintenance of balance requires the integration of many sensory inputs including visual, somatosensory, vestibular, and cognitive functions. Dysfunction in the vestibular system has been linked to cognitive impairment as suggested by animal studies (Russell et al., 2003, Stackman et al., 2002, Wallace et al., 2002) and by neuroimaging studies (Brandt et al., 2005, Helmchen et al., 2014, Hufner et al., 2007, Hufner et al., 2009, zu Eulenburg et al., 2010). It has been suggested that patients with vestibular dysfunction have difficulties with multitasking due to decreased concentration, auditory short term and spatial memory (Hanes and McCollum, 2006) which may adversely affect their ability to divide attention in order to carry out two or more tasks

simultaneously. Dual-tasking limitations have been noted in older adults and are an important risk factor for falls (Shumway-Cook et al., 1997, Siu et al., 2009). Individuals with a vestibular disorder have an increased falls risk and impairments in dual tasking have been noted. Dual tasking ability is of paramount importance in this world. It is imperative that this vulnerable group of patients be able to negotiate day-to-day activities safely without further increasing their risk of fall.

Although vestibular patients report most of their symptoms in the urban environment (Bronstein, 2004, Guerraz et al., 2001), all previously published studies have been carried out in indoor controlled laboratory environments. Such environments are unable to expose patients to the full range of challenges they may encounter in everyday life when walking in the community.

In this project, we used a novel approach to investigate the effect of dual tasking while carrying out indoor and outdoor walking tasks in patients with unilateral vestibular disorders (Chapters 4 and 5) and in a group of younger and older healthy adults (Chapter 3).

Functional gait assessment, with its ten gait-related tasks, is a validated tool that has been used in older adults (Walker et al., 2007, Wrisley and Kumar, 2010) and in patients with vestibular disorders (Wrisley et al., 2004). Our novel approach of conducting FGA under dual tasking conditions was used in both groups. The aim was to simulate real life situations in which individuals needed to multitask inside their house, office, and so on.

All previous studies using an accelerometer were carried out in laboratory environment for both healthy elderly people (Asai et al., 2013, Asai et al., 2014, Doi et al., 2011, Doi et al., 2013, Kavanagh et al., 2004, Kavanagh et al., 2005, Menz et al., 2003), as well as patients with vestibular disorders (Wilhelmsen et al., 2010). Our study is the first to implement this modality to investigate gait under dual tasking conditions with exposure to different and unpredictable situations in the urban environment.

The results of this project have helped us understand the balance strategy used under dual tasking situations, may be useful to further develop advances in vestibular rehabilitation.

6.2 Dual Tasking and Indoor Gait Assessment

The novel design of dual tasking whereby patients had to complete a cognitive task while simultaneously completing a functional gait assessment was used in patients diagnosed with unilateral peripheral vestibular disorders and in healthy young and older adult groups. We concluded that both the UVD and healthy control groups (Chapter 4) were affected by the addition of a cognitive task. However, the UVD group had a significant increase risk of falling compared with the control group. The same observation was noted when comparing healthy older versus the younger group (Chapter 3) whereby the former showed a significantly greater falls risk compared with the latter when dual tasking was added, as opposed to single tasking in which no significant between-group differences were noted.

Neither study showed a significant difference between participants' numeracy and literacy cognitive task scores, indicating that both the UVD (Chapter 4) and

healthy older adult group (Chapter 3) did not adopt a “posture first” strategy. Instead they appeared to prioritise cognitive task performance over balance task performance, despite not having been provided with any prioritization instruction. This had the effect of compromising their balance and increasing their risk of fall and injury. The effect of dual tasking on the posture first strategy may be attributed to many proposed theories. The secondary task might exceed processing capacity (capacity sharing), might require parallel processing using the same neural network (bottlenecking), or might share similar resources with the primary task. Alternatively, this may be due to an impaired attention switching mechanism (Liston et al., 2014, Siu et al., 2009, Yogev-Seligmann et al., 2008).

Comparing the performance of the young UVD group with the older healthy adult group revealed that, despite a significant difference in the FGA total score under single and motor task conditions, the addition of a cognitive task did not display a significant difference between the two groups. This reflects the fact that, under dual tasking conditions, healthy older adults have a similar risk of fall as young patients with unilateral peripheral vestibular disorders.

This finding in healthy older adults may be attributed to age-related changes in: a) sensory systems including the visual, vestibular, and proprioceptive systems; b) the musculoskeletal system, such as reduced muscle strength, reduced reaction times, and increased muscle fatigue; and c) the nervous system, such as slowing nerve conduction and slower information processing (Maki et al., 1994, Maki and McIlroy, 2003).

Despite recruiting only a limited number of healthy participants and only active healthy older adults, this finding strongly suggests that older healthy adults have

an increased falls risk when dual tasking, as reflected in their FGA score under cognitive conditions. This indicates that measures implemented to prevent falls and their detrimental consequences for individuals and the health system need to include dual task activities.

6.3 Dual Tasking and Outdoor Gait Assessment

This is the first study we are aware of that investigates the effect of dual tasking on locomotion in a real life outdoor setting using tri-axial accelerometers to measure walking velocity and accelerations at the level of the head, neck, and trunk, while ambulating in five different urban environments.

In Chapter 5, the UVD group had reduced walking velocity compared with the control group under single and dual tasking conditions. In addition, a significant reduction in walking velocity was noted in the colonnade, busy, and cobble flooring environments. This may be explained by the fact that a significant percentage of people with a vestibular disorder rely too heavily on visual cues for postural and perceptual orientation and report symptom exacerbation or provocation in rich busy surroundings such as crowds (Bronstein, 1995, Guerraz et al., 2001). Moreover, patients with vestibular disorders rely more on the ankle strategy to control posture, this may result in excessive hip sway when walking on uneven or unstable surfaces (Han et al., 2011, Horak et al., 1990). As a result, such patients will try to minimise head movement by adopting a slower gait velocity to increase the efficiency of acceleration attenuation by the trunk (Mamoto et al., 2002).

In Chapters 3 and 5, the healthy older adults and patients diagnosed with peripheral vestibular disorders showed impairment in the medio-lateral attenuation rate compared with their control groups. Moreover, this ML trunk attenuation was further decreased with dual tasking. These finding suggest that laterally stability is impaired in healthy older adults and in patients diagnosed with peripheral vestibular disorders, which might increase their risk of injurious falls and hip fractures.

Cognitive task performance was significantly reduced in the UVD group during outdoor walking in the cobble and street crossing segments but not during indoor assessment. This suggests that, upon exposure to challenging urban environment, patients with vestibular disorders recognise the perceived threat and adjust their performance accordingly by adopting posture first strategies rather than the alternative strategy adopted in indoor environments that are relatively safe.

Despite receiving no prioritization instruction in either indoor or outdoor dual task conditions, the outdoor environment seems to have many distractors and challenges which may exceed the processing capacity of the patient group, or alter their ability to flexibly shift their attention between safe walking and correct responses to cognitive tasks. This will leave these patients with the safer option of adopting the postural first strategy, in which cognitive tasks are given less weight. This clearly did not happen in the indoor environment, which had fewer distractors and is considered to be controlled and safe. This perception may be the reason behind adopting a posture second strategy in indoor settings, and may explain the fact that more than half of the fall injuries among older people occur inside their houses (Gill et al., 2000, Kochera, 2002).

6.4 Cognitive Assessment

Decline in cognitive function has been linked to an increased risk of falls and injuries (Lord and Fitzpatrick, 2001, Rapport et al., 1998, Beauchet et al., 2003, Lundin-Olsson et al., 1997). The effect of dual tasking on posture and stability has been reported in the elderly (Alexander et al., 2005, Maylor and Wing, 1996, Shumway-Cook et al., 1997), as well as in vestibular patients (Redfern et al., 2004, Yardley et al., 2001, Bessot et al., 2012, Nascimbeni et al., 2010, Roberts et al., 2011).

At present, a neuropsychological assessment does not form part of routine clinical practice for people with a vestibular disorder. Cognitive assessments used in previous research studies are designed to assess the single skill of executive function at one time, while the BADs test battery (Norris and Tate, 2000, Wilson et al., 1996) is designed to assess a range of cognitive abilities that form a large component of many everyday activities such as organizing, planning, temporal judgment, problem solving, attention, cognitive flexibility, and adjustment.

Chapter 4 revealed that our cohort of vestibular patients has significantly lower cognitive flexibility, novel problem solving and planning abilities, as reflected in their BADs sub-scores relative to age-matched healthy controls. The deficit in cognitive flexibility, planning, and decision making might lead to improper decision making, especially when negotiating an obstacle or while walking in a complex environment with many distractors. Moreover, the inability to flexibly divide attention will compromise performance in either motor or cognitive tasks,

or both. Impairment in cognitive skills may be the reason for the decrease in balance, especially when dual tasking.

The vestibular patients might appear to be very lucid and engage in intelligent behaviour, such that the treating physician and family members may not acknowledge the presence of a subtle cognitive problem. Any neuropsychological assessment used should test for the presence of skills required to carry out everyday life functions such as attention, memory, planning, organizing, temporal judgment, problem solving, and cognitive flexibility. It should not be limited to the assessment and management of the emotional aspect of the disease (i.e., anxiety and depression) that most vestibular patients suffer from. It has been reported that vestibular dysfunction is linked to anxiety and depression (Grimm et al., 1989, Simon et al., 1998). The anxiety and depression score was significantly higher in our cohort of vestibular patients and this may be a confounding factor affecting posture and dynamic balance. Patients with depression may have decreased inner motivation to move, and this may make them feel isolated and inactive. In turn, a higher anxiety level might increase levels of apprehension and fear of falling when mobile. This may affect the patient's gait and balance strategy, resulting in their being very conservative and conscious, especially if they have a previous history of fall.

In contrast to individuals with UVD, no significant between-group differences were observed for healthy younger versus older healthy adult participants in any of the BADs test totals or component scores (Chapter 3). These findings need to be carefully interpreted, however, as the study had a low number of

participants and our older adult cohort was active and independently living in the community.

6.5 Study Limitations

One of the main limitations of this study was the limited number of participants. In addition, the healthy older adult participants studied in Chapter 3 were all physically and mentally active, and may not be representative of the wider older adult population. Therefore, findings can only be applied for a similar group of older healthy adults and cannot be generalized to other older groups.

Another limitation is that our analysis was mainly focused on walking velocity, acceleration in the ML, AP, and V directions and, consequently, TAR. Other data that could be extracted from the accelerometer such as angular velocity, stepping frequency, stride length, and stride variability were not extracted or analyzed due to the large number of currently analyzed variables, and the relatively small number of study participants. However, these data could be extracted and analyzed for future publications.

One of the important limitations of this study is that some of the patients diagnosed with unilateral peripheral vestibular disorders also suffered from hearing loss. Therefore, it is possible that patients' performance under dual cognitive task conditions may have been affected by their hearing loss.

6.6 Clinical Implications

The finding from this study may indicate that an objective tool is needed to assess gait in the clinical setting besides the currently available subjective tools. For example, the use of the accelerometer technology may provide a

quantitative dimension for gait analysis and provide valuable information about patients' fall risk and trunk stability. It could be used as a baseline assessment, and at follow-up, to determine whether there has been a clinically meaningful change in determination of the effect of rehabilitation on improving dynamic balance. Moreover, incorporating dual tasking techniques in such assessment tests may provide important information not readily available during routine examination.

On the other hand, including dual tasking in a vestibular rehabilitation programme may provide better treatment outcomes as dual task rehabilitation studies in older people indicate that it is more effective than single task training (Silsupadol et al., 2009, Uemura et al., 2012).

Patients with vestibular disorders need to be asked about their dual task abilities, and further tests (perhaps BADs or alternative, more robust tests) need to be validated for individuals with vestibular disorders. This may aid in clinical decision making for rehabilitation or further assessment. This will not only improve the cognitive function of the patients, but may also reduce the risk of fall.

6.7 Future Research

Our study is the first to investigate dynamic balance in outdoor environments and future studies on the current topic are therefore recommended to confirm our finding using larger samples, and to investigate the effect of rehabilitation on used measures.

Further research should investigate the effect of incorporating dual task training within a vestibular rehabilitation programme on treatment outcome and, specifically, its impact on environmental mobility and ability. A study comparing the effect of customised vestibular rehabilitation with and without dual-tasking training on treatment outcome is currently underway at NHNN.

This study highlights the need for further research investigating cognitive functions in patients with vestibular dysfunction. More specifically, studies are needed to identify the prevalence and types of cognitive impairment present in patients with vestibular disorders and their impact on symptoms, perceived handicap, and functional task performance. This will aid in the development and delivery of appropriate treatments and interventions to this patient cohort.

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Appendix 8.1
Participants Information Sheet

University College London Hospitals NHS
NHS Trust

The National Hospital for Neurology and Neurosurgery
Department of Neuro-otology
Box 127
Queen Square, London
WC1N 3BG

INFORMATION SHEET FOR PARTICIPANTS

Study of free walking in patients with a peripheral vestibular disorder

YOU WILL BE GIVEN A COPY OF THIS INFORMATION SHEET

You are being invited to take part in a research project. Here is some information to help you decide whether or not to take part. Before you decide whether you want to take part, it is important for you to understand why the research is being done and what your participation will involve. Please take the time to read the following information carefully and discuss it with friends, relatives, and your GP if you wish. Please do not hesitate to ask us if there is anything you do not understand or if you would like more information. Please do take the time to decide whether you wish to take part. You should only participate if you want to; choosing not to take part will not disadvantage you in any way.

Background

It has been shown that individuals with balance disorders arising from the inner ear may feel more unsteady when walking, particularly in busy environments (i.e., crowds) or on uneven surfaces. Patients may also have difficulty maintaining their balance when moving their head while walking, and may also experience motion or blurred vision when walking or turning their head. It has also been shown that patients show changes in walking style compared with healthy adults without a balance disorder.

These studies, however, have been conducted in a closed laboratory setting, which is very different to walking during daily activities in a real outdoor environment.

Therefore, these studies may not provide a true indication of the walking of patients with balance problems in everyday life.

What is the purpose of this study?

Until recently it was not possible to assess walking in real environments because measuring instruments had not been developed. Now, however, the use of matchbox-sized sensor-boxes placed at the small of the back and on the back of the head are able to record walking in a wide variety of real environments in healthy adults. The aim of this study is to use this technique to assess balance strategies used by patients with inner ear balance disorders when walking in five common urban environments, including an area with a checkerboard floor pattern, a darker area, a busy section, a quiet section, and on an uneven surface (cobbled pathway). This information will be used to develop advances in rehabilitation for patients with inner ear balance disorders.

Why have I been chosen?

You have been asked to participate in this study because you are between 18-65 years of age and have been diagnosed with a peripheral inner ear balance disorder. You have been referred by your consultant physician.

Do I have to take part?

It is up to you to decide whether to take part. We will describe the study to you and then go through this information sheet. If you agree to participate we will ask you to give your verbal consent and sign a consent form to show that you have agreed to take part. You are free to withdraw at any time without giving a reason. This will not affect the standard of care you receive.

What will happen to me if I take part?

If you decide to participate, you will be asked to attend the Academic Department of Physiotherapy, King's College,, London based at London Bridge, London SE1 1UL.

1. **During the first visit** you will be asked to complete a brief set of questionnaires, two short walking tests in the laboratory, the rod and disc test, and the outdoor walking test**.**

   The brief set of questionnaires will ask about your particular symptoms and their severity (for example, feelings of unsteadiness), the situations that may

produce these symptoms (for example, crowds), your emotional state, your ability to perform various daily activities, and your confidence in your ability to maintain balance during everyday activities.

The indoor balance tests will look at your normal walking speed and your ability to maintain your balance standing or while walking during different conditions, such as when the surface is unsteady or when you move your head at the same time.

The outdoor walking test will involve following a set route in the London Bridge area, in the middle of the morning or the afternoon. We would like to gather data by using sensor boxes placed at the small of your back, at the neck level, and on the head (hidden in a hat). The sensor boxes are about the size of a match box. You will also carry a wireless data logger in a pouch or pocket. You will be followed by two researchers to help you in case you need assistance. You can wear your usual clothing and shoes but please avoid high heels. Please **DO NOT** drink alcohol for 24 hours before the test.

The test can be arranged for a day and session that is convenient for you. Your travel costs will be reimbursed. The total test will take approximately two hours and 30 minutes.

2. **After you complete the test, we will arrange a rehabilitation sessions**
   These sessions will extend over a period of 3 months in NHNN and will be performed by Ms Amanda Male.

3. Additional tests of executive function assessment by a trained neuropsychologist will be performed, in order to quantify any relevant cognitive deficits.
   This assessment will take up to half an hour and will help in assessing your concentration level, memory, and ability to carry out multi-tasking and calculations while maintaining your balance.

4. After completing the rehabilitation program, we will reassess you by repeating the indoor balance tests, outdoor walking test, and the Rod and Disc test during

a second visit. This will help us to assess the effect of the rehabilitation program on your symptoms, and explore the possibility of developing other advanced rehabilitations for the future.

Are there any risks in taking part?

You may, on occasion, feel unsteady while performing some of the more challenging walking tasks and when undertaking the balance tests. There are risks of falling and risks handling traffic, but these should not be greater than the risks you face during your daily activities. You will be closely supervised throughout when performing all tests. If you feel particularly unsteady at any point you can stop the test.

Hypoallergenic adhesive tape will be used to fix the sensor on the skin at the small of your back and on the base of your neck. We will use a spray under the adhesive that will help it to come off easily when the test is finished. There might be some discomfort (similar to taking off sticking plaster) when the sensor comes off but there should be no lasting damage or irritation to the skin. There is also a risk of having an allergic reaction to the adhesive tape. If you have an allergy to adhesives, please inform the staff before the test.

What are the benefits of taking part?

We will offer you a rehabilitation program for a period of 3 months. This program will instruct you on how to use specific balance strategies when walking in challenging outdoor environments. In addition, the information from this study will be used to develop an advanced vestibular rehabilitation programme.

Will my taking part be kept confidential?

All information that is collected about you during the course of this research will be kept strictly confidential. All information for this project will be stored on password-protected computers used only by research staff. Any documents leaving the hospital or testing site will have all personal identifiable information removed.

Will my GP or medical team know about my participation and the results of this investigation?

With your permission we would like to share this information with your referring medical team. Your GP will not be informed of your participation in this study.

Will this affect my current treatment?

Participating in this study will not affect your current treatment.

What happens if there is a problem?

This study has been reviewed and accepted by the National Hospital for Neurology and Neurosurgery and the Institute of Neurology's Joint Ethics Committee. The consultant in charge of this investigation is Dr Doris Eva Bamiou (Consultant in Audiological Medicine, NHNN). Other investigators conducting this study are Professor Linda Luxon, Professor in Audiovestibular Medicine and Consultant Neuro-otological Physician at NHNN, Dr Marousa Pavlou (Lecturer in Physiotherapy, King's College London), Dr Ruth Mayagoitia-Hill (Lecturer in Assistive Technology, King's College London) Mrs. Marniza Omar (Audiologist, PhD student at King's College London) and Dr Amal Sulaiman (Physician, PhD student at University College London).

If you have any concerns regarding the study please contact Dr Marousa Pavlou, the physiotherapist who will be leading the testing. Dr Pavlou will try to answer your questions (contact details below). If you are unhappy and wish to complain formally, you can do this using the NHS complaints procedure. Details can be obtained from the hospital.

In the event that something does go wrong and you are harmed during the research due to someone's negligence, then you may have grounds for legal action for compensation against University College London Hospital's NHS Trust. However, you may have to pay for legal costs. The normal NHS complaints procedure will still be available to you.

It is up to you to decide whether to take part or not. If you decide to take part you are still free to withdraw at any time and without giving a reason. A decision to withdraw at any time, or a decision not to take part, will not affect the treatment you receive from your medical or therapy team in any way. You may withdraw your data from the project at any time, up until it is transcribed for use in the final report, which will be written up during September, 2015.

If you do decide to take part you will be given this information sheet to keep. You will also be asked to sign a consent form. Your data will be kept anonymously and will not be passed on outside of your medical care team.

Who can I contact for further information?

If you have any queries please contact Dr Amal Al-Shaikh Sulaiman, the PhD student conducting this study.

Dr Amal Al-Shaikh Sulaiman
UCL Ear Institute
University College London
Mobile: 07521453023
Email: amal.sulaiman@ucl.ac.uk

Appendix 8.2
Participant's Consent Form

University College London Hospitals NHS
NHS Trust

Centre Number:
Patient Identification Number for this study:

UCLH Project ID number:
Form version:

CONSENT FORM

Title of project: Study of free walking in patients with a peripheral vestibular disorder.

Name of Chief Investigator: Dr. Doris-Eva Bamiou,
Consultant in Audiological Medicine, National Hospital for Neurology and Neurosurgery (University College London NHS trust) and Senior Lecturer, Ear Institute (University College London)

Please initial box

1. I confirm that I have read and understood the information sheet dated ..... (version .....) for the above study and have had the opportunity to ask questions. ☐

2. I confirm that I have had sufficient time to consider whether or not I want to be included in the study ☐

3. I understand that my participation in this study is voluntary and that I am free to withdraw at any time, without giving any reason, and without my medical care or legal rights being affected. ☐

4. I understand that sections of my medical notes may be looked at by responsible individuals from King's College London, The National Hospital for Neurology and Neurosurgery or from regulatory authorities where it is relevant to my taking part in research. I give permission for these individuals to have access to my records. ☐

5. I agree to take part in the above study. ☐

Continued on next page/

1 form for Patient;
1 to be kept as part of the study documentation,
1 to be kept with hospital notes

University College London Hospitals NHS
NHS Trust

Centre Number:
Patient Identification Number for this study:

UCLH Project ID number:
Form version:

CONSENT FORM

Title of project: Study of free walking in patients with a peripheral vestibular disorder.

Name of Principal investigator: Dr. Doris-Eva Bamiou,
Consultant in Audiological Medicine, National Hospital for Neurology and Neurosurgery (University College London NHS trust) and Senior Lecturer, Ear Institute (University College London).

Name of patient	Date	Signature
Name of Person taking consent (if different from researcher)	Date	Signature
Researcher (to be contacted if there are any problems)	Date	Signature

Comments or concerns during the study

If you have any comments or concerns you may discuss these with the investigator. If you wish to go further and complain about any aspect of the way you have been approached or treated during the course of the study, you should write or get in touch with the Complaints Manager, UCL hospitals. Please quote the UCLH project number at the top this consent form.

1 form for Patient;
1 to be kept as part of the study documentation,
1 to be kept with hospital notes

Appendix 8.3
Dizziness Handicap Inventory

Dizziness Handicap Inventory

Name: _____ DOB: _____ Date: _____

Instructions: The purpose of this scale is to identify difficulties that you may be experiencing because of your dizziness or unsteadiness. Please answer "yes", "no" or "sometimes" to each question.
Answer each question as it applies to your dizziness or unsteadiness only.

ITEM	QUESTION		Y	N	S
1	Does looking up increase your problem?	P			
2	Because of your problem, do you feel frustrated?	E			
3	Because of your problem, do you restrict your travel for business or recreation?	F			
4	Does walking down the aisle of a supermarket increase your problem?	P			
5	Because of your problem, do you have difficulty getting into or out of bed?	F			
6	Does your problem significantly restrict your participation in social activities such as going out to dinner, the movies, dancing or to parties?	F			
7	Because of your problem, do you have difficulty reading?	F			
8	Does performing more ambitious activities such as sports or dancing or household chores such as sweeping or putting dishes away increase your problem?	P			
9	Because of your problem, are your afraid to leave your home without having someone accompany you?	E			
10	Because of your problem, are you embarrassed in front of others?	E			
11	Do quick movements of your head increase your problem?	P			
12	Because of your problem, do you avoid heights?	F			
13	Does turning over in bed increase your problem?	P			
14	Because of your problem, is it difficult for you to do strenuous housework or yard work?	F			
15	Because of your problem, are you afraid people may think you are intoxicated?	E			
16	Because of your problem, is it difficult for you to walk by yourself?	F			
17	Does walking down a sidewalk increase your problem?	P			
18	Because of your problem, is it difficult for you to concentrate?	E			
19	Because of your problem, is it difficult for you to walk around the house in the dark?	F			
20	Because of your problem, are you afraid to stay at home alone?	E			
21	Because of your problem, do you feel handicapped?	E			
22	Has your problem placed stress on your relationship with members of your family or friends?	E			
23	Because of your problem, are you depressed?	E			
24	Does your problem interfere with your job or household responsibilities?	F			
25	Does bending over increase your problem?	P			
			X 4	X 0	X 2
		=			
		TOTAL			

Appendix 8.4
Situational Vertigo Questionnaire

SITUATIONAL VERTIGO QUESTIONNAIRE

Vertigo is the medical term used for symptoms which patients often describe as feelings of unusual disorientation, dizziness, giddiness, lightheadedness or unsteadiness. Please ring a number to indicate the degree to which each of the situations listed below causes feelings of vertigo, or makes your vertigo worse. If you have never been in one of the situations then for that item ring "N.T." for "Not Tried".

The categories are:

0	1	2	3	4	N.T.
Not at all	Very slightly	Somewhat	Quite a lot	Very much	Not tried

Riding as a passenger in a car on straight, flat roads	0	1	2	3	4	N.T.
Riding as a passenger in a car on winding or bumpy roads	0	1	2	3	4	N.T.
Walking down a supermarket aisle	0	1	2	3	4	N.T.
Standing in a lift while it stops	0	1	2	3	4	N.T.
Standing in a lift while it moves at a steady speed	0	1	2	3	4	N.T.
Riding in a car at a steady speed	0	1	2	3	4	N.T.
Starting or stopping in a car	0	1	2	3	4	N.T.
Standing in the middle of a wide open space (e.g. large field or square)	0	1	2	3	4	N.T.
Sitting on a bus	0	1	2	3	4	N.T.
Standing on a bus	0	1	2	3	4	N.T.
Heights	0	1	2	3	4	N.T.
Watching moving scenes on the T.V. or at the cinema	0	1	2	3	4	N.T.
Travelling on escalators	0	1	2	3	4	N.T.
Looking at striped or moving surfaces (e.g. curtains, Venetian blinds, flowing water)	0	1	2	3	4	N.T.
Looking at a scrolling computer screen or microfiche	0	1	2	3	4	N.T.
Going through a tunnel looking at the lights on the side	0	1	2	3	4	N.T.
Going through a tunnel looking at the light at the end	0	1	2	3	4	N.T.
Driving over the brow of a hill, around bends, or in wide open spaces	0	1	2	3	4	N.T.
Watching moving traffic or trains (e.g. trying to cross the street, or at the station)	0	1	2	3	4	N.T.

Scoring= total sum/19-number not tried

Appendix 8.5
The Activities-specific Balance Confidence (ABC) Scale

The Activities-specific Balance Confidence (ABC) Scale

For each of the following activities, please indicate your level of self-confidence by choosing a corresponding number from the following rating scale:

0% 10 20 30 40 50 60 70 80 90 100%
no confidence completely confident

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

1. ….walk around the house? ____%
2. …walk up or down stairs? ____%
3. …bend over and pick up a slipper from the front of a closet floor ____%
4. …reach for a small can off a shelf at eye level? ____%
5. …stand on your tiptoes and reach for something above your head? ____%
6. …stand on a chair and reach for something? ____%
7. …sweep the floor? ____%
8. …walk outside the house to a car parked in the driveway? ____%
9. …get into or out of a car? ____%
10. …walk across a parking lot to the mall? ____%
11. …walk up or down a ramp? ____%
12. …walk in a crowded mall where people rapidly walk past you? ____%
13. …are bumped into by people as you walk through the mall?____%
14. … step onto or off an escalator while you are holding onto a railing? ____%
15. … step onto or off an escalator while holding onto parcels such that you cannot hold onto the railing? ____%
16. …walk outside on icy sidewalks? ____%

Appendix 8.6
Vertigo Symptom Scale

VERTIGO SYMPTOM SCALE

The following questions ask about the type of symptoms you experience and how often they occur. Please circle the appropriate number to indicate about how many times you have experienced each of the symptoms listed below **during the past month**.

0	1	2	3	4
Never	A few times (1-3 times a month)	Several times (4-12 times a month)	Quite often (on average more than 4-7 times a week)	Very often (on average more than once a day)

How often in the past month have you had the following symptoms:

1. A feeling that either you, or things around you, are spinning or moving, lasting (PLEASE ANSWERS ALL THE CATEGORIES)

a. Less than 2 minutes 0 1 2 3 4

b. Up to 20 minutes 0 1 2 3 4

c. 20 minutes to one hour 0 1 2 3 4

d. Several hours 0 1 2 3 4

e. More than 12 hours 0 1 2 3 4

2. Pains in the heart or chest region

0 1 2 3 4

3. Hot or cold spells

0 1 2 3 4

4. Unsteadiness so severe that you actually fall

0 1 2 3 4

5. Feel (feeling sick), stomach churning

0 1 2 3 4

6. Tension/soreness in your muscles

0 1 2 3 4

7. A feeling of being light-headed, 'swimmy' or giddy, lasting (PLEASE ANSWERS ALL THE CATEGORIES)

a. Less than 2 minutes 0 1 2 3 4

b. Up to 20 minutes 0 1 2 3 4

c. 20 minutes to one hour 0 1 2 3 4

d. Several hours 0 1 2 3 4

e. More than 12 hours 0 1 2 3 4

8. Trembling, shivering

0 1 2 3 4

9. Feeling of pressure in the ear(s)

0 1 2 3 4

10. Heart pounding or fluttering

0 1 2 3 4

11. Vomiting

0 1 2 3 4

12. Heavy feeling in arms or legs

0 1 2 3 4

13. Visual disturbances (e.g. blurring, flickering, spots before the eyes)

0 1 2 3 4

14. Headache or feeling of pressure in the head

0 1 2 3 4

15. Unable to stand or walk properly without support

0 1 2 3 4

16. Difficulty in breathing, short of breath

0 1 2 3 4

17. Loss of concentration or memory

0 1 2 3 4

18. Feeling unsteady, about to lose balance lasting: (PLEASE ANSWER ALL THE CATEGORIES)

a. Less than 2 minutes 0 1 2 3 4

b. Up to 20 minutes 0 1 2 3 4

c. 20 minutes to one hour 0 1 2 3 4

d. Several hours 0 1 2 3 4

e. More than 12 hours 0 1 2 3 4

19. Tingling, prickling or numbness in parts of the body

0 1 2 3 4

20. Pains in the lower part of your back

0 1 2 3 4

21. Excessive sweating

0 1 2 3 4

22. Feeling faint, about to black out

0 1 2 3 4

23. Feeling 'spaced out', out of touch with your body

0 1 2 3 4

Appendix 8.7
Vestibular Disorders Activities of Daily Living Scale

Vestibular Disorders Activities of Daily Living Scale

Name/ID_____ Rater_____ Date_____

Instructions

This scale evaluates the effects of vertigo and balance disorders on independence in routine activities of daily living. Please rate your performance on each item. If your performance varies due to intermittent dizziness or balance problems please use the greatest level of disability. For each task indicate the level which most accurately describes how you perform the task. If you never do a particular task, please check the box in column NA. The rating scales are explained on bottom of page.

Independence Rating

Task	1 Independent	2 Uncomfortable, No Change in Ability	3 Decreased Ability, No Change in Manner of Performance	4 Slower, Cautious, More Careful	5 Prefer Using an Object for Help	6 Must Use an Object for Help	7 Must Use Special Equipment	8 Need Physical Assistance	9 Dependent	10 Too Difficult, No Longer Perform	NA
F-1 Sitting up from lying down											
F-2 Standing up from sitting on the bed or chair											
F-3 Dressing the upper body (eg, shirt, brassiere, undershirt)											
F-4 Dressing the lower body (eg, pants, skirt, underpants)											
F-5 Putting on socks or stockings											
F-6 Putting on shoes											
F-7 Moving in or out of the bathtub or shower											
F-8 Bathing yourself in the bathtub or shower											
F-9 Reaching overhead (eg, to a cupboard or shelf)											
F-10 Reaching down (eg, to the floor or a shelf)											
F-11 Meal preparation											
F-12 Intimate activity (eg, foreplay, sexual activity)											
A-13 Walking on level surfaces											
A-14 Walking on uneven surfaces											
A-15 Going up steps											
A-16 Going down steps											
A-17 Walking in narrow spaces (eg, corridor, grocery store aisle)											
A-18 Walking in open spaces											
A-19 Walking in crowds											
A-20 Using an elevator											
A-21 Using an escalator											
I-22 Driving a car											
I-23 Carrying things while walking (eg, package, garbage bag)											
I-24 Light household chores (eg, dusting, putting items away)											
I-25 Heavy household chores (eg, vacuuming, moving furniture)											
I-26 Active recreation (eg, sports, gardening)											
I-27 Occupational role (eg, job, child care, homemaking, student)											
I-28 Traveling around the community (car, bus)											

Explanation of Independence Rating Scale

This scale will help us to determine how inner ear problems affect your ability to perform each task. Please indicate your current performance on each task, as compared to your performance before developing an inner ear problem, by checking one of the columns in the center of the page. Pick the answer that most accurately describes how you perform the task.

1. I am **not disabled**, perceive no change in performance from before developing an inner ear impairment.
2. I am **uncomfortable** performing the activity but **perceive no difference** in the quality of my performance.
3. I **perceive a decrement** in the quality of my performance, **but have not changed** the manner of my performance.
4. I **have changed** the manner of my performance, eg, I do things more slowly or carefully than before, or I do things without bending.
5. I **prefer using an ordinary object** in the environment for assistance (eg, stair railing) but I am not dependent on the object or device to do the activity.
6. I **must use** an ordinary object in the environment for assistance, but I have not acquired a device specifically designed for the particular activity.
7. I must use **adaptive equipment** designed for the particular activity (eg, grab bars, cane, reachers, bus with lift, wedge pillow).
8. I require another person for **physical assistance** or, for an activity involving 2 people, I need unusual physical assistance.
9. I am **dependent** on another person to perform the activity.
10. I **no longer perform** the activity due to vertigo or a balance problem.

NA. I **do not usually perform this task** or **I prefer not to answer** this question.

Appendix 8.8
Hospital Anxiety and Depression Scale

This questionnaire will help your physician know how you are feeling. Read every sentence. Place an "X" on the answer that best describes how you have been feeling during the LAST WEEK. You do not have to think too much to answer. In this questionnaire, spontaneous answers are more important. Mark only one answer for each question.

A (1) I feel tense or wound up:
- 3 ( ) Most of the time
- 2 ( ) A lot of times
- 1 ( ) From time to time
- 0 ( ) Not at all

D (2) I still enjoy the things I used to:
- 0 ( ) Definitely as much
- 1 ( ) Not quite so much
- 2 ( ) Only a little
- 3 ( ) Hardly at all

A (3) I get a sort of frightened feeling as if something awful is about to happen:
- 3 ( ) Very definitely and quite badly
- 2 ( ) Yes, but not too badly
- 1 ( ) A little, but it doesn't worry me
- 0 ( ) Not at all

D (4) I can laugh and see the funny side of things:
- 0 ( ) As much as I always could
- 1 ( ) Not quite as much now
- 2 ( ) Definitely not so much now
- 3 ( ) Not at all

A (5) Worrying thoughts go through my mind:
- 3 ( ) Most of the time
- 2 ( ) A lot of times
- 1 ( ) From time to time
- 0 ( ) Only occasionally

D (6) I feel cheerful:
- 0 ( ) Most of the time
- 1 ( ) Usually
- 2 ( ) Not often
- 3 ( ) Not at all

A (7) I can seat at ease and feel relaxed:
- 0 ( ) Definitely
- 1 ( ) Usually
- 2 ( ) Not often
- 3 ( ) Not at all

D (8) I feel as I am slowed down:
- 3 ( ) Nearly all the time
- 2 ( ) Very often
- 1 ( ) From time to time
- 0 ( ) Not at all

A (9) I get a sort of frightened feeling like butterflies in the stomach:
- 0 ( ) Not at all
- 1 ( ) From time to time
- 2 ( ) Quite often
- 3 ( ) Very often

D (10) I have lost interest in my appearance:
- 3 ( ) Definitely
- 2 ( ) I don't take so much care as I should
- 1 ( ) I may not take quite as much care
- 0 ( ) I take just as much care as ever

A (11) I feel restless, as if I had to be on the move:
- 3 ( ) Very much indeed
- 2 ( ) Quite a lot
- 1 ( ) Not very much
- 0 ( ) Not at all

D (12) I look forward with enjoyment to things:
- 0 ( ) As much as I ever did
- 1 ( ) A little less than I used to
- 2 ( ) Definitely less than I used to
- 3 ( ) Hardly at all

A (13) I get a sudden feeling of panic:
- 3 ( ) Very often indeed
- 2 ( ) Quite often
- 1 ( ) From time to time
- 0 ( ) Not at all

D (14) I can enjoy a good TV or radio program or book:
- 0 ( ) Often
- 1 ( ) Sometimes
- 2 ( ) Not often
- 3 ( ) Hardly at all

Appendix 8.9
Functional Gait Assessment

Appendix.
Functional Gait Assessment[a]

Requirements: A marked 6-m (20-ft) walkway that is marked with a 30.48-cm (12-in) width.

_____1. GAIT LEVEL SURFACE

Instructions: *Walk at your normal speed from here to the next mark (6 m [20 ft]).*

Grading: Mark the highest category that applies.

(3) Normal—Walks 6 m (20 ft) in less than 5.5 seconds, no assistive devices, good speed, no evidence for imbalance, normal gait pattern, deviates no more than 15.24 cm (6 in) outside of the 30.48-cm (12-in) walkway width.

(2) Mild impairment—Walks 6 m (20 ft) in less than 7 seconds but greater than 5.5 seconds, uses assistive device, slower speed, mild gait deviations, or deviates 15.24–25.4 cm (6–10 in) outside of the 30.48-cm (12-in) walkway width.

(1) Moderate impairment—Walks 6 m (20 ft), slow speed, abnormal gait pattern, evidence for imbalance, or deviates 25.4–38.1 cm (10–15 in) outside of the 30.48-cm (12-in) walkway width. Requires more than 7 seconds to ambulate 6 m (20 ft).

(0) Severe impairment—Cannot walk 6 m (20 ft) without assistance, severe gait deviations or imbalance, deviates greater than 38.1 cm (15 in) outside of the 30.48-cm (12-in) walkway width or reaches and touches the wall.

_____2. CHANGE IN GAIT SPEED

Instructions: *Begin walking at your normal pace (for 1.5 m [5 ft]). When I tell you "go," walk as fast as you can (for 1.5 m [5 ft]). When I tell you "slow," walk as slowly as you can (for 1.5 m [5 ft]).*

Grading: Mark the highest category that applies.

(3) Normal—Able to smoothly change walking speed without loss of balance or gait deviation. Shows a significant difference in walking speeds between normal, fast, and slow speeds. Deviates no more than 15.24 cm (6 in) outside of the 30.48-cm (12-in) walkway width.

(2) Mild impairment—Is able to change speed but demonstrates mild gait deviations, deviates 15.24–25.4 cm (6–10 in) outside of the 30.48-cm (12-in) walkway width, or no gait deviations but unable to achieve a significant change in velocity, or uses an assistive device.

(1) Moderate impairment—Makes only minor adjustments to walking speed, or accomplishes a change in speed with significant gait deviations, deviates 25.4–38.1 cm (10–15 in) outside the 30.48-cm (12-in) walkway width, or changes speed but loses balance but is able to recover and continue walking.

(0) Severe impairment—Cannot change speeds, deviates greater than 38.1 cm (15 in) outside 30.48-cm (12-in) walkway width, or loses balance and has to reach for wall or be caught.

_____3. GAIT WITH HORIZONTAL HEAD TURNS

Instructions: *Walk from here to the next mark 6 m (20 ft) away. Begin walking at your normal pace. Keep walking straight; after 3 steps, turn your head to the right and keep walking straight while looking to the right. After 3 more steps, turn your head to the left and keep walking straight while looking left. Continue alternating looking right and left every 3 steps until you have completed 2 repetitions in each direction.*

Grading: Mark the highest category that applies.

(3) Normal—Performs head turns smoothly with no change in gait. Deviates no more than 15.24 cm (6 in) outside 30.48-cm (12-in) walkway width.

(2) Mild impairment—Performs head turns smoothly with slight change in gait velocity (eg, minor disruption to smooth gait path), deviates 15.24–25.4 cm (6–10 in) outside 30.48-cm (12-in) walkway width, or uses an assistive device.

(1) Moderate impairment—Performs head turns with moderate change in gait velocity, slows down, deviates 25.4–38.1 cm (10–15 in) outside 30.48-cm (12-in) walkway width but recovers, can continue to walk.

(0) Severe impairment—Performs task with severe disruption of gait (eg, staggers 38.1 cm [15 in] outside 30.48-cm (12-in) walkway width, loses balance, stops, or reaches for wall).

_____4. GAIT WITH VERTICAL HEAD TURNS

Instructions: *Walk from here to the next mark (6 m [20 ft]). Begin walking at your normal pace. Keep walking straight; after 3 steps, tip your head up and keep walking straight while looking up. After 3 more steps, tip your head down, keep walking straight while looking down. Continue alternating looking up and down every 3 steps until you have completed 2 repetitions in each direction.*

Grading: Mark the highest category that applies.

(3) Normal—Performs head turns with no change in gait. Deviates no more than 15.24 cm (6 in) outside 30.48-cm (12-in) walkway width.

(2) Mild impairment—Performs task with slight change in gait velocity (eg, minor disruption to smooth gait path), deviates 15.24–25.4 cm (6–10 in) outside 30.48-cm (12-in) walkway width or uses assistive device.

(1) Moderate impairment—Performs task with moderate change in gait velocity, slows down, deviates 25.4–38.1 cm (10–15 in) outside 30.48-cm (12-in) walkway width but recovers, can continue to walk.

(0) Severe impairment—Performs task with severe disruption of gait (eg, staggers 38.1 cm [15 in] outside 30.48-cm (12-in) walkway width, loses balance, stops, reaches for wall).

_____5. GAIT AND PIVOT TURN

Instructions: *Begin with walking at your normal pace. When I tell you, "turn and stop," turn as quickly as you can to face the opposite direction and stop.*

Grading: Mark the highest category that applies.

(3) Normal—Pivot turns safely within 3 seconds and stops quickly with no loss of balance.

(2) Mild impairment—Pivot turns safely in >3 seconds and stops with no loss of balance, or pivot turns safely within 3 seconds and stops with mild imbalance, requires small steps to catch balance.

(1) Moderate impairment—Turns slowly, requires verbal cueing, or requires several small steps to catch balance following turn and stop.

(0) Severe impairment—Cannot turn safely, requires assistance to turn and stop.

_____6. STEP OVER OBSTACLE

Instructions: *Begin walking at your normal speed. When you come to the shoe box, step over it, not around it, and keep walking.*

Grading: Mark the highest category that applies.

(3) Normal—Is able to step over 2 stacked shoe boxes taped together (22.86 cm [9 in] total height) without changing gait speed; no evidence of imbalance.

(2) Mild impairment—Is able to step over one shoe box (11.43 cm [4.5 in] total height) without changing gait speed; no evidence of imbalance.

(1) Moderate impairment—Is able to step over one shoe box (11.43 cm [4.5 in] total height) but must slow down and adjust steps to clear box safely. May require verbal cueing.

(0) Severe impairment—Cannot perform without assistance.

(Continued)

Appendix.
Continued

_____7. GAIT WITH NARROW BASE OF SUPPORT

Instructions: *Walk on the floor with arms folded across the chest, feet aligned heel to toe in tandem for a distance of 3.6 m [12 ft]. The number of steps taken in a straight line are counted for a maximum of 10 steps.*
Grading: Mark the highest category that applies.

(3) Normal—Is able to ambulate for 10 steps heel to toe with no staggering.
(2) Mild impairment—Ambulates 7–9 steps.
(1) Moderate impairment—Ambulates 4–7 steps.
(0) Severe impairment—Ambulates less than 4 steps heel to toe or cannot perform without assistance.

_____8. GAIT WITH EYES CLOSED

Instructions: *Walk at your normal speed from here to the next mark (6 m [20 ft]) with your eyes closed.*
Grading: Mark the highest category that applies.

(3) Normal—Walks 6 m (20 ft), no assistive devices, good speed, no evidence of imbalance, normal gait pattern, deviates no more than 15.24 cm (6 in) outside 30.48-cm (12-in) walkway width. Ambulates 6 m (20 ft) in less than 7 seconds.
(2) Mild impairment—Walks 6 m (20 ft), uses assistive device, slower speed, mild gait deviations, deviates 15.24–25.4 cm (6–10 in) outside 30.48-cm (12-in) walkway width. Ambulates 6 m (20 ft) in less than 9 seconds but greater than 7 seconds.
(1) Moderate impairment—Walks 6 m (20 ft), slow speed, abnormal gait pattern, evidence for imbalance, deviates 25.4–38.1 cm (10–15 in) outside 30.48-cm (12-in) walkway width. Requires more than 9 seconds to ambulate 6 m (20 ft).
(0) Severe impairment—Cannot walk 6 m (20 ft) without assistance, severe gait deviations or imbalance, deviates greater than 38.1 cm (15 in) outside 30.48-cm (12-in) walkway width or will not attempt task.

_____9. AMBULATING BACKWARDS

Instructions: *Walk backwards until I tell you to stop.*
Grading: Mark the highest category that applies.

(3) Normal—Walks 6 m (20 ft), no assistive devices, good speed, no evidence for imbalance, normal gait pattern, deviates no more than 15.24 cm (6 in) outside 30.48-cm (12-in) walkway width.
(2) Mild impairment—Walks 6 m (20 ft), uses assistive device, slower speed, mild gait deviations, deviates 15.24–25.4 cm (6–10 in) outside 30.48-cm (12-in) walkway width.
(1) Moderate impairment—Walks 6 m (20 ft), slow speed, abnormal gait pattern, evidence for imbalance, deviates 25.4–38.1 cm (10–15 in) outside 30.48-cm (12-in) walkway width.
(0) Severe impairment—Cannot walk 6 m (20 ft) without assistance, severe gait deviations or imbalance, deviates greater than 38.1 cm (15 in) outside 30.48-cm (12-in) walkway width or will not attempt task.

_____10. STEPS

Instructions: *Walk up these stairs as you would at home (ie, using the rail if necessary). At the top turn around and walk down.*
Grading: Mark the highest category that applies.

(3) Normal—Alternating feet, no rail.
(2) Mild impairment—Alternating feet, must use rail.
(1) Moderate impairment—Two feet to a stair; must use rail.
(0) Severe impairment—Cannot do safely.

TOTAL SCORE: _____ MAXIMUM SCORE 30

[a] Adapted from Dynamic Gait Index.[1] Modified and reprinted with permission of authors and Lippincott Williams & Wilkins (http://lww.com).