THE RELATIONSHIP BETWEEN ANXIETY, GAZE DIRECTION AND INCREASED FALLS RISK IN WALKING OLDER ADULTS

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CONTENTS

The relationship between anxiety, gaze direction and increased falls risk in walking older adults

Looking (directing gaze) in the right place at the right time is crucial for safe walking, and there are age-related changes to gaze behaviour which increase falls-risk in older adults. For example, older adults at a high risk of falling tend to look away from a stepping target that they are still stepping towards in order to look at potentially challenging obstacles ahead. This early gaze transfer impairs the accuracy of stepping and increases the likelihood of tripping. It has previously been shown that this maladaptive gaze behaviour is associated with increased task-specific anxiety and may be a consequence of older adults spending insufficient time previewing the route ahead during the approach to the target. This thesis aims to elucidate the causal relationships between anxiety, sub-optimal gaze behaviour and increased falls risk in older adults.

In separate experiments we manipulated experimental conditions to: 1) temporarily increase older participants anxiety via Social Evaluative Threat 2) reduce anxiety via relaxation exercises and 3) alter the extent to which participants previewed obstacles and walking goals via a gaze training intervention. We studied the effects of these manipulations on measures of anxiety (self-report and physiological measures), eye movement characteristics (eye tracking devices) and stepping accuracy (3D motion capture).

Results showed that increasing older adults' anxiety resulted in reduced stepping performance, and a measured reduction in anxiety was accompanied by increased stepping performance. There were few effects on eye movement timing characteristics suggesting that these changes in stepping behaviour were not mediated by altered gaze strategies.

The route previewing intervention resulted in significant changes to older adults' gaze behaviour. Following the intervention, the duration of target fixation during walking more closely resembled that of younger participants. Route previewing also led to increased self-confidence and reduced stepping errors.

These studies have demonstrated a link between anxiety and stepping inaccuracies contributing to falls-risk in older adults. The mechanisms underlying the effects of anxiety on behaviour remain unclear; however, the effects seem largely independent of the timing of gaze transfer. It is likely that the relative timing between eye and stepping movements may be less important for visuomotor control than the total time for which a target or obstacle is viewed during its approach. These findings highlight the possibility of using interventions aimed at reducing anxiety and/or guiding gaze behaviour to address falls-risk in older adults.

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Chapter 1

General Introduction

1.1 The general problem

Falls are a common cause of injury in older adults and the leading cause of death from injury among people aged over 75 in the UK. Around one in three over 65s will experience a fall each year (Blake et al., 1988) and those who survive a fall will often suffer ongoing problems such as injury and infection, increasing risk for loss of mobility, depression, anxiety and an increased mortality risk. The treatment and long term care of these unintentional falls costs the NHS and Personal Social Services nearly £1 billion annually in the UK (Scuffham et al., 2003). Therefore, understanding the ageing process and factors contributing to fall-risk is important in order to improve the quality of later life through falls prevention, and reduce the financial burden on health services.

1.2 Why are older people more susceptible to falls?

The majority of falls occur during walking and result from slips or trips (Berg et al., 1997; Blake et al., 1988) which represent a failure to place the feet appropriately to meet environmental demands usually specified by visual information describing the locations of features such as stair tread edges, the location and dimensions of obstacles and safe areas in the terrain. The reasons for failing to adapt to environmental demands can be due to: impaired neuromuscular function, cognitive processing or sensorimotor function, or a combination of these factors. Impaired neuromuscular function as a factor

of falling is an inability to generate the necessary torque about a joint or force against external objects to maintain an upright posture. Cognitive processing relates to the speed and accuracy that an appropriate motor response can be selected by the central nervous system based on sensory information. The accuracy of this sensory information is based on our sensory receptors' ability to receive environmental information. Vision is our primary source of sensory information used in order to navigate our environment and avoid obstacles, and therefore visual impairment has repercussions for motor planning and execution.

Visual impairment is common in older age (Branch et al., 1989), and is a significant risk factor for falls (Lord & Dayhew, 2001). However, recent research suggests that older adults, particularly those deemed to be at a high risk of falling, also exhibit different gaze behaviour patterns during locomotion compared to younger adults which are independent of visual deficits. Chapman and Hollands (2007) found that older adults with a history of falls tended to transfer gaze to future stepping constraints rather than maintain online guidance of current steps. These changes in gaze behaviour were accompanied by reduced target stepping accuracy, which has since been causally linked with falls risk (Yamada et al., 2011). Furthermore, this stepping inaccuracy was reduced when older adults were instructed to maintain gaze fixation on current stepping targets until foot contact in the target box (Young & Hollands, 2010). These studies suggest that there is a reversible, maladaptive mechanism driving high-risk older adults to prioritise planning of future stepping actions over guiding ongoing stepping actions. The reason that older adults behave in this manner still needs elucidating.

Research has shown a correlation of early gaze transfer with self-reported state anxiety (Young et al., 2011) and that early gaze transfer was accompanied by less frequent

fixations of future targets during the approach of the first target (see Figure 1-1, Young & Williams, 2015).

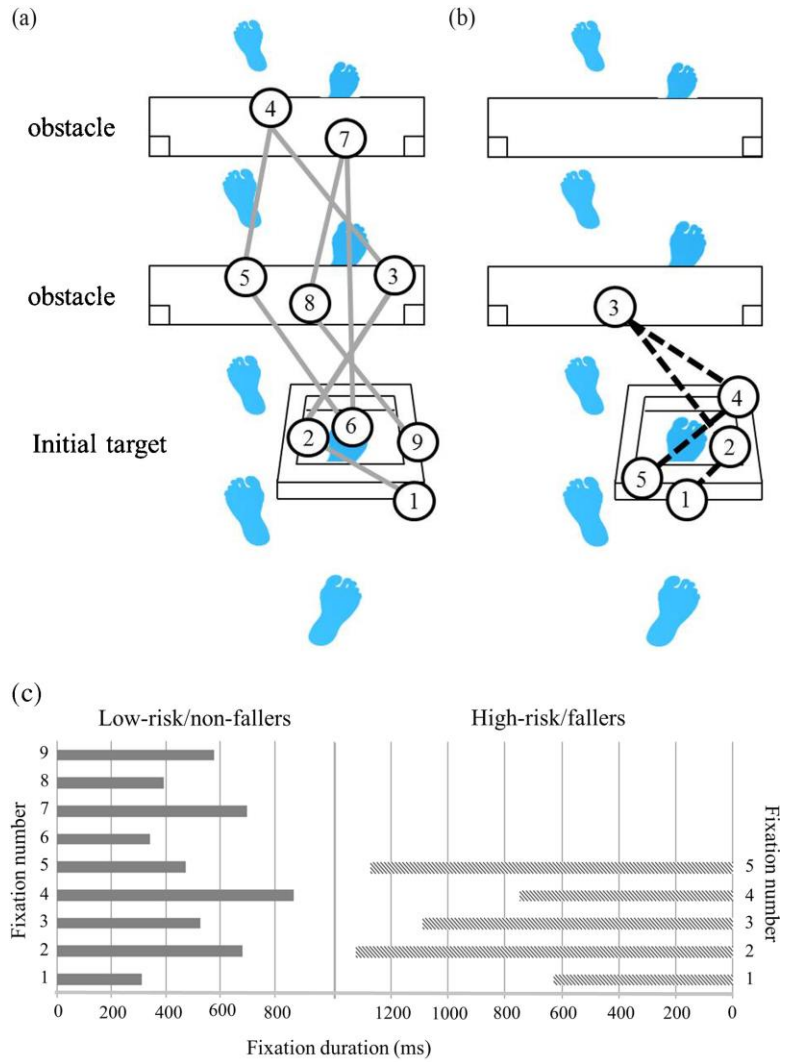

Figure 1-1 Schematic example of gaze behaviours and fixation order when approaching a series of obstacles of (a) a low-risk older adult, and (b) a high-risk older adult. Bar chart (c) shows the duration of fixations represented above. (Figure from Young & Williams (2015)).

These results offer a potential mechanistic explanation for maladaptive gaze and stepping behaviour based on anxiety-related failure to adequately plan future actions.

The work presented in this thesis aimed to provide evidence of a causal link between anxiety and early gaze transfer from current stepping targets, and also explore how increased planning time might alter gaze behaviour, state anxiety and stepping accuracy. In order to explore these relationships, it is important to first understand how ageing can affect the sensory and motor systems involved with walking, and also how psychological factors can influence these systems.

1.3 Age-related changes to gait and neuromuscular decline

As we age there is a significant reduction of walking speed in general, this is more pronounced in older adults that have recently fallen, and who also exhibit shorter step length, a more uneven stepping frequency, and narrower step width (Guimaraes & Isaacs, 1980). However, more recent research has found that wider stepping is also associated with a fear of falling and falls, and that this, along with increases in double support time and reduced speed, are adaptations to the gait pattern in order to increase stability (Maki, 1997). Stride time variability has been shown to be a good predictor of falls (Hausdorff et al., 2001; Maki, 1997), however some research suggests that mediolateral step variability is more pertinent as an indicator of falls risk (Owings & Grabiner, 2004). It is likely that these fall predictors are a product of a decline in the quality of visual and somatosensory information due to degeneration of sensory and motor nerve fibres (Shaffer & Harrison, 2007). Nerve conduction shows a curvilinear reduction of velocity with ageing over 40 (Taylor, 1984), this could be due to a reduction in the number of myelinated nerve fibres, and also a reduction in the size of these fibres (Mittal & Logmani, 1987). The consequence of these reductions, is an increase in reaction times with age (Porciatti et al., 1999) which can have important

consequences when responding to unexpected perturbations to stability (Pijnappels et al., 2005).

Another factor that related to falls-risk is age-related decline in muscle strength. Lexell et al. (1988) took muscle biopsies from a selection of participants from the ages of 15 to 83 and found that muscle atrophy started at around 25 years old, and increased with age. This atrophy was mainly due to a decrease in the number of muscle fibres, but they also found some reduction in fibre size. This decrease in muscle mass with age, termed sarcopenia, has been associated with a decreased, and delayed peak in anteroposterior force generation when performing voluntary rapid forward steps (Melzer et al., 2010). The implications of this reduction in strength and speed have been previously highlighted by Pijnappels et al. (2005). They conducted a study in which an obstacle suddenly appeared from the floor and caused young and older adults to trip. They reported that while young participants managed to regain balance, some older participants fell due to a delayed, and insufficient reduction of the knee angle velocity, and errors in placement of the recovery limb. The impact of neuromuscular problems and their implications for falls risk can be amplified if an individual has arthritis (Sturnieks et al., 2004); a condition prevalent in 24 – 48% of the population over 75 years old (Dunlop et al., 2001). Arthritis can also impact older adults' range of motion, which is associated with impaired performance of physical tasks (Beissner et al., 2000).

Rehabilitative strength training programmes show good results in increasing muscle strength in the elderly, however these improvements tend to focus on specific muscle groups and can show a quick reversal if the programme is not adhered to (see Liu & Latham (2009) for a review). Training programmes that also incorporate balance, stretching and endurance have shown more promising results (Means et al., 2005).

The reduction of muscle strength and increased reaction times associated with normal ageing have implications for functional mobility of older adults during locomotion. However appropriate motor outputs usually rely on the reception of accurate sensory information to adjust to the environmental demands of everyday life. The next section looks at how the quality of the information provided by these sensory inputs is attenuated with age.

1.4 Sensory systems and ageing

The sensory information we receive when moving through our environment allows us to adjust to our surroundings and make appropriate motor responses in order to maintain balance and navigate successfully. We receive a combination of proprioceptive, kinaesthetic, cutaneous, and vestibular signals that allow us to determine our body position and movement relative to our head. There are various sensory inputs that allow us to achieve this: Golgi tendon organs located in our muscle tendons sense changes in muscle tension, muscle spindle fibres are located within the muscle and detect changes in the length of the muscle, and cutaneous mechanoreceptors and nociceptors are located in the dermis of the skin and detect pressure and pain respectively.

Muscle spindles are important in maintaining postural stability, as they detect postural sway and are part of reflex pathways to make appropriate balance adjustments. Hurley et al. (1998) showed that there is an age-related decline in the acuity of joint position sense, and postural stability when testing young, middle-aged and older adults. Feedback from cutaneous mechanoreceptors in the feet is also important in maintaining postural stability and balance (Kavounoudias et al., 1998), and reduced function of these receptors is associated with a reduction in balance in the elderly (Menz et al., 2005).

The vestibular system also contributes to sensory input during balance and postural control. It is located in the inner ear and detects information regarding head movement and rotation, and spatial orientation. Degeneration of the vestibular system occurs with age (Johnsson, 1971), however there is evidence that vestibular habituation head movement exercises, such as repeatedly rotating the head through various planes at a variety of speeds over a certain period, can reduce vertigo and improve vestibular function in patients (Cohen & Kimball, 2003).

In healthy functioning individuals, visual information can override vestibular information. This has been shown through allowing vision during galvanic vestibular stimulation, and measuring the resulting changes to posture and gait deviations; however this overriding ability is reduced with age (Deshpande & Patla, 2007). Furthermore, older adults deemed to be at a higher risk of falling have been shown to have a reduced ability to supress the vestibulo-ocular reflex when going from sitting to standing (Di Fabio et al., 2001), and showed overcompensation in gaze movements related to head pitch. This suggests that there in an unbalanced weighting of vestibular input with visual image stabilisation, which might compromise the quality and clarity of visual information while walking.

Image stabilisation also requires compensatory head stabilising movements. Cromwell et al. (2002) showed that denying visual information decreased head stabilisation during gait in older adults to a greater extent than in young adults. This suggests that older adults rely more on vision to stabilise the head through neck stiffening due to age-related decrements in other sensory systems (such as the vestibular system). This reliance on vision in older adults in the absence of sufficient vestibular input can cause

further problems, due to an age-related reduction in the quality of visual information received.

1.5 Visual input with ageing

Visual information is the primary means of gathering spatial information about our environment, and we rely on it more than any other sensory input in order to maintain balance and posture. When the visual environment is artificially moved around a person without any real changes to their orientation or movement, there is initially a complementary postural alteration that results from visual proprioception (Lee & Lishman, 1975). Sundermier et al. (1996) used this environmental visual stimulus to measure changes in centre of foot pressure in young adults, healthy older adults, and older adults with balance problems. They found that older adults with balance problems had the greatest response to these stimuli, and used a maladaptive compensatory strategy that paradoxically led to greater instability. However, in addition to perceiving motion, vision is also used to detect obstacles and spatially map our surroundings in order to navigate through our environment. The next section will describe studies that have investigated how and when we require vision to effectively navigate our environment.

Studies of intermittent visual sampling behaviours have shown that even over novel and challenging terrain we require less than a 50% sampling rate of the environment (i.e. we only require visual information about our surroundings for 50% of the time) to safely navigate our way through (Patla et al., 1996). Hollands et al. (1995) demonstrated that saccadic eye movements to a stepping target invariably preceded the initiation of the step. Further research then demonstrated that during intermittent visual denial when stepping on an illuminated series of targets, visual information during stance was

enough to guide the foot to the required destination (Hollands & Marple-Horvat, 1996). However if vision of the target was removed during the stance phase, then there was a delay in the initiation of the step onto the target. This suggests that vision is used in a feedforward manner, and once the stepping action is planned there is a tight coupling between directional saccades and stepping responses. Furthermore, after initiation of these target fixations prior to stepping, in young adults it has been shown that gaze fixation is maintained until foot contact (Hollands & Marple-Horvat, 2001; Chapman & Hollands, 2006a), suggesting a possible role for online visual guidance to fine-tune foot placement on a target.

The extent to which online adjustments can be made to stepping trajectories during the swing phase was recently investigated in young adults, older adults deemed to be at a high-risk of falling, and older adults deemed to be at a low-risk of falling by Young and Hollands (2012a). They found that when responding to targets that unexpectedly changed position in the swing phase, older adults at a high-risk of falling made significantly later deviations in their stepping trajectory than young adults, and consequently had a higher final foot placement error which could be accounted for by the delay. Interestingly, they also showed delays in the onset of gaze refixation toward the new target location, suggestive of delays in visuomotor processing. These delays in visuomotor processing time measured in high-risk older adults might be a contributing factor to their prioritisation of future stepping constraints (Chapman & Hollands, 2007) i.e. they need more time to generate coordinated eye and stepping movements.

1.6 Age-related changes in visual sampling

The way in which we gather visual information about our surrounding changes as we age. Di Fabio et al. (2003b) showed that elderly participants initiated downward

saccades prior to stepping on to a platform earlier than younger adults. They suggested that this earlier movement was part of a strategy by the CNS to accommodate for age-related processing delays. This earlier fixation of an intended stepping target was also found during locomotion. Chapman and Hollands (2006b; 2007) identified that older adults fixated upcoming obstacles earlier than younger adults. This was also the case when multiple stepping constraints were present, which resulted in prioritisation of upcoming obstacles over current stepping constraints. This early gaze transfer was found to be associated with decreased stepping accuracy, presumably due to a lack of online visual guidance of the ongoing step. This notion is supported by the finding that, when older adults deemed to be at a high risk of falling were instructed to delay gaze transfixion until foot contact, there was a significant improvement in stepping performance (Young & Hollands, 2010). Research from the same group identified that this early transfer from a stepping target, was correlated with self-reported state anxiety (Young et al., 2011), and suggested that anxiety may be a mediating factor in this maladaptive gaze behaviour. In addition to this, Young & Hollands (2012b), found that following two falls, an individual who previously displayed characteristics of an adult with a low-risk of falling (i.e. later gaze transfer and more accurate stepping) reported an increased fear of falling, and exhibited corresponding earlier gaze transfer and decreased stepping accuracy. Elucidating this mechanism by which anxiety influences the timing of gaze transfer in older adults was one of the main aims of this thesis. However it is important to understand the attentional requirements of older adults, and why they might prioritise future stepping constraints.

1.7 Executive function and attentional demands during gait

Attention is the focus of one or more sensory inputs toward a stimulus of interest; regardless of whether that interest is voluntary or not. The attentional capacity of an individual describes the maximum cognitive load that can be allocated for attentional demands. It is within this attentional capacity that multiple processes compete for cognitive processing power, and if the capacity is not great enough to accommodate these processes, errors or delays may occur in the selected responses. Gait is a sensorimotor task that requires attention and uses varying amounts of attentional resources dependent on task complexity and an individual's cognitive capacity. This capacity for attention is part of a larger cognitive system called executive function, which is the combination of several higher cognitive components that receive, prioritise and process sensory information for goal oriented tasks. These cognitive components can be subcategorised as volition, self-awareness, planning, response inhibition, response monitoring, and attention (Yogev-Seligmann et al., 2008).

While walking, an individual must attend to a variety of hazards and objects that must be navigated in order to retain postural stability. As vision is our primary sense for gathering information regarding our surroundings, healthy individuals will look towards a stimulus, obstacle, or goal of interest in order to gather information about it and select an appropriate response (Herman et al., 1981; Hollands & Marple-Horvatt, 1995; 1996). This processing of visual information requires attentional capacity, which is limited if the individual is engaged in additional concurrent tasks that share the same attentional resources. Furthermore, when vision is denied the attentional demand of postural tasks increases (Teasdale et al., 1993).

The “dual-task” protocol is a commonly used study intervention that challenges and tests a participant’s attentional capacity by making them complete multiple tasks simultaneously. The primary task during these studies when researching the relationship between attention and posture and gait relates to a postural control and/or gait stepping performance task, with the secondary task being one that might compete for attentional resources. Kerr et al. (1985) were the first group to demonstrate the attentional demands of standing in young adults. Participants stood on a force plate while wearing a blindfold, and changes in their centre of pressure were measured while they completed two separate secondary memory tasks. In one condition they completed the Brooks spatial memory test in which they were asked to place numbers in an imaginary matrix and remember their locations (spatial memory), and a second memory task in which they remembered similar sentences (non-spatial memory). There was no increase in postural sway during either task, however they found an increase in the number of memory task errors during the spatial memory task, but not in the non-spatial task. They concluded that postural control is attentionally demanding, and that the attentional capacity for a secondary task is dependent on the type of task.

Lajoie et al. (1993) found that increasing the postural difficulty of a task increased participants’ reaction times to an auditory cue. Participants sat, stood normally, stood with a narrow base of support, and walked while responding the cues. They found that standing and walking require more attentional capacity than sitting, that standing reaction times were longer when participants had a narrow base of support, and that walking reaction times were longer during the single support compared to the double support phases of walking.

The anatomical areas involved with this attentional capacity have also been studied in patients to better understand how damage and atrophy might affect our attentional resources. The prefrontal cortex is activated during visuospatial and verbal dual-tasks (D'Esposito et al., 1995; Szameitat et al., 2002). Impairment of this region can result in decreased executive function task-related performance (Barbey et al., 2012), and more specifically, dual-task performance (Baddeley et al., 1997). However, Vilkki et al. (1996) found that focal frontal lobe damage alone did not impact dual-task performance, and suggest wider brain pathology is involved with attenuation of dual-tasks in patients.

Deterioration of anterior white matter is associated with ageing (Head et al., 2004), and accompanied by variable levels of reduced memory and executive function (O'Sullivan et al., 2001; for a review see Buckner, 2004). Zelazo et al. (2004) conducted a cross-sectional study demonstrating a decline of executive function in older adults. They found an inverted U relationship between age and executive function – executive function being greater in young adults when compared to children and older adults.

During simultaneous memory and walking tasks, Lindenberger et al. (2000) showed that there are increased dual-task costs (both memory and stepping performance decrease) with age. Li et al. (2001) then went on to show that older adults prioritise gait stabilisation and walking performance over memory performance when compared to young adults. However, older adults are able to consciously improve cognitive performance at the cost of stepping performance when instructed to do so (Verghese et al., 2007), and there is also attenuation of stepping performance in individuals that show significant age-related impairments of executive function (Coppin et al., 2006).

Hawkes et al. (2012) conducted a study in which older adults at a high-risk and low-risk of falling completed a visuo-spatial task switching test in which reaction times to the

appearance of a high or low dot were measured. Participants pressed spatially corresponding or opposing buttons on a keypad during two conditions, and then alternately switched between response type in a third condition. The high-risk group's reaction times were significantly greater than the low-risk group during the switching task. The high-risk group also completed an obstacle walk while responding to an auditory Stroop test in a dual-task condition. Gait velocity was negatively correlated with the switching task reaction times. The authors suggest that reduced neuromuscular and attention switching capacities might contribute towards the gait instability of high-risk adults, however the low-risk group did not complete the dual-task obstacle walk, so a direct comparison of this interaction between the two groups cannot be made.

The affect of age on appropriate attentional prioritisation during gait has been the subject of much research. Hausdorff et al. (2008) found significant reductions in gait speed, and increases in swing time variability in older adults during dual-task walking. In a recent systematic review, Ruffieux et al. (2015) compared seventy-nine studies that measured dual-task performance of postural tasks across a range of age groups from children to older adults. They concluded that older adults require greater cognitive input to maintain posture due to the degradation of neural structures. The results of the studies reviewed in this section support the findings of Ruffieux et al. (2015), but also suggest a more complex relationship between attention and the nature of the secondary task (i.e. spatial vs. non-spatial), and the balance ability (i.e. those at a high-risk vs. low-risk of falling) of older adults. The research suggests that older adults who are at a high-risk of falling have the most limited attentional capacity, and require the most cognitive input to maintain balance. This already limited attentional capacity can also be further

impacted by the effects of anxiety. The nature of anxiety, and methods of quantification are discussed in the next section.

1.8 Psychological and physiological measurements of anxiety

The term "anxiety" is used to describe an emotional state of unease or worry about a particular circumstance, task, or event with an uncertain outcome. Lazarus and Averill (1972) define anxiety in the following terms:

> *"Anxiety is an emotion based on the appraisal of threat, an appraisal which entails symbolic, anticipatory, and uncertain elements. These characteristics, broadly conceived, mean that anxiety results when cognitive systems no longer enable a person to relate meaningfully to the world about him."*

The symbolic nature of anxiety defined above relates to concepts that may or may not pose a real threat, but to which an individual is nonetheless invested in. The anticipatory and uncertain elements refer to the unknown nature of forthcoming perceived threats, however Lazarus and Averill go on to state that these threats can also exist in the present.

Anxiety can be split in to two catagories: state anxiety, which is an acute, transitional feeling of anxiety; and trait anxiety, which is a consitent state associated with personality. When faced with external stimuli, these two aspects of anxiety variably influence the cognitive evaluation and behavioural outcomes that are selected dependent on the individual's psychological and physical state (Spielberger, 1966).

In order to measure state and trait anxeity, Spielberger et al. (1970) originally developed the 40-item State-Trait Anxiety Inventory (STAI) to quantify self-reported anxiety; and

since, the shorter "Form Y" 20-item STAI (Spielberger, 1983). Thousands of studies have used the STAI to asses anxiety, and it is considered the "gold standard" within its field (Kain et al., 1997). Multiple, shortened versions of this inventory have been developed in order to save time while testing, however Marteau and Bekker (1992) developed the first standardised 6-item short-form questionnaire that highly correlates with the 20-item STAI ($r < .90$).

When an individual experiences acute, state anxiety, there is increased activation of sympathetic nerve pathways that cause physiological changes that are sometimes categorised as the "flight-or-fight" response (Hoehn-Saric & McLeod, 1988). An increase in heart rate and contraction force, dilation of blood vessels in skeletal muscle, and dilation of bronchioles in the lungs occur from the release of local adrenaline and noradrenaline from various afferent neurons, and circulatory adrenaline and noradrenaline from the adrenal cortex (Triposkiadis et al., 2009). These responses cause a state of alertness and readiness, and are thought to have had evolutionary benefits when confronting danger or hunting (Bracha, 2004).

In addition to these adrenergic responses, several other hormones are released when an individual experiences anxiety. Cortisol in particular has been the subject of much anxiety-related research due to its relative ease of measurement and correlation with self-reported anxiety measures (Bohnen et al., 1991). Levels of salivary cortisol are raised during acute stress tasks, and remain elevated for around 20 to 30 minutes following the stressor (Nater et al., 2005). However in recent years, salivary α-amylase has started to receive greater attention as a more reactive, non-invasive index measure of sympathetic activity (Rohleder et al., 2004). Following a rise in salivary α-amylase production due to a stress task, the measured concentration of salivary α-amylase is

largely reduced within 10 minutes (Nater et al., 2005). That being said, the extent to which salivary α-amylase, sympathetic nervous system activity, and anxiety correlate is unclear. Saliva production is stimulated by parasympathetic nervous activity, and protein secretion is stimulated by sympathetic nervous activity; both of which influence measured concentrations of salivary α-amylase (Bosch et al., 2011). Furthermore, the standard method of saliva collection via a Salivette being moved around in the mouth also stimulates the production of salivary α-amylase as a digestive protein. This method of collection might provide inaccurate measurements of salivary α-amylase, however a study by Rohleder et al. (2006) found that valid measurements could be obtained this way. The studies presented in this thesis are the first to use salivary α-amylase as measure of anxiety in the elderly during adaptive locomotion tasks. The next section looks at how anxiety affects attention and task prioritisation during gait.

1.9 Anxiety and fear of falling during locomotion

As previously mentioned, gait is an attentionally demanding task that requires greater attention as we age (Chapter 1.7). Anxiety is another factor influencing the attentional requirements of gait. Gage et al. (2003) looked at how increasing the height, and decreasing the width of a walkway can instil anxiety and alter attentional demands of locomotion in both young and older adults. They found reaction times to an auditory signal were greater for older adults compared to young, and that the younger group allocated more attention to single-limb support than double-limb support periods of gait. This phase dependent allocation of attention was not found in older adults. The authors suggest that this is due to an increased attentional demand during double-limb support in older adults. They also found that increasing anxiety increased reaction times to a

secondary task in both age groups, and that attention was prioritised to the task that posed the most threat.

Anxiety and old age both increase the attentional demands of gait (Gage et al., 2003), and changes in the gait cycle are also associated with anxiety. Using a similar methodology to Gage et al., (2003), Brown et al. (2006) found that a conservative gait pattern was adopted in anxiety inducing trials, and this resulted in a reduced obstacle contact frequency. However, some older adults develop a fear of falling, which can further reduce balance performance and is associated with a higher fall risk (Hadjistavropoulos et al., 2011). During periods of anxiety, there is increased activation of postural muscles, which stiffens the movement about joints and reduces the range of motion in the lower limbs of older adults (Brown et al., 2002). This stiffening strategy might be beneficial during activities that are of a low postural threat, but limits the adaptability of the lower limbs to respond to an unexpected perturbation (i.e. tripping on a raised pavement).

In order to avoid potential hazards, a visuospatial map of the surroundings must be obtained. During an unexpected perturbation, stored visuospatial information can be used to guide corrective steps without online visual guidance (Zettel et al., 2007). However, older adults, particularly those deemed to be at a high risk of falling, inadequately gather information about future stepping constraints on the approach to a target step (Young & Williams, 2015). Furthermore, high-risk older adults look away from a target step earlier than young adults to gather visual information about upcoming constraints (Chapman & Hollands, 2007). This might be due to the insufficient gathering of visuospatial information on the approach to the target step (see Figure 1-1). In a case study of a elderly faller, Young and Hollands (2012b) found that prior to

falling the participant delayed gaze transfer from the current stepping target, but following two falls she displayed gaze characteristics consistent with those of high-risk older adults and looked to future constraints earlier. This premature gaze transfer is also correlated with task-specific anxiety (Young et al., 2011). The work presented in this thesis aimed to explore the relationship of anxiety and the visual allocation of attention during adaptive locomotion, and how anxiety influences stepping performance.

1.10 Aims

This work in this thesis aimed to experimentally manipulate anxiety in order to see if it is the underlying cause of altered gaze behaviour and associated stepping errors demonstrated by older adults during adaptive locomotion. Firstly, we aimed to see if social evaluative threat could be used as a successful method of increasing anxiety during locomotion in young adults (Chapter 3). We then used this method to experimentally increase anxiety in older adults, and measured changes in their gaze behaviour and stepping performance (Chapter 4). We then investigated whether an intervention aimed at reducing anxiety in older adults was effective in improving gaze behaviour and stepping performance (Chapter 5). Finally, we investigated the effects of previewing the walking path on older adults' allocation of attention during adaptive locomotion and the impact on gaze behaviour, anxiety and stepping performance (Chapter 6).

Chapter 2

General Methods

Whilst each study differed according to its aims, many of the same instruments and protocols were used in the collection of data. This chapter covers the methods that were consistent throughout studies presented in this thesis, unless otherwise stated.

2.1 Participant Recruitment

Participants in these studies were classified as either young adults or older adults. All recruitment methods were given full approval from the University of Birmingham's ethical review committee. Participants all read study information sheets and signed a consent form knowing that they were free to withdraw from the study at any time without reason. An example information sheet and consent form can be found in Appendix A.

2.1.1 Young Adults

Young adults were recruited either from the School of Sport & Exercise Sciences' research hours programme in return for course credit, or from the school's postgraduate research student cohort. All young adults were between the ages of 18 and 30, and were healthy with no known mental or physical impairments.

2.1.2 Older Adults

All older adults were over 65 and able to walk independently. They were recruited from the local community via poster advertisements, from visits to local assisted living homes, or from a university research pool of elderly people interested in taking part in

research. They were offered between £10 and £20 (depending on the study) for taking part in this research in addition to their travel expenses.

2.2 General Study Protocol

The general protocol and task-specific equipment used throughout the studies presented here remains constant, and is fundamentally based on that of Young, Wing, and Hollands (2011).

Participants were required to walk a 7-metre path starting with their right foot. On their second right step they had to accurately step into a target box and then over a varying number of obstacles until they reached the end of the course (Figure 2-1). The target box was a raised black rectangular outline that was 4cm high and 5cm wide all the way around. The length of the inside stepping area was 8cm plus the length at the longest part of the participant's right shoe, and the width was 8cm plus the width at the widest point of the right shoe. This meant that each participant had the same spatial stepping constraints as each other. The target box (Figure 2-2) was made from solid corner blocks, and joined with collapsible sides to reduce the risk of falling if accidentally stepped on. The obstacles used were 60cm x 2cm x 20cm (width x depth x height) wooden boards with two stabilising blocks at either end to allow it to stand upright. This meant that if the obstacle was knocked in the direction of walking that it would fall flat and not cause a trip or fall. Participants were required to step over these obstacles with their right foot first.

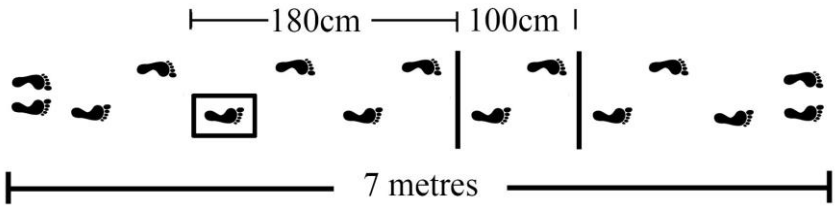

Figure 2-1 A schematic diagram of a trial with two obstacles.

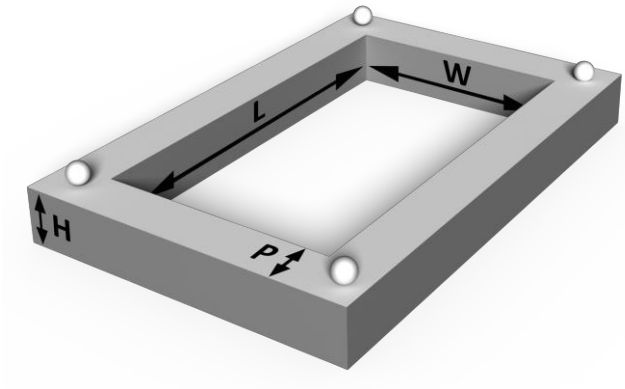

Figure 2-2 A 3D example of the stepping target used in all studies presented in this thesis. The inside length (L) was 8cm plus the length of the participants shoe, the inside width (W) was 8cm plus the width of the shoe. The height (H) of the target box was 4cm, and the depth of the perimeter (P) was 5cm. The box was black and its sides collapsed if it were stepped on. The four spheres on each of the corners represent reflective kinematic marker positions.

Prior to starting the trials, each participant completed two walks from the start line without the target or obstacles present so the investigators could identify the correct position for the target box. Participants initiated stepping with their right foot, and the average heel strike of their second right step was used as a distance marker to position the target box so that their heel would have landed 4cm from the rear had it been present. The target box was positioned so that the left exterior edge was in line with the centre of the walkway. It was then moved: 8cm forward, 12cm to the right, or a combination of the two from the original location to marginally alter step positions and reduce any effects of learning. These target box locations were evenly counterbalanced throughout each study's trials and participants could not see their position until they opened their eyes at the beginning of each trial.

There were a maximum of two obstacles positioned after the target box in any one trial, these were placed 180cm and 280cm past the rear edge of the target box. Participants completed several practice trials before testing began in order to familiarise themselves with the task. The specific arrangements of these obstacles are described in each experimental chapter.

2.3 Psychological Evaluation

2.3.1 Cognitive Wellbeing and Function

Participants completed a series of cognitive tests to evaluate their well-being and suitability for these experiments prior to taking part. The 28-question General Health Questionnaire (GHQ-28, see Appendix B.1) was used to assess participants' psychological state in four areas: somatic symptoms, anxiety and insomnia, social dysfunction and severe depression (Goldberg & Hillier, 1979). This allowed identification of any psychological problems that could confound experimental findings or render participants unsuitable for testing.

In order to assess each participant's ability to follow instructions, the Mini-Mental State (MMS, see Appendix B.2) examination was used to test for signs of dementia that might compromise the participants understanding of the task (Folstein et al., 1975). The MMS is a series of verbal instructions and questions that evaluate the participant's orientation, registration, attention and calculation, memory, and language. Out of a possible 30 points, a score of 27 or above is considered normal, while a score of 20 or below is indicative of dementia.

Another aspect of cognitive function relevant to the following studies is an individual's ability to scan their environment, process that information and make informed decisions based on it. The widely used trail-making A and B tests assess these characteristics, and are a commonly used method of assessing executive function (Tombaugh, 2004, see Appendix B.3). Part A involves the participant taking a pen and joining a line from one numbered circle to another on an A4 sheet of paper whilst timed. Part B involves a similar task, however the circles are alternate numbers and letters (e.g. 1-A-2-B-3-C

etc.). The difference between the times that participants took to complete the two tasks was calculated as a measure of executive function.

2.3.2 Task Efficacy

Due to the wide range of physical capabilities in the older population, it was important to identify participants' perception of their physical ability in order to assess task confidence. The Activities-specific Balance Confidence (ABC - Appendix B.4) scale lists 16 common daily tasks and asks the participant to state how confident they are about doing the task without losing their balance (Powell & Myers, 1995). In addition to this, the International Falls Efficacy Scale (FES-I – Appendix B.5) is a 16 question 4-point Likert scale questionnaire asking how concerned the participant is about falling whilst completing specific daily tasks (Yardley et al., 2005). These questionnaires allow determination of an individual's balance confidence while completing common daily tasks.

2.3.3 Self-Reported Anxiety

Anxiety was measured throughout the experiments using a short state-version of Spielberger's Trait-State Anxiety Inventory (Marteau & Bekker, 1992; Spielberger et al., 1970). Participants completed this questionnaire as a baseline measure to start, and then following each set of trials. There were four state anxiety questions (1, 3, 4 and 6) and two additional questions (2 and 5 - N.B. not included in Chapter 3) that were not taken in to account when scoring participants' anxiety. Each question was worded to be relevant to the stepping task they had just completed and answers were on a Likert scale from 1 (not at all) to 4 (very much). The questions were:

1. I feel calm about completing the task
2. I am frustrated by the task
3. I feel tense about stepping into the box
4. I feel relaxed about stepping into the box
5. I feel embarrassed about completing the task
6. I am worried that I will lose my balance

Questions 1 and 4 were reverse scored and then the sum of the four anxiety related questions minus 4 gave their final anxiety score, ranging from 0 (no anxiety) to 12 (extreme anxiety). This questionnaire allowed measurement of a participant's self-reported anxiety before and during each experiment. Typical scores reported in this thesis ranged from around 0 to 7.

The Profile of Mood States (POMS – Chapter 3 – Appendix C.1) and Immediate Anxiety Measurement Scale (IAMS – Chapters 3 and 6 – Appendix C.2) questionnaires were used in two of the studies presented in this thesis, and are explained in further details within their separate methods sections.

2.3.4 Physiological Anxiety

2.3.4.1 Heart Rate

Heart rate was measured using an Oregon Scientific strapless heart rate monitor (Oregon Scientific, UK). This was a watch that participants wore around their wrist that measures heart rate through a finger-based ECG system. They had to place two fingers on the metal parts of the watch face and hold them there for several seconds for the watch to give a reading.

Participants were asked to wear the watch throughout the testing period. During that time, heart rate was measured at baseline levels following a 5-minute (Chapter 6) or 20-minute (Chapters 3 to 5) rest period, and then immediately following each set of trials to give a measurement relative to the trials just completed.

2.3.4.2 Salivary α-amylase

During the first three studies presented in this thesis, salivary α-amylase was used as a cursor to represent physiological anxiety. To measure this, a timed, passive drooling collection technique was used. A Salimetrics salivary α-amylase assay was used to determine salivary α-amylase activity (Salimetrics Europe Ltd., UK).

Prior to testing, participants were not allowed alcohol or non-prescription drugs in the 24 hours leading up to the experiment. They were also asked to refrain from exercise that morning, and from brushing their teeth, caffeine, acidic drinks and eating during the hour before. These measures were taken to ensure the most stable levels of salivary α-amylase (Nater et al., 2005).

50ml Corning centrifuge tubes were used to collect saliva from participants. They were asked to void their mouths of saliva, and then with their heads tipped forward, allow saliva to naturally pool in the bottom of their mouths. Participants refrained from speaking and moving the muscles around their mouths to avoid stimulating more saliva production. After one minute, the participants emptied the collected pool of saliva from their mouths into a pre-weighed sterile tube. This process was repeated 2 more times in to the same tube, so that 3 minutes worth of saliva had been collected in total.

The saliva collection process was practiced once before testing to familiarise the participants with the collection protocol. Once testing had begun a baseline sample was collected following a 20-minute rest period, then after each set of trials further samples were collected. Once all samples for a participant had been collected, the tubes were weighed again, vortex mixed and then centrifuged at 4000 g for 10 minutes. Two 500µl samples of supernatant were then pipetted into sterile eppendorphs for freezing at -20°C until further analysis.

A Salimetrics salivary α-amylase assay kit (Salimetrics Europe, Ltd., UK) was used to determine the kinetic measurement of α-amylase activity in the saliva. A 1:200 dilution of each saliva sample was made using the provided diluent, 8µl of this solution was then pipetted into the provided plate wells. The substrate provided with the kit was heated to 37°C, and then 320µl was added simultaneously to the sample wells. The plate was then mixed at 37°C and read on a plate reader with a 405nm filter at 1-minute and 3-minutes following the addition of the substrate.

The final equation used to determine the α-amylase activity considering the assay volumes and properties was:

$$\Delta\text{Absorbance (3min – 1min reading)} \times 328 = \text{U/ml of } \alpha\text{-amylase activity}$$

2.4 Physical Evaluation

2.4.1 Visual Function

A Snellen eye chart was used to determine visual acuity. Participants stood at a distance of 6ft from the chart and read out each letter while covering their left eye, then their right eye, and then with both eyes open. In addition to this, the Pelli-Robson contrast sensitivity test was completed at a distance of 1 metre, with the letters at eye level in left, right, and both eyes (Pelli et al., 1988). These test were of particular importance in the older adult group, due to the varied decline in visual performance with age (Branch et al., 1989). If needed, the participants' own corrective glasses or contact lenses were worn during their participation.

2.4.2 Mobility Assessment

The Berg Balance Scale was used to assess participants' balance and mobility (Berg et al., 1989). It consists of 14 mobility tasks that the participant is asked to complete, such as move from standing to sitting, or stand on one leg for 10 seconds. Each task is scored from 0 to 4 according to the level of independence and ability shown. A score of 0 to 20 is indicative of someone who cannot walk, 21 to 40 is someone who needs assistance walking, over 40 is someone who can walk independently, and the maximum score is 56 (Appendix B.6).

In Chapters 5 and 6, the Timed Up-and-Go (TUG) test was used as an additional measure of mobility (Podsiadlo & Richardson, 1991). This required participants to start seated in a comfortable firm backed chair with armrests, and upon hearing a verbal signal, stand up and walk 3m to a mark on the floor, turn through 180°, walk back to the

chair, turn 180° and sit back down. They did this at a comfortable pace, and the time taken to complete it was recorded.

2.5 Kinematic Recording

Full body movement was recorded using a 100Hz 13-camera Vicon MX system running on Vicon Nexus 1.7.1 software (Vicon Oxford, UK). The cameras were calibrated using a 3-point calibration wand to an accuracy of <1mm. Four 14mm reflective markers were placed centrally on each corner of the target box. Four more markers were placed on each obstacle, two on top and two by the floor at either side. An adapted version of the Vicon lower-body plug-in gait model was used for labelling participants. Marker placement was mirrored on both left and right sides with variations in height of the upper and lower leg markers to distinguish between sides. Markers were placed on the anterior and posterior super iliac spines, the lateral thighs, lateral epicondyle of the knees, and the lateral tibias. The foot markers were placed on the outside of participants' shoes on the calcaneus of the heel, on the middle of the front, top surface of the shoes (toe marker), and equidistant between these two markers on the medial and lateral sides of the shoe (see Appendix E). In Chapter 3 the toe marker was placed on the head of the 3rd metatarsal rather than on the front edge of the shoe, this was subsequently changed in further studies to provide a more central measurement of foot placement (Figure 2-3). A headband with 4 reflective markers was also worn to mark the lateral forehead and posterior head on both sides.

Figure 2-3

An example of foot placement markers relative to target box markers.

2.5.1 Gait Event Detection

Trials were labelled in Vicon Nexus using custom models for each study. Each marker's (x, y, z) position coordinates were then exported to a CSV format, and then analysed in Matlab (The Mathworks, Inc. MA, USA, see Appendix F for scripts). In Chapter 3, the flat-foot frame was manually exported using visual frame-by-frame playback in the Vicon Nexus suite. In Chapters 4 to 6, gait events were detected using the methods in this section, and foot contact time was verified against manual identification (results below).

Data were filtered with a zero-phase fourth-order Butterworth Filter with a cut-off frequency of 7Hz. An adapted method of foot contact identification used by O'Connor et al. (2007) was used to detect separate heel and toe contact rather than general foot contact. Foot-contact and toe-off events were identified by using the vertical acceleration profile of heel and toe markers. A large acceleration peak in the respective traces coincided with heel and toe contact with the floor. To isolate the foot contact peak, a window of 400ms following the heel crossing the rear edge of the target box was used to identify the range of data in this area for both heel and toe markers. A

window size of 400ms was chosen as it would include the contact peaks, but would not include the peaks generated by toe off and heel off events. 30% of the y-axis range of this 400ms window was chosen to be a suitable cut-off point to isolate the contact peaks. If contact peaks were not identified, or if multiple peaks occurred in the isolated section, the trials were flagged for manual data extraction. The local maximum of the earliest occurring peak identified the foot contact time and also the participants stepping strategy. During these studies it was noted that some participants stepped into the target box with their toe first instead of heel first; the frequency of this is reported in each relevant chapter. Adoption of this alternate stepping strategy might represent an adaptation to compensate for the perceived postural threat of the stepping target. Our chosen method of foot contact identification allowed us to identify and record the stepping strategy (i.e. heel-first or toe-first) in addition to the timing of foot contact. (see Appendix F.1 for Matlab script)

In Chapter 4 foot contact time was also visually exported using frame-by-frame playback of each trial in order to validate the accuracy of the acceleration peak foot contact identification method described above. As expected, Pearson's product moment correlation revealed a very strong correlation between the manually selected contact frame number and the heal/toe acceleration peak frame number ($r_{(432)} = 0.99$, $p < .001$). The difference between each of the two frames was calculated, and the mean difference was less than a single video frame (-8 ± 17ms (M ± SD), N.B. 1 frame = 10ms).

Heel off and toe off events were identified as the second peaks that exceeded 30% of the y-axis range within the 400ms following the heel crossing the rear edge; however, only the toe off peak was necessary as it would be impossible for the toe to leave the ground before the heel during normal gait (Figure 2-4).

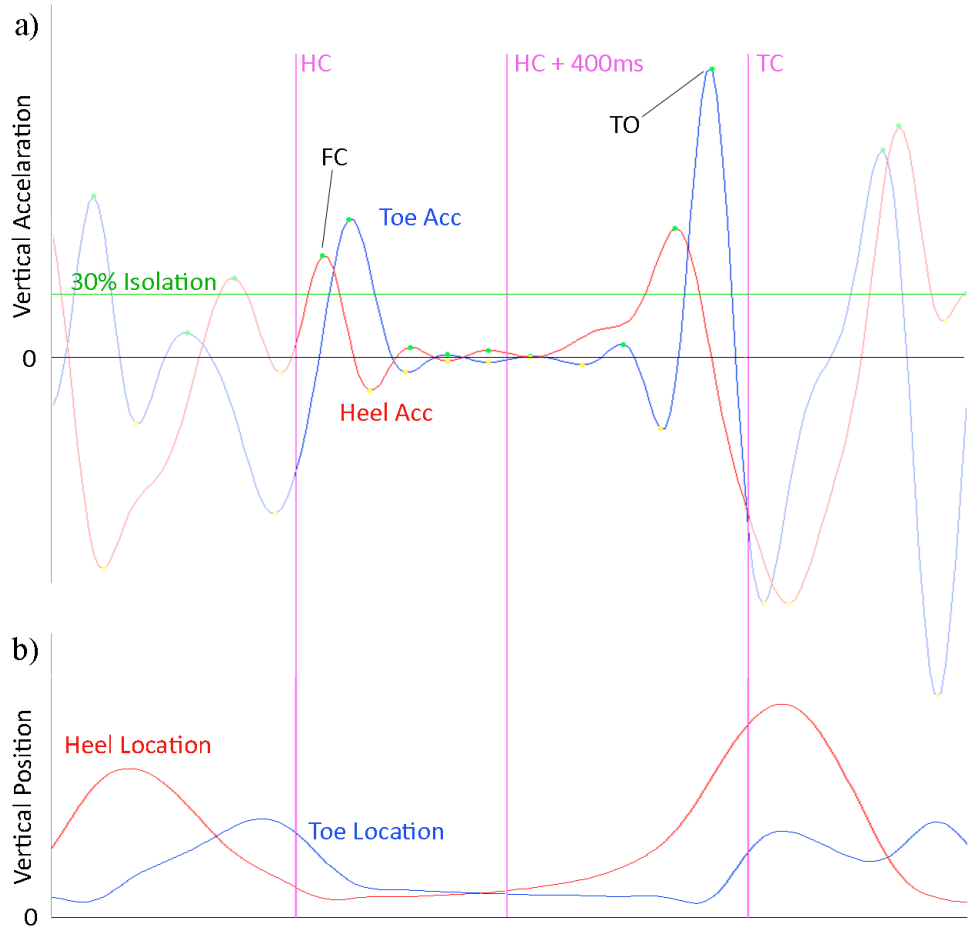

Figure 2-4 A schematic of how foot contact and toe off were identified. The x-axis represents time and the y-axis represents vertical marker acceleration (a), and vertical marker postion (b). The time at which the heel marker crossed the rear edge of the target box flagged the correct step (Heel Cross - HC). The window to identify foot contact was set to 400ms (HC + 400ms). TC indicates when the toe marker moved beyond the front target edge. Data was isolated if it was greater than 30% of the range of this 400ms window. The earliest heel acceleration (Heel Acc - red) or toe acceleration (Toe Acc - blue) peak was then identified as foot contact (FC - heel first or toe first stepping identified). Toe off (TO) was the 2nd toe acceleration peak above the isolation point. The middle section represents stance.

2.5.2 Identifying Anteroposterior and Mediolateral Stepping Errors

Position data from a flat foot frame midway between foot contact and toe off was used to identify stepping accuracy. The centre point of the box was determined by finding the average of the four corners' (x, y) coordinates. The centre of the foot was found similarly but using the (x, y) coordinates of the four foot markers. In order to account for any misalignment of the target box within the Vicon capture field, anteroposterior and mediolateral displacements were calculated relevant to the target box orientation. To do that, a line crossing through the midpoint of the rear edge and centre of the box was calculated. The x-coefficient and y-intercept from that line were applied to the foot centre coordinates to create a parallel line running through the centre of the foot. Another perpendicular line running through the centre of the box, and subsequently its point of crossing the central foot line, were calculated. Pythagoras' theorem was then used to determine the anteroposterior, and mediolateral displacement of the foot relative to the target box (Figure 2-5). This latter step was probably unnecessary as the box was placed straight during the trials, but it improved accuracy consistency between participants (see Appendix D for equation details).

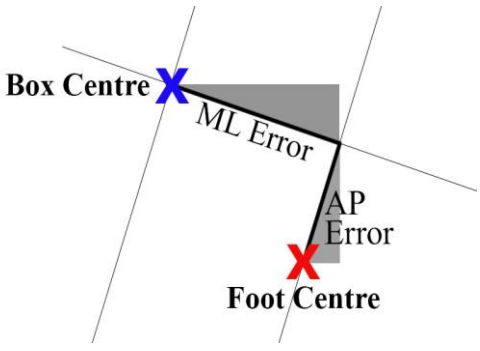

Figure 2-5 A visual representation of how the Mediolateral (ML) and Anteroposterior (AP) errors were calculated using Pythagoras' theorem.

2.6 Visual Data Capture

2.6.1 Electrooculography (EOG)

EOG data was recorded using a BlueGain EOG Biosignal Amplifier at 1000Hz (Cambridge Research Systems Ltd., UK). Horizontal eye movements were recorded by placing two surface electrodes adjacent to either eye's lateral canthi. To record vertical eye movements, electrodes were placed centrally on the upper and lower orbital rim of the left eye socket. An earthing electrode was placed in the centre of the forehead (Figure 2-6).

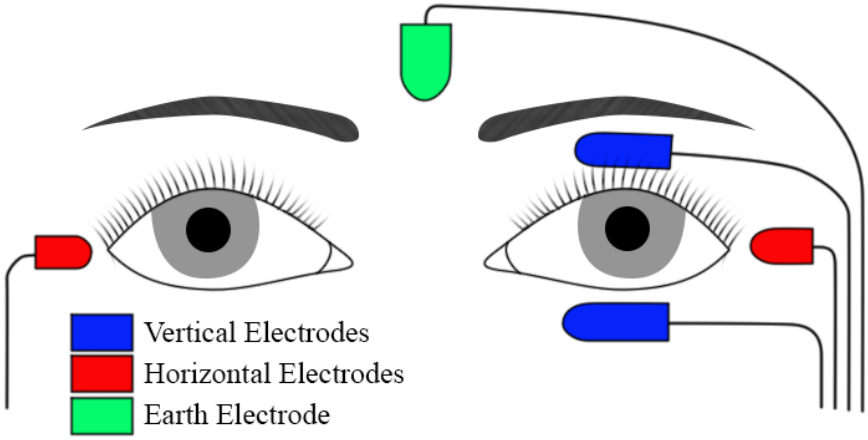

Figure 2-6 A diagram showing the position of EOG electrodes on the face.

Electrodes fed in to an arm mounted biomedical amplifier, which wirelessly transferred the data in real-time to a computer. A manually operated infrared trigger sent pulses of infrared light to a receptor channel on the BlueGain amplifier, and fed in to the Vicon system at 1000Hz allowing for accurate temporal alignment between the EOG and kinematic data. The electrodes detected the potential difference between the positively

charged cornea and negatively charged retina of each eyeball. When the eyes rotated in their socket, the corneas moved closer to an electrode altering the potential difference between the electrode pairs. This was detected and recorded on an electrooculogram as vertical and horizontal eye position within the head.

Prior to testing, each participant was asked to fixate gaze on a central point straight ahead and rotate their head from side-to-side and then up and down. Head rotation in any direction was accompanied by eye counter-rotation driven by the vestibuloocular reflex. The eye movement signal generated was then correlated with the angle of the head segment to produce a scale-factor by which their EOG data could be translated into degrees. Raw EOG data was filtered using a zero-phase second-order Butterworth filter with a cut-off frequency of 30Hz, and then converted to degrees (see Appendix F.2 for Matlab script). Saccade initiation was identified as when the velocity of the eye movement was greater than $100°s^{-1}$ (Young et al., 2011). The time of these eye movement onsets were marked on the EOG trace with a vertical line depicting foot contact time and the saccade closest to the foot contact time being highlighted by default. In some trials, small deviations in the EOG trace could result in incorrect identification of a saccade; therefore each trial was visually examined to ensure the largest, closest saccade to foot contact time was identified (see Appendix F.3 for Matlab script). The time difference between the saccade initiation and foot contact time was then calculated (Figure 2-7). Due to some technical errors with the synchronisation pulses it was not possible to temporally align the EOG and kinematic data in the study presented in Chapter 3, therefore saccade timings were excluded from this study.

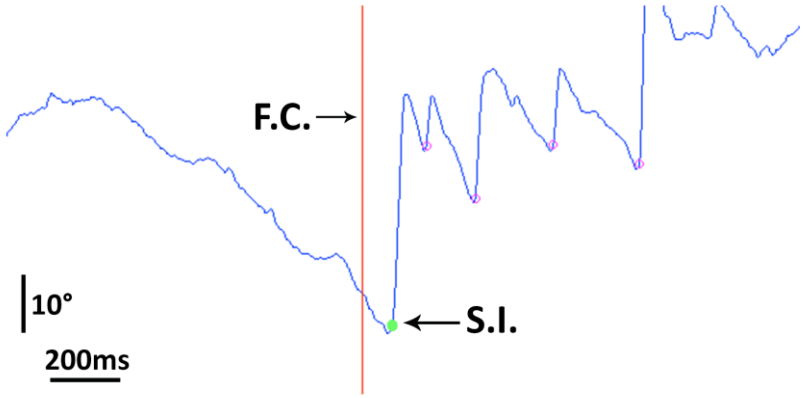

Figure 2-7 An example of trial EOG data showing how gaze transfer time was calculated. The x-axis represents time and the y-axis represents vertical eye rotation within the head. The vertical red line indicates foot contact in the stepping target (F.C.). Participants generally looked at the target box during the final part of their approach as can be seen as the trace drops. Their gaze transfixion changes around foot contact time to focus further obstacles or steps (the saccade). Saccade initiation (S.I.) was highlighted when velocity surpassed 100°s^{-1}. The time difference between foot contact time and saccade initiation was used to measure gaze transfer time. In this example gaze transfer occurred following foot contact, so the value would be positive.

2.6.2 Video Eye Tracking

In the final study presented in this thesis (Chapter 6), a 25Hz Dikablis wireless head-mounted monocular eye tracker was used (Ergoneers GmbH, Manching, Germany). This system used a small infrared camera pointing back in to the subjects left eye to correlate relative pupil position to locations from a scene-view forward facing camera. The luminance of the infrared view of the eye was adjusted such that the pupil was the

darkest area of the image (Figure 2-8). The built in Dikablis algorithm then isolated the pupil and found the centre point, meaning that the pupil could be tracked within the image. Participants were then asked to stand facing the obstacle course while four small reflective vicon markers were placed near the corners of the scene view capture area to identify a calibration area. To calibrate the pupil position to the scene view, participants were asked to stand with their head still and to only move their eyes as they looked at each of the 4 calibration points. When focused on these points, the respective points on the scene view image were selected, allowing calibration of the area between them using the Dikablis software. Once the calibration was complete, a crosshair could be recorded on the scene view to identify where each participant was looking.

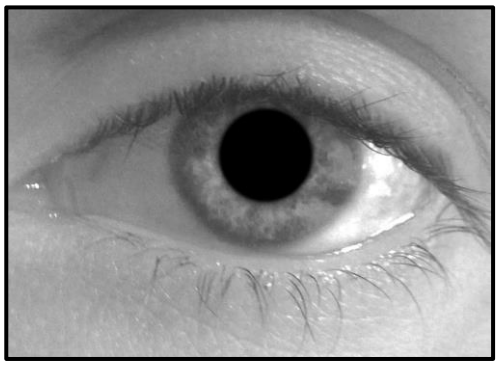

Figure 2-8

An example of the image used by Dikablis to isolate the pupil.

Throughout the trials in this study, 20cm square black and white markers were placed throughout the trial area (Figure 2-9a); two parallel to the near and far left edge of the target box, and two on either side of each obstacle. These markers were automatically detected in each trial by the D-Lab software (Ergoneers GmbH, Manching, Germany). This means that areas specific to the target and obstacles could be marked out within the video recordings (Figure 2-9b), and gaze fixations and timings within these areas throughout each trial could be measured. Sectioned events (i.e. preview time start and

finish, and walk time start and finish) were marked on the video recording in D-Lab. The output variables of D-Lab were total fixation time, mean fixation time, number of fixations, percentage fixation time of the section (preview or walk), and fixation frequency (Hz).

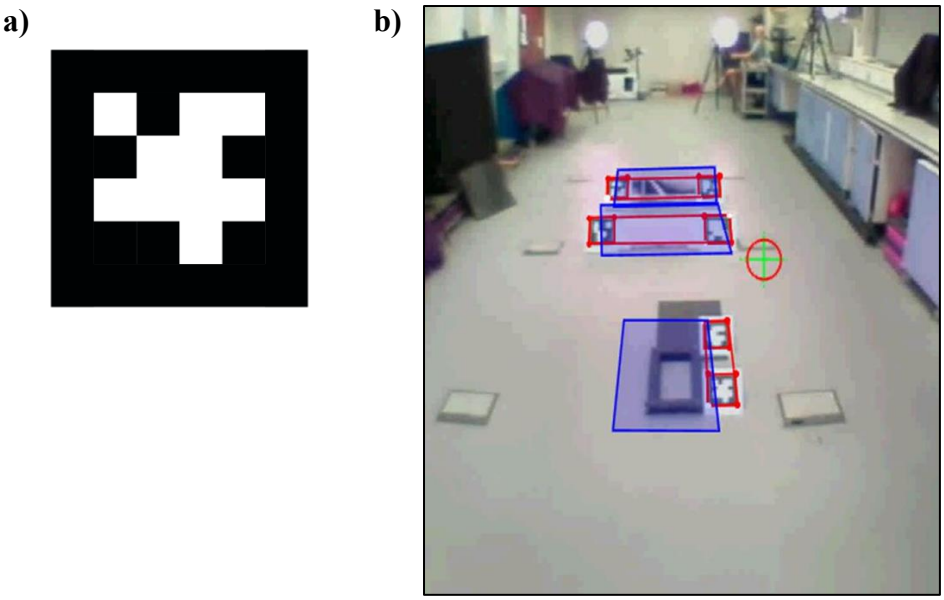

Figure 2-9 a) An example of a marker image automatically detected in the D-Lab software, and b) a screenshot of the marker images being identified (outlined in red), and the areas which were anchored to them (blue) while the scene view moved. The green crosshair represents current fixation.

Chapter 3

Using social evaluative threat as a novel method of increasing task-specific state anxiety during locomotion in young adults.

3.1 Introduction

In order to safely navigate across challenging terrain, we must safely guide our feet to pre-selected step locations that we deem to be safe. When falls occur, they are usually due to a trip or slip that interrupts the gait cycle, and either causes the centre of mass to move beyond the centre of pressure without proper stabilisation, or causes the centre of pressure to move from beneath a person (Wright et al., 2015). A trip occurs during the swing phase of a step, and a slip usually occurs when placing the foot (Lockhart, 2008). Therefore when walking on uneven or wet ground, inaccuracy and variability of a planned step are significant risk factors for falls, and are characteristic of older adults identified to be at a high risk of falling (Chapman & Hollands, 2006b).

The aim of this first experimental chapter was to pilot a method to experimentally increase anxiety in the laboratory in order to determine whether the previously observed changes to stepping inaccuracies (Chapman & Hollands, 2006b; 2007; Young et al., 2011) could be elicited. In order to gauge the effectiveness of our anxiety inducing intervention we also needed a reliable method of measuring anxiety levels. The next section briefly reviews previously used methods of inducing anxiety.

The Trier Social Stress Test is a common method of manipulating state anxiety in a controlled laboratory setting (Kirschbaum et al., 1993). The test usually requires participants to deliver improvised free speech and mental arithmetic while an audience

watches. Participants are also told that their performance of the task is being judged and marked, the legitimacy of which is irrelevant as long as anxiety is successfully induced (Mansell et al., 1999; Mansell et al., 2002). This increases anxiety through fear of social evaluation and social comparison (Festinger, 1954; Taylor & Lobel, 1989), however state anxiety cannot be directly measured and must rely on a participant's perception and truthfulness about their anxiety (self-reported anxiety), or biochemical analysis of proteins that are released during stress.

The State-Trait Anxiety Inventory is a commonly used measure of anxiety (Spielberger et al., 1970; Spielberger, 1983). In order to test its reliability, and its ability to distinguish between state and trait anxiety, Metzger (1976) used it to measure anxiety pre- and post-examination. He found that state anxiety increased prior to examination, whereas trait anxiety didn't. Furthermore, he found no changes in either form of anxiety for a control group. This provides evidence that this self-reported measure of anxiety can offer reliable results, and can also distinguish between the state and trait forms. However, participant truthfulness and understanding can vary when using self-reported measures of anxiety, which might result in inaccurate measurements.

When an individual is stressed there is an increase in sympathetic nervous activity (Hoehn-Saric & McLeod, 1988), which also increases heart rate directly. Salivary α-amylase has shown promise as an index measurement of sympathetic activity (Rohleder et al., 2004), and levels of the enzyme are increased by stress tasks within several minutes (Takai et al., 2004). During the Trier Social Stress Test, salivary α-amylase was shown to increase almost immediately after the test started, and returned to baseline levels within 10 minutes (Nater et al., 2005). Therefore salivary α-amylase was selected

as our chosen measure of biochemical physiological anxiety, due to the reactive time frame, and the stress-task conditions in which it is seen to increase being applicable in this study.

Young et al. (2011) have recently shown evidence that self-reported anxiety is correlated with an early gaze transfer from a current stepping target in older adults deemed to be at a high risk of falling. This early gaze transfer observed in high-risk older adults has also been shown to correlate with mediolateral foot placement variability (Chapman & Hollands, 2006; 2007).

We hypothesise that stepping performance during precision stepping tasks is mediated, in part, by task specific anxiety. This study aimed to validate social evaluative threat, through use of a judging panel, as an effective method of increasing task specific anxiety during a precision walking task. It also served to validate salivary α-amylase as a useful tool when assessing physiological anxiety levels in young adults, with intention for future use in older populations. We predicted that under the social evaluative threat condition, participants would show increased anxiety, and a moderate reduction in precision stepping performance when compared to normal walking conditions.

3.2 Methods

3.2.1 Participants

Eight undergraduate students (4 male, 4 female) were recruited from the Sport & Exercise Sciences School at the University of Birmingham in exchange for course credit contributing towards their final grade. The University of Birmingham Ethical Committee gave written permission for this protocol prior to data collection. Each participant also gave written consent indicating his or her understanding and willingness to take part in the current study.

Testing took place in the afternoon between 1pm and 5pm in order to control for daily fluctuations in salivary α-amylase (Nater et al., 2007). Participants were asked to abstain from alcohol and non-prescription drugs during the 24 hours prior to testing, and to not take part in any exercise on the morning of testing as this might increase salivary α-amylase levels (Nexø et al., 1988; Kivlighan & Granger, 2006). In the hour prior to testing, participants were instructed to avoid consuming caffeine, acidic drinks and food, and to avoid brushing their teeth as this might cause slight bleeding of the gums and contaminate the saliva samples. All females involved in the study were tested during the luteal phase of the menstrual cycle.

Participants underwent Snellen and Pelli-Robson eye tests to measure visual acuity and contrast sensitivity respectively. All participants had ≥ 20/25 visual acuity when tested using both eyes, and contrast sensitivity ≥ 1.95 with both eyes (see Chapter 2.4.1 for details of measures).

3.2.2 Data Collection

Motion capture was carried out using a 13-camera Vicon MX Motion Capture system collecting at 100Hz, and Vicon Nexus 7.2 was used for analysis of the data (Vicon Oxford, UK). Reflective markers were attached to the participants clothing following the Vicon Plug-In Gait model with adapted foot marker placement to include additional markers placed at the medial and lateral midpoints of each foot (see Appendix E). Participants wore tight fitting clothes to minimize marker movement with respect to clothing, and flat-soled shoes that they felt comfortable walking in. Details of target box marker placement and size can be found in Chapter 2.5.

Saliva samples were collected before and during testing to assess salivary α-amylase concentrations over a 3-minute period. During the saliva collection time, heart rate was taken using an Oregon Scientific SE138 strapless heart rate monitor (Oregon Scientific, Oregon, USA) (see Chapter 2.3.4 for details on saliva and heart rate collection).

Participants also completed a series of questionnaires to measure self-reported anxiety. The Profile of Mood States (POMS – see Appendix C-1) was completed for all eight participants, and the State Anxiety Inventory (SAI) and the Immediate Anxiety Measurement Scale (IAMS – see Appendix C-2) were completed for five participants. The latter two questionnaires were added after data collection had started in order to explore a greater variety of questionnaires that would be suitable for further research.

The POMS consisted of 32 mood-related words and asked on a Likert scale of 1 to 5, how much they felt each mood in relation to the task (1 = not at all, 5 = extremely). These answers were then split in to 6 categories: Tension/Anxiety, Anger/Hostility, Depression/Dejection, Vigour/Activity, Fatigue/Inertia, and Confusion/Bewilderment.

The sum of each of these categories was then divided by the mean to get a ratio figure used in analysis.

The IAMS consisted of three questions with two parts each. Participants had to indicate on a scale of 1 to 7 how cognitively anxious, somatically anxious and self-confident they were about the task. They then answered on a scale of -3 to 3 how their levels of each anxiety subcategory and confidence affected their task performance (-3 = very debilitative, +3 = very facilitative).

The SAI consisted of 4 statements relating to how they felt when stepping in to the target box. These were:

1. I feel calm about completing the task.
2. I feel tense about stepping into the box.
3. I feel relaxed about stepping into the box.
4. I am worried that I will lose my balance.

Participants then indicated on a scale of 1 to 4 how much they agreed with each statement (1 = not at all, 4 = very much so). During analysis, questions 1 and 3 were reverse coded, then all answer values were summed and had 4 subtracted to give a final anxiety score between 0 and 12.

3.2.3 Protocol

Prior to starting the walking tasks, participants completed the Snellen and Pelli-Robson visual tests followed by a 20-minute rest period, after which baseline measures of salivary α-amylase and heart rate were obtained.

The set-up and positioning of the target box and obstacles is explained in Chapter 2.2. There were four experimental conditions: Target Only (TO), Far Obstacle (FO), Near Obstacle (NO), and Both Obstacles (BO). These conditions are listed in order of difficulty based on the proximity and number of obstacles. The target box was present in all conditions. The TO condition had no further obstacles following the target box, FO had one obstacle following the target box placed at the 280cm mark, NO had one obstacle placed at the 180cm mark, and BO had two obstacles, one at each mark (Figure 3-1). There were 6 trials in each condition, which were blocked together, making 24 trials for each session. There were 2 sessions: a control session and a judged session. The order of the sessions was randomised and equally balanced across participants, the order of the condition blocks were randomised within each session, and the acute target box position in each trial was randomised across each participant.

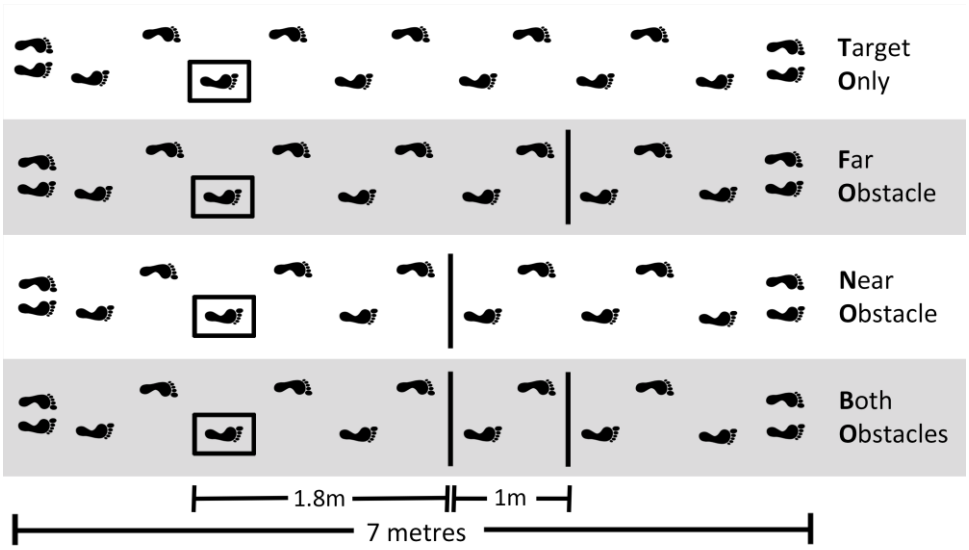

Figure 3-1 Schematic of the four trial difficulties used in this study

Participants were required to face away from the walkway while the target and obstacles were positioned. They then had to close their eyes and turn to face the obstacles. On a verbal cue, participants then opened their eyes and walked down the walkway starting with their right foot. They then stepped into the target box with their right foot, stepped over any obstacles that were present with their right foot leading and progressed to the end of the walkway. Participants completed several familiarisation trials for each experimental condition so that they were comfortable with the protocol before starting the recorded trials. They also completed a baseline POMS questionnaire (all participants), as well as IAMS and SAI (5 participants).

Between each set of 6 trials, heart rate, POMS, IAMS and SAI questionnaires were taken, and saliva samples were collected to measure salivary α-amylase. These measures were taken to represent the set of trials just completed by the participant.

During the judged trials, social evaluative threat was used with the aim of increasing anxiety in participants. Four PhD students were brought in to lab and sat behind a desk and computer screens facing the walkway from behind the start line. Participants were told that these four individuals were gait researchers and would be receiving accurate, live information about the accuracy and consistency of participant stepping performance, and would be scoring them out of 100 on their performance. A board showing a list of 9 fictitious names and scores was placed next to the judges, with the participants' real name also being ranked with a consistently low fictitious score on the board. Participants were told that the other names on the board were averages from previous participants and it was their job to try and score as highly as possible. They were also told that the results would be made public following the experiment, and that there was a prize for the top score. The judges and score board were positioned so the participants

could not see them whilst walking so that this did not interfere with visual data collection during the trials. Participants could see the judges and their score when returning to the start line between trials. Random false scores were updated every 2 trials and never moved the participant above 6th place. Once all data collection was complete, participants were informed that the judges and scores were false, and that they were present to raise anxiety levels during those trials.

3.2.4 Data Analysis

Stepping accuracy was determined by manually labelling and exporting right-foot mid-stance frames for each trial from Vicon Nexus, and analysed using a custom-built MATLAB script (The MathWorks, Inc., MA, USA). The script located the centre of the foot markers and target box markers relative to the exact orientation of the target box and returned separate anteroposterior and mediolateral foot offsets measured in millimetres (see Chapter 2.5.2)

Salivary α-amylase concentration was analysed using a Salimetrics Kinetic Enzyme Assay kit (Salimetrics Europe, Ltd., UK). Following saliva collection, each saliva sample was weighed and centrifuged at 4000 g for 10 minutes. Two 500μL samples of the resulting supernatant for each set of trials were collected and stored in epindorph tubes at -20°C until assayed (see Chapter 2.3.4.2 for details on assay).

A 2 x 4 (session x difficulty) repeated measures ANOVA was carried out on means from the 6 trials of each condition and participant for (1) anteroposterior step error, (2) mediolateral step error, (3) salivary α-amylase, (4) heart rate, (5) SAI, (6) IAMS, and (7) POMS. Items 3 to 7 were analysed as a change from baseline measures obtained prior to each session. The standard deviation of anteroposterior and mediolateral step

accuracy was also analysed using this method as a measure of step variability. All post-hoc tests, where required, used the Bonferroni correction for multiple comparisons. Correlations were carried out using Pearson's product-moment correlation for continuous data, and Spearman's rank correlation for non-parametric questionnaire data.

3.3 Results

A summary of results can be found in Table 3-1. All values presented are mean ± standard error unless otherwise specified.

3.3.1 Self-Reported Anxiety Measures

There was a main effect of task difficulty on self-reported cognitive anxiety represented in the IAMS ($F_{(3, 12)} = 2.636$, $p < .05$). Mean values (± standard error) were 0.2 ± 0.3 for TO, -0.1 ± 0.4 for FO, 0.3 ± 0.3 for NO and 0.6 ± 0.3 for BO. There was also a trend for IAMS cognitive anxiety to be greater in the judged session when compared to the control session (0.65 ± 0.27 and -0.15 ± 0.37 respectively), however this difference fell just outside of our accepted boundary for statistical significance ($F_{(1, 4)} = 7.64$, $p = .051$, Figure 3-2). There were no significant differences for session or condition in the SAI, nor in any of the six POMS sub-categories (see Table 3-1).

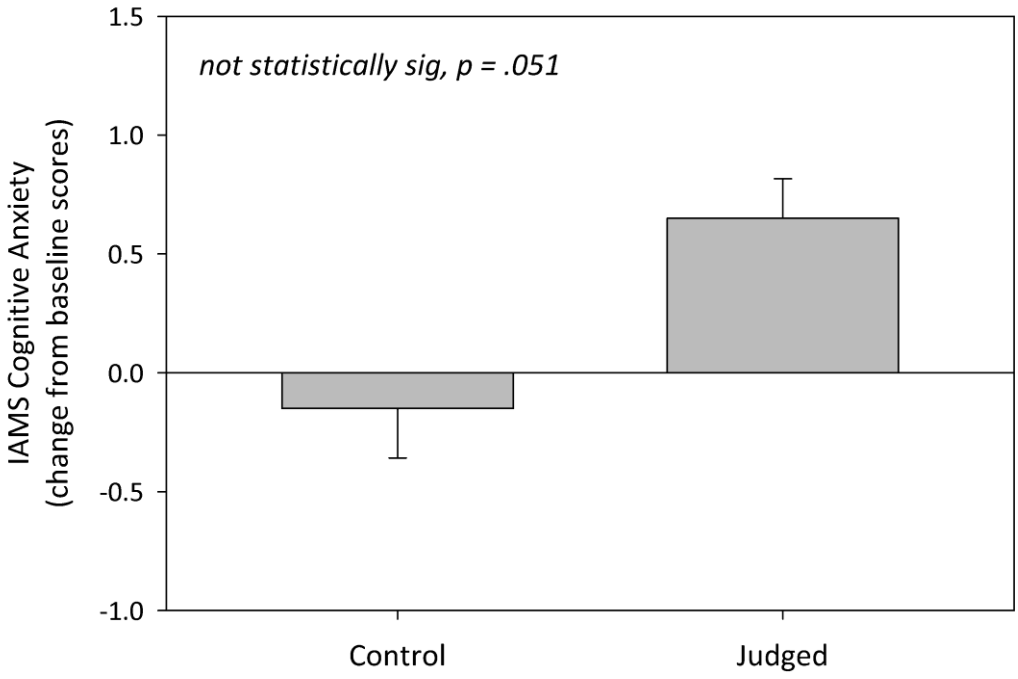

Figure 3-2. The change in IAMS self-reported cognitive anxiety between control and judged trial sessions.

3.3.2 Physiological Anxiety Measures

There was a greater change in heart rate from baseline in judged trials when compared to control (2.9 ± 1.7 and -2.0 ± 0.7bpm respectively), however this was not statistically significant at the .05 level ($F_{(1, 7)} = 5.07$, $p = .059$). There were no significant differences in salivary α-amylase levels. Five out of 8 participants did show a moderate increase in salivary α-amylase between control (6.8 ± 23.9 U/mL) and judged sessions (65.2 ± 39.1 U/mL); however this was not significant ($p = .061$).

3.3.3 Step Accuracy and Variability

There was a main effect of task difficulty on mean mediolateral stepping error ($F_{(3, 21)} = 3.12$, $p < .05$ – TO:-10.2 ± 1.6mm, FO: -13.2 ± 1.8mm, NO: -9.9 ± 1.7mm and BO: -

11.5 ± 1.5mm), however post-hoc analysis revealed no significant differences between conditions. There was also a main session x difficulty interaction effect of mean anteroposterior step variability ($F_{(3, 21)} = 3.44$, $p < .05$). During FO trials, there was greater step variation during judged trials compared to control (20.1 ± 2.5 and 15.7 ± 1.6mm respectively, Figure 3-3). There were no significant main effects of session on mean mediolateral variability, nor were there any main effects of session or difficulty on mean anteroposterior error or mediolateral variability.

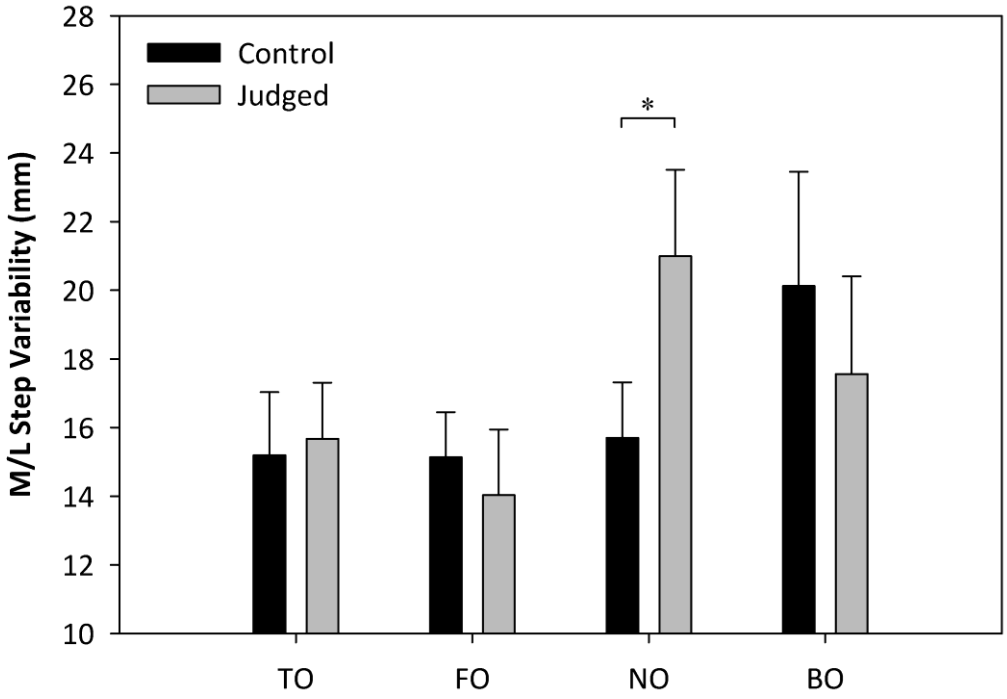

Figure 3-3 Mean mediolateral step variability of each task difficulty and session. * Sig. difference between sessions for the near obstacle (NO) trial difficulty $p < .05$. Error bars represent standard error.

Table 3-1 Means and standard deviations across sessions and difficulties

		Control				Judged			
mean ± standard deviation	TO	NO	FO	BO	TO	NO	FO	BO
Stepping Performance								
A/P Stepping Error *(mm)*	-7.38 ± 15.6	-10.91 ± 11.58	-10.95 ± 11.09	-10.71 ± 10.16	-13.05 ± 7.65	-11.68 ± 10.69	-13.16 ± 7.98	-15.04 ± 3.53
A/P Stepping Variability *(mm)*	15.2 ± 5.18	15.14 ± 3.71	15.7 ± 4.57 †	20.12 ± 9.41	15.67 ± 4.63	14.03 ± 5.42	20.99 ± 7.14	17.56 ± 8.04
M/L Stepping Error *(mm)* *	-11.23 ± 4.81	-13.99 ± 5.1	-11.26 ± 2.38	-12 ± 5.04	-9.19 ± 5.68	-12.44 ± 6.52	-8.52 ± 8.11	-10.95 ± 4.62
M/L Stepping Variability *(mm)*	7.29 ± 4.18	8.74 ± 3.26	8.09 ± 4.37	9.02 ± 3.47	7.93 ± 2.48	6.61 ± 2.86	8.53 ± 3.71	7.38 ± 2.69
Questionnaire/Anxiety Measures								
Salivary α-amylase *(U/mL/min)*	3.48 ± 18.26	4.77 ± 17.9	9.3 ± 20.25	6.05 ± 16.2	10.76 ± 16.16	15.82 ± 28.9	15.63 ± 31.25	17.03 ± 26.64
State Anxiety Inventory	0.2 ± 0.84	-0.6 ± 1.52	0 ± 1.22	0.2 ± 0.84	0.4 ± 1.67	0.6 ± 0.89	0.8 ± 3.11	0.8 ± 1.64
I AMS Cognitive Anxiety *	0 ± 0.71	-0.6 ± 1.34	-0.2 ± 1.1	0.2 ± 0.45	0.4 ± 0.89	0.4 ± 0.55	0.8 ± 0.45	1 ± 1
- Direction	0.6 ± 1.34	1 ± 1.41	0.8 ± 1.1	1 ± 1	-0.4 ± 1.67	-0.6 ± 1.95	-0.2 ± 1.92	-0.8 ± 1.64
IAMS Somatic Anxiety	0 ± 0.71	-0.6 ± 1.34	-0.2 ± 1.1	-0.2 ± 0.45	0 ± 0.71	0.2 ± 0.45	0.6 ± 0.89	0.4 ± 0.55
- Direction	0 ± 1.22	0.4 ± 0.89	0.2 ± 1.1	0.4 ± 0.89	0.2 ± 0.84	0 ± 0.71	-0.2 ± 1.3	0.2 ± 0.84
IAMS Self-Confidence	0 ± 0	0.2 ± 0.45	0.2 ± 0.45	-0.2 ± 0.45	0.2 ± 1.1	0 ± 0.71	0 ± 0.71	-0.2 ± 0.84
- Direction	0 ± 0	0 ± 0	0.2 ± 0.45	0 ± 0	0.2 ± 0.45	0 ± 0.71	-0.6 ± 1.95	-0.2 ± 0.84
POMS Tension/Anxiety	0.01 ± 0.05	0.02 ± 0.07	0.01 ± 0.05	0.01 ± 0.03	0.01 ± 0.08	0.01 ± 0.06	0.02 ± 0.06	0.03 ± 0.1
POMS Anger/Hostility	0 ± 0.01	0.01 ± 0.03	0 ± 0	0 ± 0	0.02 ± 0.02	0 ± 0.01	0.02 ± 0.03	0.04 ± 0.06
POMS Depression/Dejection	-0.01 ± 0.01	0 ± 0.02	-0.01 ± 0.01	-0.01 ± 0.01	0.02 ± 0.03	0.01 ± 0.01	0.01 ± 0.03	0.02 ± 0.02
POMS Vigour/Activity	0 ± 0.06	-0.03 ± 0.08	0.03 ± 0.03	-0.01 ± 0.06	-0.04 ± 0.1	-0.01 ± 0.11	0.01 ± 0.1	-0.01 ± 0.09
POMS Fatigue/Inertia	0.02 ± 0.02	0.02 ± 0.03	0.01 ± 0.03	0.04 ± 0.03	-0.01 ± 0.03	-0.02 ± 0.03	-0.01 ± 0.03	0.01 ± 0.03
POMS Confusion/Bewilderment	-0.01 ± 0.02	-0.01 ± 0.02	0 ± 0	0 ± 0	0.02 ± 0.06	0.02 ± 0.08	0.01 ± 0.04	0.03 ± 0.08

* = sig. main effect of difficulty

† = sig. difference between sessions in that difficulty

3.3.4 Correlations

Using the Bonferroni correction, p values for correlations were only considered significant at the .003 level. Salivary α-amylase levels were not correlated with any measures of self-reported anxiety that were taken; they were however moderately correlated with mediolateral step variability ($r_{s\,(64)} = .45$, $p < .001$, Figure 3-4). Table 3-2 shows self-reported anxiety and self-confidence correlations.

The IAMS measure of somatic anxiety was correlated with heart rate ($r_{s\,(40)} = .51$, $p < .001$), and IAMS cognitive anxiety was associated with mediolateral step variability, although it was just outside of our adjusted value of significance ($r_{s\,(40)} = .44$, $p = .004$).

The tension/anxiety subsection of the POMS was correlated with both anteroposterior and mediolateral stepping error ($p < .003$).

Table 3-2 Spearman's correlations between self-reported anxiety measures

Measure: (n = 40)	***(1)***	***(2)***	***(3)***	***(4)***
(1) IAMS Cognitive Anxiety				
(2) IAMS Somatic Anxiety	r = .676* *p < .001*			
(3) IAMS Self Confidence	r = -.536* *p < .001*	r = -.425 *p = .006*		
(4) State Anxiety Inventory	r = .328 *p = .039*	r = .711* *p < .001*	r = -.282 *p = .078*	
(5) POMS Anxiety/Tension	r = .585* *p < .001*	r = .750* *p < .001*	r = -.217 *p = .179*	r = .466* *p = .002*

** p < .003 – the Bonferroni-corrected value of significance*

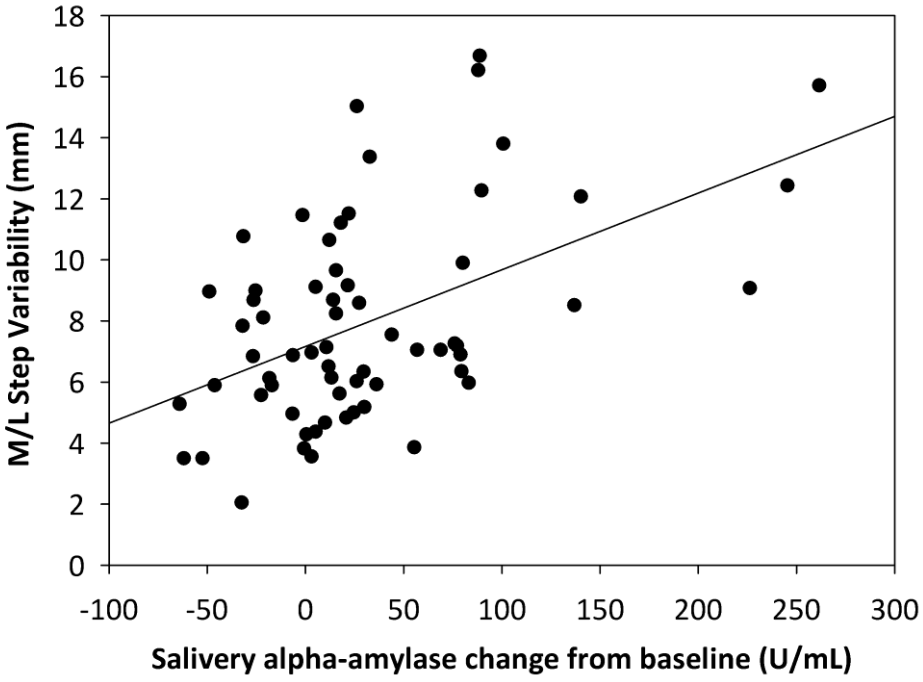

Figure 3-4 Correlation of salivary α-amylase change from baseline and mediolateral step variability in the target box.

3.4 Discussion

The aim of this study was to validate the use of social evaluative threat during adaptive locomotion to experimentally increase state anxiety in young adults for future use on older populations. Moderate, but non-significant increases in IAMS self-reported cognitive anxiety (Figure 3.2) and heart rate were observed. An increase in salivary α-amylase concentrations was observed in 5 out of 8 participants, however this increase was not statistically verified at the $p < .05$ level. We also observed greater IAMS cognitive anxiety scores during the BO condition, however post hoc tests did not show this to be significantly greater than the other conditions.

Although the effects of our intervention on younger adult anxiety were fairly modest, the increase in the self-reported anxiety measure is encouraging given the participants' age, education and familiarity with the lab environment. Participants were undergraduates with a background in sports science and may have known about or studied social evaluative threat in their course. In addition to this, their relative walking confidence during this simple stepping task may have lessened their overall anxiety about the study. While this stepping task might prove challenging to older adults, it would be relatively easy for this young subject group. Therefore the moderate anxiety effects observed in this study show promise for future research in older adults who, we predict, would show greater susceptibility to the experimental protocol.

We also demonstrated an increase in step variability under the social evaluative threat paradigm in the NO task complexity, despite the intervention's subtle effects. During near obstacle trials, participants exhibited greater mediolateral step variability in the judged trials when compared to control trials (Figure 3-3), even though the effects of our social evaluative threat paradigm were modest. However, this effect was not observed in the both obstacle trials as would be expected if the evaluative threat differences were due to a simple relationship with increasing task complexity. We speculate that this may have been due to the apparent simple nature of the NO task causing an initial overconfidence of step placement which then increased step variability as participants felt they were being watched by the judges. The same effect may not have been observed in the BO condition as participants saw that the task was harder and concentrated more on stepping consistently. We suggest that the slight anxiety induced by social evaluation had negligible effects on participants during the

easier task complexities (TO and FO), but then had effect during NO trials as participants had a more immediate threat of the upcoming obstacle.

In summary, this preliminary validation of methods failed to show social evaluative threat as a useful tool in increasing task specific anxiety during locomotion in younger adults. However it did produce effects on stepping performance in a confident group of walkers. We predict that in an older group, the effects of this intervention will be greater. The next chapter looks at how social evaluative threat induces anxiety in older adults and its consequent influences on gaze behaviour and stepping performance.

Chapter 4

The effects of increasing anxiety on eye-stepping coordination and stepping performance in older adults during adaptive locomotion.

4.1 Introduction

We have previously shown how social evaluative threat can be used in an adaptive walking task to increase the mediolateral step variability when an obstacle immediately follows the target step. A modest, but non-significant increase in self-reported anxiety was also observed in the conditions of social evaluative threat in young adults. We also identified a correlation between salivary α-amylase concentration and mediolateral step variability in young adults (see Figure 3-4) which suggests that this biological marker of sympathetic nerve activity might be somewhat associated with the decreased stepping performance observed. Having developed a methodology that shows a modest effect of social evaluative threat on some of the measured variables in young adults, we now apply these techniques to an older population.

In this chapter, we expand the scope of our preliminary findings to measure changes in temporal gaze transfer that are typically associated with reduced stepping performance (Chapman & Hollands, 2006b; 2007; Young & Hollands, 2012b), and the relationship between this seemingly maladaptive gaze behaviour and anxiety (Young et al., 2011).

The majority of falls occur during locomotion (Prince et al., 1997). In order to avoid obstacles while walking, a spatial map of potential future steps is gathered by fixating an obstacle during the steps leading up to it. When stepping over an obstacle, gaze fixation is transferred to plan follow up steps rather than focusing on the current

obstacle (Patla & Vickers, 1997). However, compared to young and middle-aged adults, older adults require longer periods of visual input in order to plan motor responses during obstacle avoidance (Chandra et al., 2011), and saccade-step latencies are greater in older adults than in young adults when initially transferring gaze to the target area prior to stepping on to a platform (Di Fabio t al., 2003b). These findings suggest an age-related delay in cognitive processing when planning steps, potentially due to slower activation patterns in the motor cortex that are associated with age (Yordanova et al., 2004).

Young adults are still able to complete a target step accurately when visual information is denied during the swing phase (Hollands & Marple-Horvat, 1996; Chapman & Hollands, 2006a), suggesting that a spatial map is retained in order to plan future steps. Chapman & Hollands (2006a) found that older adults missed a higher percentage of steps when vision was only available during the swing phase of the target step compared to when vision was only available during the stance phase, and when vision was not restricted. These finding indicate the importance of visual information for older adults when planning steps in a feedforward manner, rather than relying solely on online visual guidance. That being said, visual guidance is an important factor when fine-tuning a step during the swing phase. Reynolds and Day (2005) found a greater stepping error when vision was occluded at step initiation. Furthermore, when vision was available, participants initiated a correction to their step when the foot was ~64mm away. This implies that while steps are ballistic, and rely on predetermined visual information prior to step initiation, online visual guidance is important when trying to step accurately on to a target. Young & Hollands (2012a) conducted an experiment in which they measured the latency of a saccade, and of the time taken to significantly

adjust an ongoing step to a stepping target that moved at an unpredictable time, to an unpredictable location during the swing phase of the step. They found that both saccade latency and the time to a significant deviation in foot swing trajectory towards a moving target was greater for older adults compared to young, particularly those deemed to be at a high risk of falling. Older adults also had greater stepping error compared to young adults. These findings provide further evidence of an age-related reduction in visuomotor cognitive processing speed during adaptive locomotion.

When completing a obstacle walk with stepping targets, older adults tend to prioritise gathering information about future stepping constraints rather than maintaining fixation on the current step to fine-tune stepping accuracy when compared to young adults (Chapman & Hollands, 2006b; 2007; Young & Hollands, 2010; 2012b; Young et al., 2011). This is presumably to allow them extra time to process visual information about further constraints. This age-related change in gaze behaviour has been shown to correlate with self-reported anxiety (Young et al., 2011). In this chapter we observe the effects that social evaluative threat exerts on eye movement behaviour and movement characteristics in order to test existing theories regarding the mechanisms underlying the influence of anxiety on stepping performance.

We hypothesize that: 1) there is a causal relationship between raised anxiety and increased stepping errors in older adults during locomotion and 2) that altered visuomotor control due to altered gaze behaviour is one of the mechanisms responsible.

This study aimed to: 1) increase anxiety in older adults using social evaluative threat during a precision walking task, and 2) measure associated changes to eye-stepping coordination and stepping performance. We predicted that increased anxiety would

result in earlier gaze transfer from the target, resulting in increased stepping error and variability.

4.2 Methods

This study was based on the study detailed in Chapter 3 and uses many of the same techniques and measurements. The following methods section describes the adaptions made to the methods of Chapter 3 for suitability with an older subject pool.

4.2.1 Participants

Eleven (8 female, 3 male) community-dwelling adults over the age of 65 were recruited from posters advertising the study placed on local notice boards and in shops and churches. They received £20 for their participation as well as reimbursement of travel expenses. Potential participants received a study outline through the post detailing what would be required of them. Once participants were in the laboratory, they read the information sheet again and signed a consent form indicating that they understood the study and that they could drop out at any time without giving a reason. There was no mention of anxiety or stress in the study outline, and participants were told that the judges would be marking their stepping performance. Participants were excluded from taking part if they wore a pacemaker, reported having musculoskeletal or neurophysiological impairments, required a walking aid for short distances, or had diabetes as this might interfere with salivary α-amylase measurements. The University of Birmingham Ethics Committee granted approval for the current study. Participant details can be found in Table 4-1.

Table 4-1 Participant Information and Test Scores

Measure:	Mean	Standard Deviation
Age *(years)*	68.82	4.51
Height *(cm)*	163.65	7.49
Weight *(kg)*	66.15	15.70
Body Mass Index	24.70	3.83
Foot Length *(cm)*	27.38	2.18
Foot Width *(cm)*	9.75	1.13
Snellen Visual Acuity (min score)		
Left Eye Only	≥20/40	
Right Eye Only	≥20/40	
Both Eyes	≥20/40	
Pelli-Robson Contrast Sensitivity *(max 2)***:**		
Left Eye Only	1.49	0.24
Right Eye Only	1.53	0.11
Both Eyes	1.69	0.14
Berg Balance *(/56)*	55.91	0.30
Trail Making A *(s)*	38.37	10.70
Trial Making B *(s)*	84.31	26.78
Δ Trail Making *(s)*	45.94	25.44
Mini-Mental State *(/30)*	28.64	0.92
FES-I *(/48)*	2.45	1.92
ABC *(%)*	93.30	5.04
GHQ-28 *(max 21 each)***:**		
Somatic Symptoms	2.09	1.58
Anxiety/Insomnia	3.45	2.07
Social Dysfunction	6.91	0.54
Severe Depression	0.73	1.27

Participants were tested in the afternoon between 1pm and 5pm, and were asked to abstain from alcohol and non-prescription drugs 24 hours prior to testing, exercise on the morning of testing, and caffeine, acidic drinks, food and brushing their teeth one hour before testing. All female participants were post-menopausal, and thus did not have a specific window of time available for testing as described with younger female subjects in Chapter 3.

Participants completed Snellen and Pelli-Robson tests to measure visual acuity and contrast sensitivity prior to testing. If participants normally wore glasses to walk then these were also used in the visual tests and for the walking trials. Berg balance, trail making and mini-mental state tests were carried out to assess balance, executive function and cognitive function respectively (see Chapter 2.3 and 2.4 for further details).

4.2.2 Data Collection

A 100Hz 13-camera Vicon MX motion capture system was used to record kinematic data. Reflective markers were placed according to the full body plug-in gait model, however four markers were used on each foot. One marker was placed centrally on the posterior heel of the participants' shoes, a toe marker was placed centrally on the anterior top of the participants' shoes, and a lateral and medial marker placed equidistant from the toe and heel markers. The toe marker used in this study is in a slightly different position to that used in Chapter 3. This was done to acquire a more accurate centre of the standing foot whilst wearing a shoe, as opposed to simply marking the 2nd metatarsal of the foot. Markers were also placed on the four corners of the target box, and laterally on the top of the two obstacles used.

Electrooculography was used to record saccadic eye movements. A 1000Hz BlueGain EOG Bluetooth system (Cambridge Research Systems, UK) was used with electrodes placed above and below the participants' left eye, and next to the lateral canthus of each eye to measure vertical and horizontal eye movements. A calibration trial that required participants to stare at a dot directly in front of them while rotating their head slowly side-to-side and up-and-down was carried out prior to testing. This elicited a vestibulo-ocular reflex characterized by an automatic counter-rotation of the eyes in the opposite direction to head rotation to maintain a stable image of the target dot, and allowed the angle changes of the Vicon head markers to be correlated with the EOG signal in order to convert eye rotation in to degrees for analysis (see Chapter 2.6.1).

Unstimulated, passive saliva samples were collected for 3 minutes using the techniques described previously (see Chapter 2.3.4.2). Following each lab session, samples were centrifuged at 4000 g for 10 minutes. Two 500 μL samples of the supernatant were stored at -20°C until assayed. Heart rate was recorded periodically using an Oregon Scientific strapless heart rate monitor (Oregon Scientific, MA, USA).

Self-reported anxiety was assessed using a 6-question version of the State Anxiety Inventory (SAI). The questions used were the same as those used in Chapter 3, however two additional questions were added which were not related to anxiety (see Chapter 2.3.3). This was done to reduce participant awareness of the anxiety-related aims of the study. The same reasoning was used when removing the IAMS questionnaire from this study despite previous results showing promise as a measure, as it explicitly mentions both cognitive and somatic anxiety. The POMS questionnaire was also dropped from this study due to the time needed to complete it, and the relative excess of information acquired that is not directed towards the aims of the study.

4.2.3 Protocol

Participants stood at the start line of a 7-metre walkway and walked, starting with their right foot, at a self-selected speed. After two walks, the average position of the 2nd right heel strike was marked on the floor and 4 target box positions, and 2 obstacle positions were marked around this as explained in Chapter 2.2. The target box was made from four solid corners connected with black tape on the top and sides that would collapse if stepped on. The target was made so that the inside area was 8cm longer and wider than the longest and widest parts of the participants right shoe, leaving a 4cm clearing around the foot when the foot was placed centrally. Obstacles were 20cm high, 60cm wide and 2cm deep, and were designed to fall over in the direction of travel if the participants made contact with them during the trials.

In this study there were 3 task difficulties: target only (TO), one obstacle (OO), and both obstacles (BO). For the TO trials, only the target box was present on the walkway. In the OO trials an obstacle was placed 180cm anteriorly from the rear outer edge of the target box (referred to as near obstacle (NO) in Chapter 3). In the BO condition there were two obstacles placed 180cm and 280cm ahead of the rear outer edge of the target box. This is different from the previous study as there was no far obstacle (FO) condition (Figure 4-1). This condition was removed to save time and prevent fatigue in older adults as there were minimal differences in stepping performance between this condition and the target only (TO) condition in our previous findings.

Participants completed several practice runs of each trial difficulty to familiarise themselves with the task. Following a 20-minute rest period, participants' saliva samples, heart rate and baseline SAI scores were collected.

There were 6 trials of each task difficulty (TO, OO and BO), and these were completed in both control and judged sessions (total of 36 trails). The four acute target box positions were randomised and counterbalanced throughout each participant's data collection. Trial difficulty order was randomised within each session, and the order of each session was counterbalanced across all participants.

Following each set of 6 trials, saliva samples, heart rate, and SAI scores were collected in relation to the set of trials just completed. There was a 30-minute break between sessions to allow salivary α-amylase and heart rate levels to return to normal.

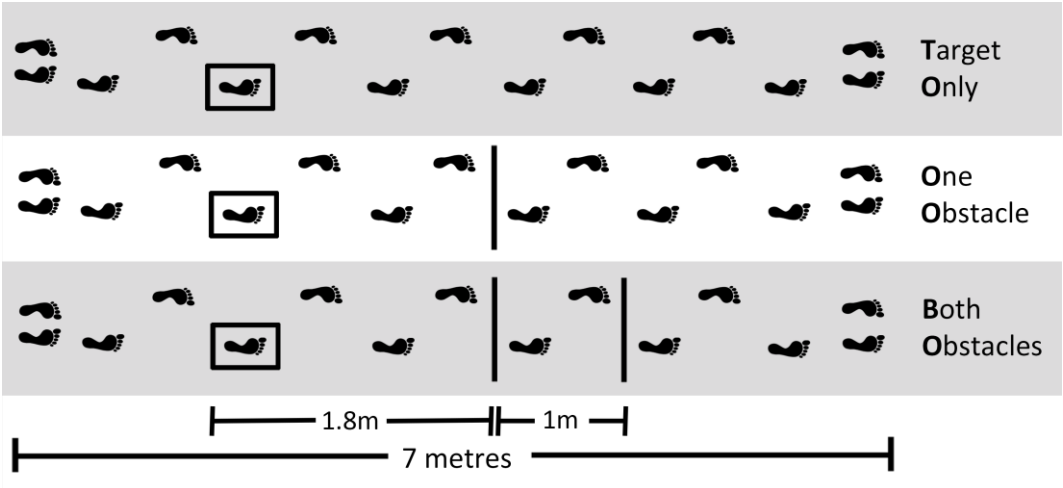

Figure 4-1 A schematic showing the three trial conditions used in the current study. Participants stepped into the target box with their right foot, and over each obstacle with the right foot first.

During the judged session, social evaluative threat was used in an attempt raise participant task-related anxiety. The social evaluative threat technique used in this study was also used in the study described in Chapter 3. Four doctorate researchers entered

the room and sat behind a desk and computer screens. The participants were told that the researchers were gait research experts and would be receiving accurate information about their stepping performance in real time and marking them compared to previous study participants. A live scoreboard displayed on a computer screen was visible to the participants between trials. The scoreboard displayed their name, age, and a made-up performance score amongst 9 fictional names, ages and scores. They were told that the scores had been adjusted to their Berg balance scores from earlier, that the top place should be achievable, and that there was a prize if they came first. Their fictional scores were updated every two trials and never moved them above 6th place. Once all data collection for each participant was complete, they were informed that the judges and scores were fictional and were present in order to raise anxiety.

4.2.4 Data Analysis

Gait events and accuracy were detected using exported comma-separated variable files from Vicon Nexus and analysed using the techniques described in Chapter 2.5.1. Vertical acceleration peaks of heel and toe markers were used to identify foot-contact and toe-off. Anteroposterior and mediolateral stepping error of the mid-stance frame, stance duration, and leading (right foot) and trailing (left foot) toe clearance over the near obstacle were determined from the kinematic data. Step technique was also identified indicating whether the participant stepped with their heel or toe making first contact with the floor of the target step. The percentage of trials in each task difficulty that toe-first stepping occurred is reported.

Hit frequency was calculated as the number of times the target box was visually contacted by the right foot in each set of 6 trials.

EOG data was temporally aligned with the kinematic data using a near infrared synchronisation pulse emitted from a trigger box connected to a 1000Hz analogue input channel of the Vicon MX system. The pulse was detected by an infrared sensor on the BlueGain EOG unit and produced an event marker in the data stream. Using the vestibulo-ocular reflex calibration trial, the vertical EOG signal was converted in to degrees. Saccade onset was identified when the eye movement velocity surpassed $100°s^{-1}$. The difference between foot contact time and saccade onset was then analysed (see Chapter 2.6.1).

Saliva samples were analysed for salivary α-amylase using a Salimetrics enzyme assay kit (Salimetrics Europe, Ltd., UK) (see Chapter 2.3.4.2). Salivary α-amylase, heart rate and SAI scores were all analysed as a change from baseline measures.

Trial data was analysed with a 2 x 3 (session x task difficulty) repeated measures ANOVA using the means of each group of 6 trials for each participant. The variables analysed were (1) mean anteroposterior step error and variability, (2) mean mediolateral step error and variability, (3) stance duration, (4) hit frequency, (5) step technique, (6) saccade timing relative to foot contact, (7) salivary α-amylase levels, (8) SAI score, and (9) heart rate. Leading and trailing toe clearance over the first obstacle were analysed using a 2 x 2 repeated measures ANOVA as there were no obstacles in the target only trials. The Bonferroni correction was applied to all post-hoc pairwise comparisons. Correlations involving a non-parametric variables were carried out using Spearman's rank correlation. Correlations of continuous parametric data used Pearson's product moment correlation. All correlation analyses were two-tailed.

4.3 Results

A summary of results can be found in Table 4-2. All values are mean ± standard error unless otherwise stated.

4.3.1 Anxiety

There was a main effect of session on SAI scores change from baseline ($F_{(1, 10)} = 5.24$, $p < .05$). Participants SAI score was higher during judged trials (0.49 ± 0.25) than during control trials (-0.18 ± 0.10, Figure 4-2). There were no main effects of session or task difficulty on salivary α-amylase levels or heart rate (see Table 4-2).

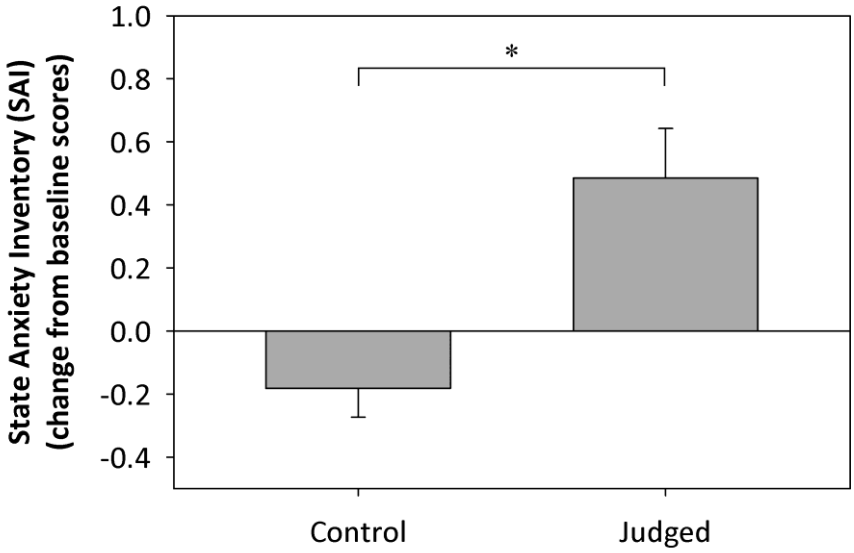

Figure 4-2 The change from baseline State Anxiety Inventory (SAI) scores for control trials, and the social evaluative threat trials (judged). * Sig. difference between the conditions, $p < .05$. Error bars represent standard error.

4.3.2 Stepping Accuracy and Variability

There was a main effect of session on mean mediolateral stepping error ($F_{(1, 10)} = 6.98$, $p < .05$), indicating that participants stepped more medially in the judged session than

during the control trials (-6.4 ± 2.2mm and -3.0 ± 2.5mm respectively, Figure 4-3a). There was also a main effect of difficulty on mean mediolateral stepping error ($F_{(2, 20)}$ = 5.18, $p < .05$). Post hoc tests revealed that there was significantly less mediolateral error during TO (-2.9 ± 2.2mm) than OO trials (-6.2 ± 2.5mm); mediolateral error in the BO trials was -5.0 ± 2.3.

There was a main effect of session on mean anteroposterior step variability ($F_{(1, 10)}$ = 7.19, $p < .05$), which was reduced during the judged trials compared to control (12.0 ± 0.7 and 14.0 ± 0.9mm respectively). However, there was no main effect of session on mean anteroposterior stepping accuracy (Control: -21.9 ± 2.5mm and Judged: -22.6 ± 2.4mm) There was a main effect of difficulty on mean anteroposterior stepping error using the Greenhouse-Geisser correction for violating Mauchley's test of sphericity ($F_{(1.30,\ 14.01)}$ = 6.61, $p < .01$). Post hoc analysis revealed that during the BO trials participants stepped more posteriorly in the target than during TO trials (-25.7 ± 2.4mm and -21.3 ± 2.5mm respectively, $p < .05$, Figure 4-3b). There were no significant differences in hit frequency or stance duration between sessions or difficulties.

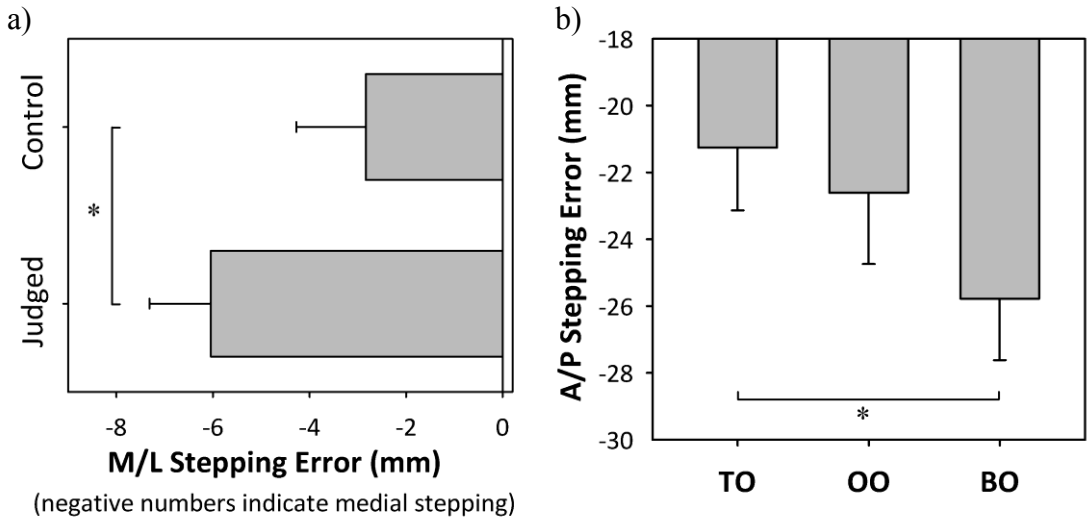

Figure 4-3 Graph a) indicates the mean mediolateral stepping error in each session across all task difficulties; negative numbers indicate that the centre of the foot was medial to the centre of the target box. Graph b) shows the anteroposterior stepping error of each task difficulty across both sessions; negative numbers indicate that the centre of the foot was posterior to the centre of the target box. * Sig. difference between indicated conditions, $p < .05$. Error bars represent standard error.

4.3.3 Gaze Transfer from Stepping Target

Three of the EOG data files were unable to be analysed due to synchronisation channel errors and stepping artefacts that rendered it impossible to identify saccadic eye movements; 8 out of the 11 subjects were included in the analysis. There was a main effect of task difficulty on mean gaze transfer time relative to foot contact in the target box ($F_{(2, 14)} = 4.25$, $p < .05$). Post hoc tests revealed that gaze transfer from the stepping target was significantly later during TO trials compared to BO trials (61 ± 56ms and -7

± 53ms respectively, $p < .05$). The mean transfer time for OO trials was 8 ± 50ms. Negative values indicate gaze transfer prior to foot contact in the target.

4.3.4 Toe Clearance Over First Obstacle

There was a main effect of session on trailing foot toe clearance ($F_{(1, 10)} = 4.97$, $p = .05$). Participants cleared the obstacle by 14.8 ± 1.8mm in the control session, and 13.3 ± 1.9mm in the judged session. There was also a main effect of task difficulty on leading toe clearance ($F_{(1, 10)} = 6.23$, $p < .05$) and trailing toe clearance ($F_{(1, 10)} = 10.79$, $p < .01$). During OO trials, participants cleared the near obstacle by a greater distance with their leading right foot (13.2 ± 1.1mm) and trailing left foot (15.9 ± 2.0mm) when compared to the near obstacle in BO trials (12.4 ± 1.1mm and 12.2 ± 1.8mm respectively).

4.3.5 Target Box Stepping Technique

Task difficulty had a main effect on the percentage of trials in which participants stepped with their toe first in to the target box ($F_{(2, 20)} = 10.01$, $p < .01$). Post hoc analysis revealed that participants used the 'toe-first' technique significantly less frequently during TO trials (34.1 ± 9.2%) compared to OO (54.5 ± 9.7%) and BO trials (57.6 ± 10.1%, $p < .01$ for both).

Table 4-2 Means and standard deviations of variables across session and task difficulty.

mean ± standard deviation		Control			Judged		
		TO	OO	BO	TO	OO	BO
A/P Stepping Error *(mm)*	†	-18.7 ± 7.6	-23.03 ± 11.5	-26.45 ± 8.18	-23.82 ± 9.47	-22.18 ± 8.79	-25.1 ± 9.46
A/P Stepping Variability *(mm)*	*	17.46 ± 6.6	12.49 ± 5.26	12.1 ± 5.3	11.92 ± 4.72	12.67 ± 3.81	11.4 ± 4.72
M/L Stepping Error *(mm)*	* †	-2.4 ± 8.49	-4.41 ± 9.32	-2.26 ± 9.23	-3.42 ± 6.53	-8.06 ± 8.76	-7.66 ± 8.05
M/L Stepping Variability *(mm)*		9.16 ± 4.08	9.67 ± 3.79	9 ± 3.34	9.23 ± 5.19	6.52 ± 3.68	10.14 ± 3.61
Stance Duration *(s)*		0.78 ± 0.27	0.87 ± 0.1	0.84 ± 0.14	0.89 ± 0.15	0.89 ± 0.11	0.88 ± 0.15
Toe First Stepping *(% of trials)*	†	33.33 ± 32.49	54.55 ± 37.34	54.54 ± 36.58	34.85 ± 32.88	54.54 ± 35.82	60.61 ± 37.47
Leading Foot Toe Clearance *(mm)*	†		13.38 ± 4.45	12.51 ± 3.7		13.09 ± 3.25	12.35 ± 3.65
Trailing Foot Toe Clearance *(mm)*	* †		17.04 ± 6.8	12.58 ± 5.93		14.82 ± 6.92	11.74 ± 6.06
Target Hit Frequency *(per 6 trials)*		0.09 ± 0.3	0.27 ± 0.65	0.27 ± 0.47	0.18 ± 0.4	0.27 ± 0.47	0.09 ± 0.3
Saccade Timing *(ms)*	†	46.38 ± 165.57	-1.38 ± 124.27	-36.13 ± 155.85	75.38 ± 161.37	17.75 ± 179.87	20.5 ± 145.83
State Anxiety Inventory	*	-0.18 ± 0.4	-0.36 ± 0.67	0 ± 0.45	0.55 ± 1.04	0.64 ± 1.03	0.27 ± 0.65
Salivary α-amylase *(U/mL/min)*		7.42 ± 42.02	10.93 ± 33.12	15.65 ± 46.45	8.07 ± 49.77	7.09 ± 47.13	9.58 ± 29.49

* = sig. main effect of session

† = sig. main effect of difficulty

4.3.6 Correlations

Stance duration showed a strong correlation with gaze transfer time ($r_{(47)}$ = .478, p = .001, Figure 4-4a) and toe-first stepping occurrence ($r_{s\,(66)}$ = -.473, p < .001, Figure 4-4b). SAI scores showed a relatively weak negative relationship with mediolateral step variability ($r_{(66)}$ = -.286, p < .05).

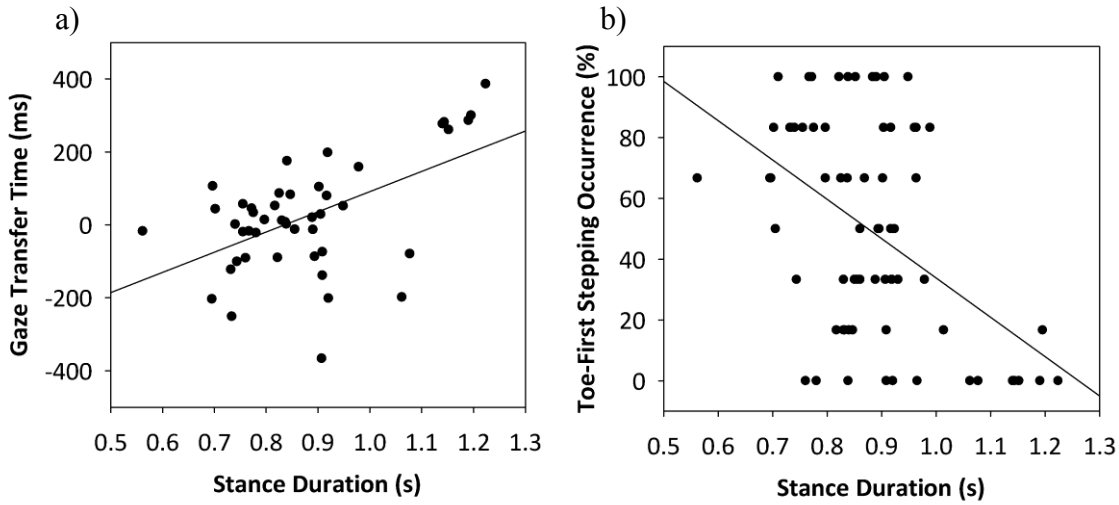

Figure 4-4 Correlations between stance duration and a) the timing of saccade initiation away from the current stepping target relative to foot contact, and b) the occurrence of toe-first stepping in each set of six trials as a percentage.

4.3.7 Comparing young and older adults

The study in this chapter used a similar protocol to that presented in Chapter 3, therefore an additional 2 x 2 x 3 (age x session x difficulty) mixed design ANOVA was used in order to analyse age-related differences in stepping performance and anxiety. The 'far obstacle' (FO) task difficulty used for young adults in Chapter 3 was removed from this analysis in order to directly compare results between groups. There was a

main effect of age on anteroposterior stepping error ($F_{(1, 14)} = 11.10$, $p < .05$), anteroposterior step variability ($F_{(1, 14)} = 7.83$, $p < .05$) and mediolateral step variability ($F_{(1, 14)} = 6.01$, $p < .05$). Older adults stepped more towards the rear of the box than young adults (-23.2 ± 2.4mm and -8.9 ±3.6mm respectively), however young adults stepped with greater anteroposterior variability (18.4 ± 1.6mm) compared to older adults (13.0 ± 1.1mm). There was also greater mediolateral step variability in the older group (9.0 ± 0.5mm) compared to the young (6.8 ± 0.7mm). There were no significant main effects of age on mediolateral stepping error, salivary α-amylase, or state anxiety inventory scores. Comparison values for young and older adults in both control and judged sessions can be found in Table 4-3.

Table 4-3 A comparison table of stepping performance and anxiety measures for young (Chapter 3) and older adults (Chapter 4)

mean ± standard deviation	**Control**		**Judged**	
	YA	OA	YA	OA
A/P Stepping Error *(mm)* *	-9.68 ± 12.07	-22.73 ± 9.52	-13.75 ± 6.47	-23.70 ± 9.03
A/P Stepping Variability *(mm)* *	17.01 ± 6.83	14.02 ± 6.10	18.08 ± 6.84	12.00 ± 4.33
M/L Stepping Error *(mm)*	-11.50 ± 4.07	-3.02 ± 8.79	-9.55 ± 6.12	-6.38 ± 7.88
M/L Stepping Variability *(mm)* *	8.13 ± 3.91	9.28 ± 3.64	7.94 ± 2.92	8.63 ± 4.38
State Anxiety Inventory	0.13 ± 0.92	-0.18 ± 0.53	0.67 ± 2.09	0.48 ± 0.91
Salivary α-amylase *(U/mL/min)*	6.27 ± 17.67	11.33 ± 39.76	14.47 ± 24.50	8.25 ± 41.73

* = sig. main effect of age

4.4 Discussion

This study aimed to apply the techniques of experimentally increasing task-specific state anxiety previously used in Chapter 3 to an older population and measure the effects on eye-stepping coordination and stepping performance. In this study we have demonstrated that older adults report a significant increase in psychological self-reported anxiety during social evaluative threat (SAI, Figure 4-2), and that this was accompanied by increased mediolateral stepping error (Figure 4-3a). We did not, however, find evidence of early gaze transfer away from current stepping targets during the evaluative threat condition, which suggests that this visual behaviour observed in previous research (Chapman & Hollands, 2006; 2007; Young & Hollands, 2010; Young et al., 2011) may not be entirely driven by state anxiety and might be due to a more complex interaction of anxiety and task perception.

4.4.1 The effectiveness of social evaluative threat and anxiety measures

As previously mentioned, we successfully increased the state anxiety inventory measure of self-reported anxiety by telling participants they were being judged (Figure 4-2). Our specific 6-item questionnaire was based on Marteau and Bekker's (1992) shortened 6-item version of the Spielberger State-Trait Anxiety Inventory (STAI - Spielberger et al., 1970). Marteau and Bekker correlated their shortened version at various anxiety intensities with the 20-item STAI and found a correlation coefficient of .91. This suggests that our measure of state anxiety was reliable and was a true reflection of participant anxiety.

We also measured salivary α-amylase as an indicator for physiological anxiety. We found no differences in amylase concentration between sessions or task difficulties.

This result could be due to slight variations in time and length that each task difficulty took. Salivary α-amylase shows quick adaptation to the current stress levels, and also a quick reduction following the stress stimulus (Nater et al., 2005). Due to the physical nature of the task, we were unable to collect saliva samples during the trial blocks. While there is a several minute delay in the increase and decrease of amylase concentrations, the collection period was 3-minutes long, and levels of amylase not relating to the trial blocks could have been included in analysis. Further to this, Kivlighan and Granger (2006) showed that pre-competition amylase levels in women were significantly lower than their baseline measure; a gender difference that could have elicited some effects in the current study as 8 out of 11 participants were female.

Heart rate was measured as a secondary measure of physiological anxiety, and also showed no main effects from task difficulty or session. For similar reasons to the α-amylase variable, this measure was highly susceptible to other influencing factors such as physical fitness and ageing-related impairment of vagal function (Tulppo et al., 1998).

The results of the anxiety measures presented in this chapter show that social evaluative threat affected an increase of psychological, but not physiological anxiety in older adults. We therefore conclude that the lack of change in α-amylase and heart rate between sessions and difficulties does not invalidate the main effect of the SAI measure of anxiety, and that the social evaluative threat methodology successfully induced higher psychological state-anxiety during the judged condition.

4.4.2 Target Box Stepping Accuracy and Variability

As can be seen from the Berg balance scale, FES-I and ABC results presented in Table 4-1, the participants of this study were relatively competent and confident walkers, and

would be considered to be at a low-risk of falling. Despite this, during the social evaluative threat trials, we observed a significant increase in mediolateral stepping error, and a reduction in anteroposterior step variability. Our findings that the higher anxiety trials produced more medial steps suggest an anxiety-based stiffening strategy which is characteristic of older adults who have experienced a fall. This provides support that state anxiety contributes to poor stepping performance (Young et al., 2011). We also observed more medial stepping in the more complex OO trials compared to TO. This could be due to the increased attentional demand necessary in OO trials, resulting in poorer stepping accuracy (Gage et al., 2003).

Our finding that increased anxiety reduced anteroposterior step variability suggests that social evaluative threat made participants step at more consistent lengths during the target step. This could have been a product of the intervention which explicitly told participants to step with greater consistency and precision. However, there was no main effect of session on A/P error. The mean values of mean A/P error showed minimal change from -22.6 ± 2.4mm during judged trials, compared to -21.9 ± 2.5mm during control. The reduction in A/P variability during judged trials suggests that they were stepping inaccurately with less variability under social evaluative threat. This might be due to an anxiety-mediated postural stiffening reducing the range of motion of the ankle and reducing acute variability of the foot placement in the direction of stepping (Brown et al., 2002), however we did not measure lower leg EMG to confirm this theory.

We observed a decrease in anteroposterior step accuracy as trial difficulty increased (Figure 4-3b), which shows the expected effects of increased attentional demand reducing stepping accuracy. Young et al. (2011) suggest that the effects of task

difficulty may be due to increased anxiety. Our results support this, but our anxiety measured lacked the clarity to show direct evidence of this.

There was a significant reduction in trailing toe clearance over the first obstacle from 14.8 ±1.8mm in judged trials, compared to 13.3 ±1.9mm in control. Although this difference is small, and unlikely to cause a fall in a real world situation, the finding that acute psychological anxiety reduces the clearance of the trailing toe could be detrimental to those with more severe anxiety, assuming that toe clearance might reduce further with greater anxiety. Trajectory of the trailing foot is important in planning the next step, and if it were held back unexpectedly the forward momentum might cause an individual to continue forwards without the trailing foot being able to prevent a fall. Di Fabio et al. (2004) demonstrated that older adults at a high-risk of falling showed reduced trailing foot clearance compared to low-risk older adults and young adults. They suggested the observed foot lift asymmetry could be due to limited hip extension or to reduced executive cognitive function. Here we have demonstrated a reduction in trailing toe clearance in low-risk older adults, and provided evidence of state anxiety being another contributing factor due to fear-of-falling being commonly present in high-risk older adults (Friedman et al., 2002). We speculate that anxiety drives this behaviour through attentional prioritisation of future tasks, much like that demonstrated during target stepping by Young et al. (2011).

There were task difficulty related changes in toe-obstacle clearance also for both leading and trailing feet. Participants cleared the obstacles with less space during BO compared to OO trials. The increased attentional demands of the BO condition could have reduced toe clearance, however this could also have been due to the layout of the course. There was a relatively small space between obstacles (100cm) in the BO

condition where participants had to step once with each foot in order to step over the second obstacle with a leading right step. This could have contributed to the decrease in toe clearance observed during BO trials, and therefore a direct comparison between task difficulties would be confounded.

The percentage of trials in which toe-first stepping occurred was much lower during TO trials than the other two task difficulties. To our knowledge this is the first study to look at step technique while stepping into a raised target. During regular gait, heel-first foot contact is the normal method of stance initiation, however the postural threat of the target box (see Chapter 2.2, Figure 2.2) interrupted the normal gait pattern and participants either chose to continue with the heel-first gait technique, or step with their toe first for reasons that are currently unclear. It is our assumption that participants felt there was a benefit to this toe-first stepping, probably due to an increased ability to visually judge the anteroposterior distance from the front inside edge of the target box to the front edge of their foot. The increase of its occurrence during more complex tasks suggests that there are attentional processes involved and that it might be a more cautious method of stepping when planning additional steps. The occurrence of this technique was also negatively correlated with stance duration in the target box indicating that stance duration was generally shorter when this technique was more common (Figure 4-4b). This could have been due to heel-first steps involving a transfer of pressure along the length of the foot, compared to maintaining pressure in the ball of the foot during steps using the toe-first technique.

4.4.3 Gaze-stepping relationship

Our results show an incremental relationship between the delay of gaze transfer and the reduction of task complexity, with TO trials exhibiting significantly later gaze transfer than BO trials. This is probably due to the lack of obstacles to fixate during the TO trials. This finding is consistent with previous research and suggests that participants looked up from the current stepping target earlier during more complex trials in order to plan for future stepping constraints (Chapman & Hollands, 2006; 2007), and was accompanied by increased anteroposterior stepping error (Figure 4-3b). We also found a positive correlation between gaze transfer and stance duration suggesting that longer stance duration might be necessary when gaze transfer is delayed in order to sufficiently plan for future steps (Figure 4-4a).

We did not, however, elicit an augmented earlier gaze transfer by increasing task-specific anxiety in low-risk older adults as we predicted. We therefore propose that the earlier gaze transfer observed in high-risk individuals in previous research by Young et al. (2011) might be due to a complex synergy of anxiety and other factors, such as attentional allocation capacity, specific to high-risk older adults. As mentioned previously, the participants in this study were low-risk, therefore direct comparisons with the anxiety relationships of other studies involving high-risk individuals would be invalid.

4.4.4 Comparisons between young and older adults

As expected, young adults stepped significantly more accurately with regards to anteroposterior stepping error, and also had slightly less mediolateral step variability than older adults (Table 4-3). Interestingly, older adults stepped with significantly less

anteroposterior step variability compared to young. We suggest that this was partially due to the rear edge of the target box reducing the amount of variation possible, as older adults stepped more towards to rear of the target box in both conditions. It is also worth noting that young adults stepped slightly more towards the medial line of the walkway than older adults. This could have been due to overconfidence during foot placement in young adults, however we are unable to confidently explain this non-significant finding. When interpreting these comparisons, it is important to note that toe marker positions were changed slightly between studies (see Chapter 4.2.2).

4.4.5 Limitations

The fact that physiological measures of anxiety were not increased along with psychological measures suggests that a greater anxiety inducing intervention might have yielded more promising results. Due to the nature of the intervention used, and the walking proficiency of those tested, most participants would not have felt a high form of anxiety comparable to a fear of falling. Previous research has used a raised and narrowed platform to experimentally increase anxiety (Gage et al., 2003; Brown et al., 2006), however this method of intervention was not available to us at the time of testing. We predict that if the participants tested in this study completed the judged trials on a raised platform, there would have been an increase in the physiological measures of anxiety, and a greater reduction in stepping performance. The psychological increase in anxiety that we observed was fairly small, however it was still large enough to affect changes in stepping performance.

4.4.6 Conclusions

We were able to induce greater psychological, self-reported task-specific state anxiety through use of social evaluative threat in low-risk older adults. We found that this increased anxiety subsequently increased medial stepping error, increased the consistency of inaccurate anteroposterior error, and reduced trailing toe obstacle clearance. We also showed that experimentally increasing state anxiety did not induce earlier gaze transfer from current stepping targets in low-risk older adults. This study provides new evidence that experimentally induced anxiety can decrease stepping performance in older adults during adaptive locomotion, however the mechanisms by which it does remain unclear.

Chapter 5

The effects of reduced anxiety on older adults' eye stepping coordination and stepping accuracy during adaptive locomotion.

5.1 Introduction

Having demonstrated that increased psychological anxiety is associated with decreased stepping performance in older adults, our next aim was to experimentally reduce participant task-related anxiety during locomotion in older adults, and measure the extent of any improvements in stepping performance and gaze behaviour. To achieve this we needed a suitable intervention for reducing anxiety. Progressive muscle relaxation has shown previous success in reducing anxiety in patients with Alzheimer's disease (Suhr, 1999), and diaphragmatic breathing exercises have also shown some promise in avoiding panic (Eifert & Heffner, 2003).

Dendato and Diener (1986) found that a programme of progressive muscle relaxation and diaphragmatic breathing was effective in lowering anxiety in pre-examination undergraduates. Participants completed six 1-hour sessions in which they completed 30-minutes of muscle relaxation and breathing exercises, followed by 30-minutes of cognitive therapy. The results show that the anxiety reducing exercises were more effective at reducing anxiety than a control group, and a group who completed six 1-hour study-skills sessions. Furthermore, an additional group who completed both the anxiety reduction and study-skills sessions showed a significant improvement on exam scores when compared to other groups, including the study-skills only group. Muscle relaxation and breathing exercises have also been shown to reduce anxiety in pregnant

women. Bastani et al. (2005) found that over a 7-week course of weekly 90-minute sessions, participants showed a reduction in both state and trait anxiety scores, as well as a reduction in perceived stress when compared to a control group.

Cognitive-behavioural therapy has also been shown to be effective at reducing state and trait anxiety in patients with anxiety disorders. It usually involves multiple one-on-one sessions with a trained therapist, with the idea of breaking down an overwhelming anxiety in to smaller parts, and helping the patient to reduce or remove the negative thoughts to lower an individual's anxiety. In two separate systematic reviews, cognitive-behavioural therapy was found to be an effective intervention for adults with anxiety disorders when compared to placebo trials (Hofmann & Smits, 2008), and for reducing anxiety sensitivity in adults compared to control trials (Smits et al., 2008).

While computerised cognitive-behavioural therapy has shown promising results in those with more severe anxiety and depression (Proudfoot et al., 2004), the most effective cognitive therapy requires a trained therapist to deliver it over a number of weeks. One of the benefits of muscle relaxation and diaphragmatic breathing is that once an individual is familiar with the therapy, they can perform their own sessions when they feel necessary. Furthermore, muscle relaxation and breathing exercises have been shown to be equally effective in the treatment of generalised anxiety disorder (Öst & Breitholtz, 2000). We therefore used these techniques in order to implement an anxiety-reduction intervention applicable to locomotor tasks in the elderly.

Following on from the previous chapters, in this study we investigate whether reducing anxiety in older adults leads to improved stepping performance. We hypothesise that

lower anxiety levels mediate improvements in stepping performance and are associated with delayed gaze transfer from the current stepping target.

This study aimed to 1) evaluate progressive muscle relaxation and diaphragmatic breathing over a one-week period as a useful method of reducing task-specific anxiety in older adults during a precision walking task, and 2) measure changes in stepping performance associated with reduced anxiety to provide support that task specific anxiety contributes to falls risk in a healthy elderly population. We predicted to find a reduction from pre- to post-intervention anxiety levels that would be associated with improvements in stepping performance.

5.2 Methods

This study used the same basic study protocol described in Chapter 4. Participant information, session differences, and intervention techniques that vary from the previous study are described below.

5.2.1 Participants

Twelve community dwelling older adults (11 female, 1 male) were recruited from posters displayed in the local area, and through visits to local assisted living facilities. All participants were sent information sheets describing the study, what would be required of them, and signed consent forms indicating that they understood the protocol and that they could withdraw from the study at any time without having to give a reason. They were reimbursed any travel costs and given £20 on completion of the study. Full ethical approval was granted for this study from the University of Birmingham Ethics Committee. Participants were excluded if they wore a pacemaker, had diabetes, had musculoskeletal or neurological disorders, or required walking aids to travel short

distances. A list of any prescription medication was recorded, and all participants were tested in the afternoon between 1pm and 5pm in order to control for daily fluctuations in salivary α-amylase levels.

Balance, vision, balance confidence, general mental heath, executive function and cognitive function were assessed using tests described in Chapter 2. Participants also completed the timed up-and-go test (TUG test) as an indicator of mobility (Podsiadlo & Richardson, 1991). The TUG test required participants to sit in a firm chair that had armrests and a back support at a start line. Upon hearing a verbal signal they had to stand from the chair, walk 3-metres to a line on the floor, turn through 180°, return to the seat, turn 180° and sit down whilst being timed. Mean participant scores for all these tests can be found in Table 5-1.

Participants were randomly assigned to a control group or an intervention group before taking part in this study. In total, 20 participants were initially tested in this study, however due participant withdrawals and errors during data collection, only 12 could be used in analysis. Both groups had to attend the laboratory one afternoon and complete 18 adaptive walking trials, and then return a week later for repeat testing. Following the first session, the intervention group were given MP3 audio players with recorded relaxation exercise instructions loaded on them. They were asked to complete these exercises twice a day and record their progress before returning for the 2nd session one week later. The control group were given no instructions.

Table 5-1 General Participant Information and Scores

Measure: Mean (Std dev)	Intervention *(n = 8)*	Control *(n = 4)*
Age *(years)*	78.38 (7.58)	71.75 (4.57)
Height *(cm)*	161.30 (6.63)	164.08 (12.58)
Weight *(kg)*	62.82 (11.54)	63.16 (8.11)
Body Mass Index	24.15 (2.26)	23.55 (3.14)
Shoe Length *(cm)*	26.75 (1.65)	26.13 (1.44)
Shoe Width *(cm)*	9.88 (1.13)	9.63 (0.48)
Snellen Visual Acuity *(min score)***:**		
Left Eye Only	≥20/50	≥20/50
Right Eye Only	≥20/50	≥20/50
Both Eyes	≥20/40	≥20/40
Pelli-Robson Contrast Sensitivity Score *(max 2)***:**		
Left Eye Only	1.46 (0.16)	1.54 (0.14)
Right Eye Only	1.31 (0.34)	1.46 (0.08)
Both Eyes	1.58 (0.25)	1.65 (0.12)
Berg Balance *(/56)*	51.25 (2.87)	52.75 (2.75)
TUG Test *(s)*	11.89 (2.48)	9.48 (3.24)
FES-I *(/48)*	9.50 (4.90)	4.00 (1.63)
ABC *(%)*	77.66 (12.20)	91.88 (4.05)
Trail Making A *(s)*	52.23 (13.91)	35.67 (7.53)
Trial Making B *(s)*	121.71 (64.26)	72.53 (13.17)
Δ Trail Making *(s)*	69.49 (60.99)	36.86 (19.24)
Mini-Mental State *(/30)*	28.38 (1.06)	29.50 (0.58)
GHQ-28 *(/21)***:**		
Somatic Symptoms	3.13 (1.06)	3.25 (2.87)
Anxiety/Insomnia	4.88 (4.79)	3.25 (2.63)
Social Dysfunction	7.63 (0.74)	3.50 (2.38)
Severe Depression	1.13 (2.10)	3.25 (2.22)

5.2.2 Data Collection

Kinematic data was recorded using a 100Hz 13-camera Vicon MX system (Vicon Oxford, UK). A 1000Hz BlueGain EOG biosignal amplifier was used to record horizontal and vertical eye movements. Salivary α-amylase levels were measured in 3-minute passive saliva sample collections, and heart rate was taken between blocks of trials. A 6-question State Anxiety Inventory (SAI) questionnaire was used to measure immediate self-reported task specific anxiety. Further details of these data collection methods can be found in Chapter 2.

It was also necessary to collect information regarding the progress of the participants in the intervention group, and the effectiveness of the relaxation recordings during the week between sessions. Participants were given a daily progress sheet with space to record how anxious they were before, and after, each relaxation exercise session. They rated their anxiety on a scale from 1 to 10; 1 representing the most relaxed and 10 representing "the most anxious they had ever been". Participants in the intervention group completed the relaxation exercises twice per day for the one-week between trials.

5.2.3 Protocol

Each session was carried out using the same protocol as the control trials from Chapter 4, and is described in greater detail in Chapter 2. All participants completed 18 adaptive walking trials per session. There were 6 trials consisting of a target box only (target only – TO), 6 trials with one obstacle present (one obstacle – OO), and 6 trials with two obstacles on the walking path (both obstacles – BO). Initial target box position was determined from each participant's second right heel strike during a comfortably paced previous walk with no stepping constraints.

Immediately following each set of 6 trials, salivary α-amylase samples and heart rate were collected, after which participants completed the SAI with respect to the trials they had just completed. Baseline measures of these variables were also collected prior to each session following a 20-minute rest period, and analysis was carried out using the mean change from baseline for each task difficulty.

After the first session, participants in the intervention group were given an MP3 player and headphones with a 15-minute relaxation audio file pre-loaded. They then listened to the recording and completed the exercises along with one of the researchers. The first 5-minutes of the recording were verbal instructions on progressive muscle relaxation. The participants were instructed to sit in a firm-backed chair with armrests and slowly contract and relax muscle-groups one at a time. This started in their hands, progressed up their arms and in to their face, then down their body to their toes. A researcher did these exercises with the participants to make sure they understood the instructions and were doing it correctly.

Following the progressive muscle relaxation exercises, participants were asked to carry out 10 minutes of diaphragmatic breathing. This technique required participants to sit up straight and breathe while maximising use of the diaphragm. Participants were taught how to do this, and were asked to inhale for 4 seconds, hold for 2 seconds, and exhale for 6 seconds. Verbal instructions on the recording gave cues on when to inhale, hold and exhale for the first 2-minutes, then the participants continued this technique for another 8 minutes with no instructions. There was soft gentle music playing in the background of the recording throughout the exercises. Intervention participants took the MP3 player home with them and were instructed to complete these exercises once in the

morning, and once in the afternoon/evening. They rated how anxious and tense they felt on a daily progress sheet before and after the relaxation exercises throughout the week.

On the day of the second session, prior to testing, the intervention group completed the relaxation exercises one last time as part of the 20-minute rest period, before having baseline measures of heart rate, salivary α-amylase and SAI taken. Control participants did not do any relaxation exercises, but still had 20 minutes of rest before baseline measures were taken. The second session was the same as the first. Task difficulty order was randomised within each session, and acute placements of the target box and obstacles were randomised over each participant's data collection.

5.2.4 Data Analysis

Gait events in the target box were detected using kinematic data and a custom script built in MATLAB (The MathWorks Inc., MA, USA), which has been detailed in Chapter 2, and can be found in Appendix F. The script's foot contact identification has been previously verified to within 1 frame of accuracy when compared to manual identification (see Chapter 4). Anteroposterior and mediolateral stepping error, stance duration, toe-first stepping occurrence, and leading and trailing toe clearance over the first obstacle were identified from the data. Researchers visually identified target box hit frequency when the stepping foot connected with the target box during trials.

Gaze transfer from the stepping target was automatically identified and visually verified in MATLAB as the nearest vertical saccade to foot contact time. Saccade onset was categorised as when eye rotation velocity surpassed $100°s^{-1}$.

Salivary α-amylase levels were measured using a Salimetrics enzyme assay kit (Salimetrics Europe, Ltd., UK) and a plate reader set at 405nm (see Chapter 2).

The mean difference in self-reported anxiety scores between pre- and post-relaxation exercises was calculated. To do this, the mean pre-relaxation exercise anxiety scores for all intervention participants was calculated, in effect creating a zero point. The difference between each of the individual pre- and post-relaxation scores was calculated and added to the mean pre-relaxation score, and then compared using a paired samples t-test. This was done to standardise the pre-exercise anxiety scores of participants, which was expected to change throughout the week and vary between participants. The first and last exercises were compared in a paired samples t-test to see if the relaxation exercises had altered anxiety throughout the week.

A 2 x 2 x 3 (group x session x task difficulty) mixed design ANOVA was initially used to analyse trial data, however there was a lack of statistical evidence supporting the effectiveness of the relaxation intervention in comparison to the control group (this is reviewed further in the discussion section). However, since there was a main effect of session on salivary α-amylase suggesting that anxiety was significantly reduced for both groups (see results), we decided that our hypothesis regarding the effects of reducing anxiety on our measures could still be tested if we collapsed the group data to avoid the unbalanced design resulting from our uneven group sizes. Therefore a 2 x 3 (session x task difficulty, whereby change from baseline was used where appropriate) repeated measures ANOVA was used to analyse (1) anteroposterior stepping error, (2) mediolateral stepping error, (3) target box hit frequency, (4) stance duration, (5) toe-first stepping occurrence, (6) gaze transfer time from the current stepping target, (7) salivary α-amylase levels, (8) SAI scores and (9) heart rate. Leading and trailing toe clearances

over the first obstacle were also analysed using a 2 x 2 ANOVA as there were no obstacles present in the target only condition.

5.3 Results

A summary of results can be found in Table 5-2. All values presented in this section are mean ± standard error unless otherwise specified.

5.3.1 State Anxiety Measures

The initial 2 x 2 x 3 (group x session x task difficulty) mixed design ANOVA revealed that there were no main effects or interactions of group on salivary α-amylase, SAI or heart rate anxiety measures. However, there was a significant main effect of session on salivary α-amylase levels ($F_{(1, 10)} = 11.20$, $p < .005$). Therefore, since we aimed to study the effect of reduced anxiety on eye and stepping behaviour, the between-subject group factor was removed from further analyses to simplify the statistical design in order to maximise power.

The 2 x 3 (session x task difficulty) repeated measures ANOVA revealed a main effect of session on salivary α-amylase change-from-baseline measures revealed that levels were higher in the first session (12.9 ± 10.5 U/mL/min) than in the second (-15.4 ± 12.4 U/mL/min). A paired samples t-test was also carried out on each session's baseline α-amylase measures and found that they were not significantly different from each other ($t_{(11)} = 1.41$, $p = .19$).

Effects of task order on salivary α-amylase were analysed using an additional 2 x 4 (session x baseline and task difficulty) repeated measures ANOVA within each participant. There was a main effect of session ($F_{(1, 11)} = 12.46$, $p < .01$), and an interaction effect of session and time ($F_{(3, 33)} = 3.06$, $p < .05$). Overall, salivary α-amylase was higher in session 1 than session 2, and post hoc analysis of the interaction revealed that levels were significantly higher during the first and third sets of trials in the first session compared to the second (Figure 5-1). There were no significant within session differences.

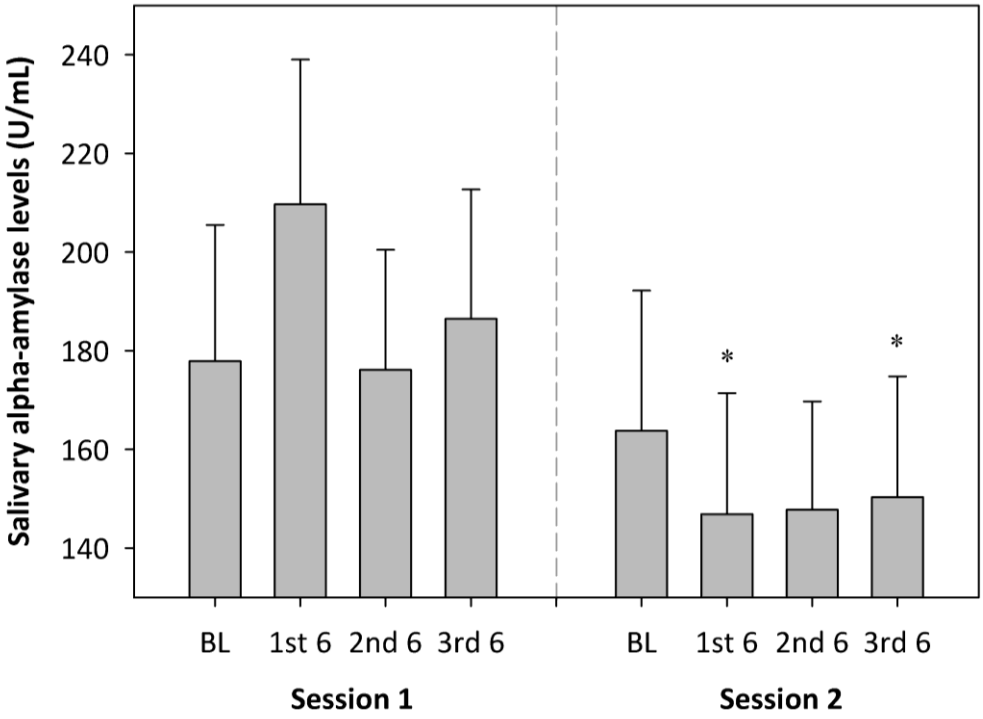

Figure 5-1 Mean baseline (BL) and trial levels of salivary α-amylase in the order they were collected, independent of task difficulty. Each bar representing trials ('1st 6', '2nd 6' and '3rd 6') represents the 6 trials preceding collection. There was a significant overall difference between sessions. * sig. different from corresponding levels during session 1, $p < .05$. Error bars represent standard error.

There was also a main effect of task difficulty on α-amylase levels ($F_{(2, 22)} = 10.7$, $p < .01$). Post hoc analysis showed that α-amylase change-from-baseline was higher in BO trials (19.1 ± 11.5 U/mL/min) compared to both OO and TO trials (-11.5 ± 11.0 and -11.5 ± 12.1 U/mL/min respectively, $p < .05$).

There were no significant effects of session or task difficulty on heart rate or SAI scores (see Table 5-2).

5.3.2 Stepping Performance

There was a main effect of session on target box hit frequency ($F_{(1, 11)} = 6.06$, $p < .05$). Participants hit the target box with their stepping foot less often in the second session compared to the first (0.77 ± 0.14 and 0.52 ± 0.13 respectively). There was also an interaction effect of session and difficulty on M/L step variability ($F_{(2, 22)} = 3.56$, $p < .05$). Post hoc tests showed that there was significantly less step variability during BO trials in session 2 compared to session 1 (Figure 5-2).

There was a main effect of difficulty on the percentage of toe-first stepping trials per set of 6. Mauchely's test of sphericity was violated ($p < .05$), therefore the Greenhouse-Geisser correction was applied to the degrees of freedom ($F_{(1.21, 13.27)} = 5.33$, $p < .05$). However, post-hoc analysis revealed no significant differences between sessions or difficulties (Figure 5-3). There were no other significant differences in kinematic data between sessions or task complexity.

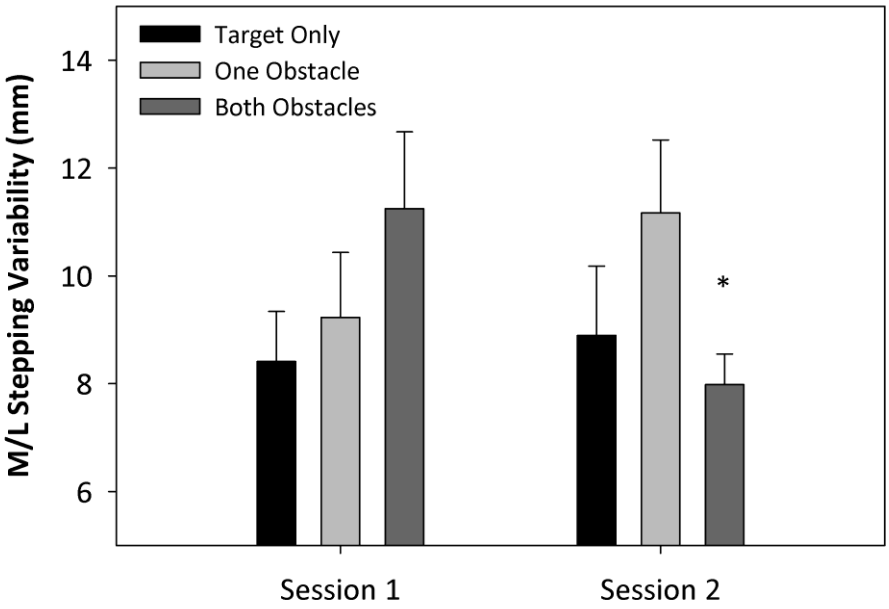

Figure 5-2 Mediolateral stepping variability in each session and task difficulty. * Sig. difference from corresponding value in session 1. Error bars represent standard error.

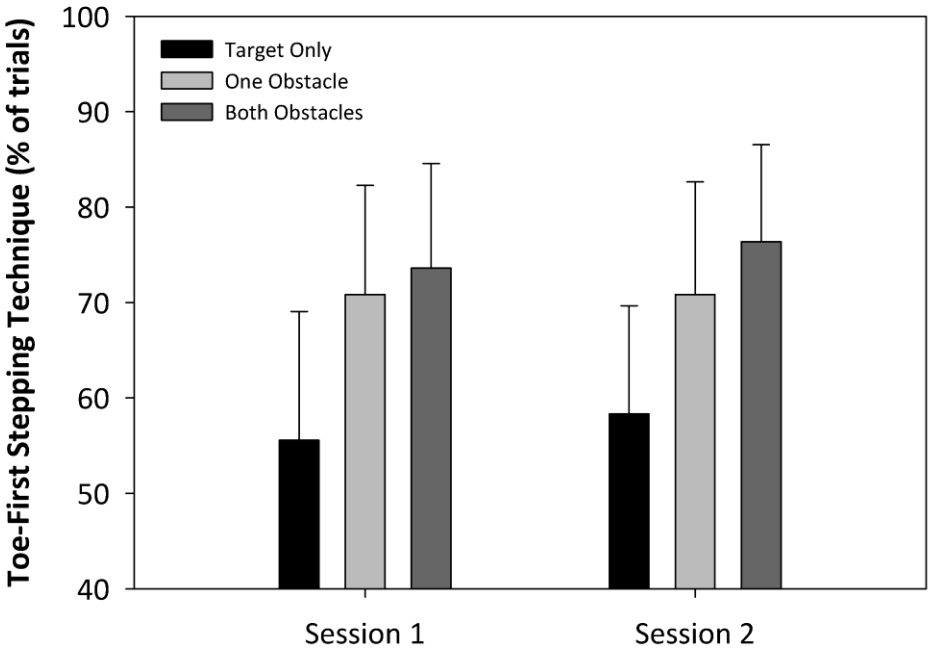

Figure 5-3 Occurrence of toe-first stepping technique across sessions and task difficulty. Error bars represent standard error.

5.3.3 Gaze Transfer Time

There was a main effect of difficulty on the timing of gaze transfer from the current stepping target ($F_{(2, 22)} = 11.22$, $p < .001$). During TO trails (87 ± 50ms), participants transferred gaze significantly later than in OO and BO trials (-25 ± 27 and -45 ± 35ms respectively, $p < .01$ for both comparisons).

5.3.4 Self-Reported Anxiety During the Intervention Week

There was a significant reduction from standardised pre-relaxation exercise scores when compared to individual post-exercise anxiety reduction ($t_{(101)} = 13.81$, $p < .001$). Overall, post-relaxation exercise anxiety scores were 2.0 ± 0.1 (M ± SE) less than pre-exercise scores. However, there was no significant difference between the mean score of the first two relaxation exercises compared to the last two relaxation exercises that intervention participants completed during the week between sessions ($t_{(7)} = 1.52$, $p = .17$).

Table 5-2 Means and standard deviations across each task difficulty in each session.

	Session 1			Session 2		
mean ± standard deviation	TO	OO	BO	TO	OO	BO
A/P Stepping Error *(mm)*	-27.84 ± 14.93	-38.6 ± 14.94	-34.16 ± 17.55	-28.01 ± 15.23	-33.77 ± 18.45	-30.98 ± 12.79
A/P Stepping Variability *(mm)*	13.48 ± 5.84	13.49 ± 4.51	13.92 ± 5.36	12.77 ± 3.99	15.21 ± 7.78	13.30 ± 5.20
M/L Stepping Error *(mm)*	-11.48 ± 8.66	-10.53 ± 10.07	-10.09 ± 9.08	-6.75 ± 7.64	-9.31 ± 8.58	-7.45 ± 8.03
M/L Stepping Variability *(mm)*	8.41 ± 3.23	9.02 ± 3.97	11.27 ± 4.97	8.89 ± 4.47	10.86 ± 4.71	8.45 ± 2.58 ‡
Stance Duration *(s)*	0.90 ± 0.11	0.96 ± 0.20	0.95 ± 0.13	0.86 ± 0.13	0.91 ± 0.12	0.91 ± 0.12
Toe First Stepping *(% of trials)* †	55.56 ± 46.78	70.83 ± 39.65	73.61 ± 37.91	58.33 ± 39.25	70.83 ± 40.90	76.39 ± 35.15
Leading Foot Toe Clearance *(mm)*	-	14.94 ± 5.02	14.07 ± 3.83	-	14.85 ± 4.74	14.53 ± 4.68
Trailing Foot Toe Clearance *(mm)*	-	12.35 ± 6.59	11.93 ± 5.17	-	13.02 ± 8.57	12.64 ± 7.28
Target Hit Frequency *(per 6 trials)* *	0.58 ± 0.79	0.75 ± 0.62	1.08 ± 0.67	0.50 ± 0.67	0.75 ± 0.75	0.42 ± 0.51
Saccade Timing *(ms)* †	79 ± 164	0 ± 104	-23 ± 118	94 ± 193	-50 ± 105	-67 ± 143
State Anxiety Inventory	-0.17 ± 2.08	-0.42 ± 2.39	0.08 ± 1.73	0.92 ± 1.62	0.42 ± 1.44	0.50 ± 1.17
Salivary α-amylase *(U/mL/min)* * †	1.04 ± 37.18	0.58 ± 51.59	37.00 ± 42.36	-23.96 ± 57.04	-23.48 ± 37.17	1.17 ± 46.51

* = sig. main effect of session

† = sig. main effect of task difficulty

‡ = sig. difference between sessions in that task difficulty

5.3.5 Correlations

Timing of gaze transfer showed a moderate correlation with M/L stepping error ($r_{(72)}$ = -.38, p = .001, Figure 5-4) and toe-first stepping technique ($r_{(72)}$ = -.32, p < .01). SAI scores also showed a moderate correlation with toe-first stepping technique ($r_{(72)}$ = .32, p < .01). Salivary α-amylase was not significantly correlated with any other variable measured. Separate correlation analysis was run between salivary α-amylase and mediolateral step variability during the BO condition only and was also found not to be significant.

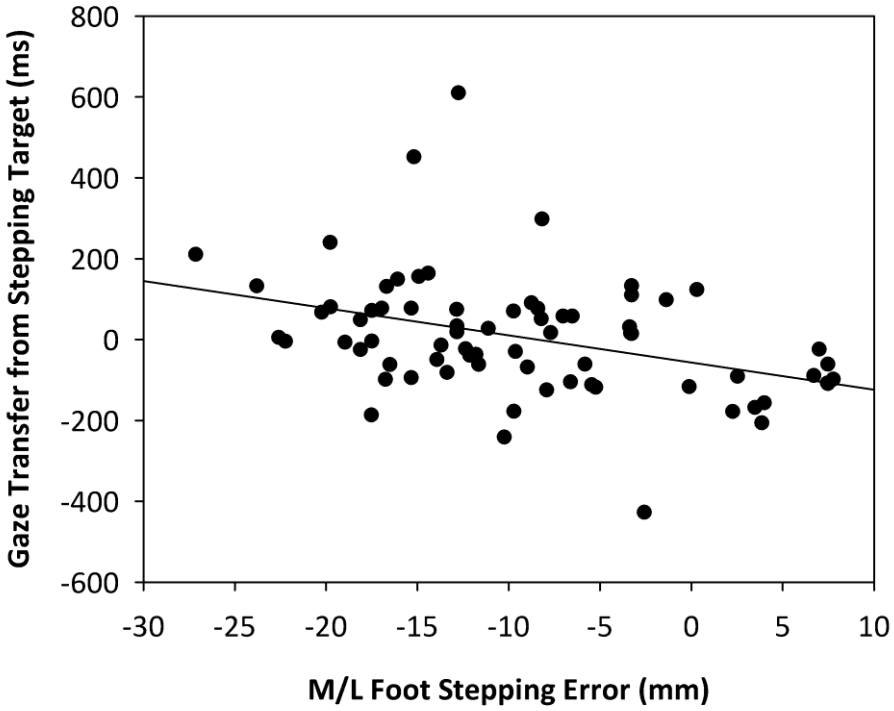

Figure 5-4 Correlation of mediolateral foot stepping error and timing of gaze transfer from the stepping target relative to foot contact. Negative M/L error values represent medial stepping. Negative gaze transfer values represent a gaze transfer away from the target prior to foot contact.

5.4 Discussion

The main aim of the current study was to reduce state anxiety in older adults and measure the consequent changes to stepping performance. Our intended method of reducing anxiety through use of a weeklong course of progressive muscle relaxation and diaphragmatic breathing did not result in significantly lower anxiety than the control group. This may have been due to the relatively short time frame, and less time-intensive method of the intervention when compared to previous research (Dendato & Diener, 1986; Bastani et al., 2005). We did however find a significant reduction in salivary α-amylase concentrations between the first and second sessions for all participants. Full statistical analysis was also run on the intervention group alone (n = 8, results not shown). This analysis revealed that there was a significant reduction in salivary α-amylase change from baseline from the first session (16.8 ± 12.4U/mL/min) compared to the second (-4.9 ± 13.1U/mL/min, $F(1,7) = 5.84$, $p < .05$). However, there were no other significant between session differences in any other anxiety, stepping performance, or gaze related variables. Therefore we collapsed the groups in order to maximise statistical power. During the second session we found a reduction in target box hit frequency, and less mediolateral step variability during the greatest task complexity; the implications of which are discussed further in this section.

5.4.1 Anxiety Reduction

The use of progressive muscle relaxation (5mins) and diaphragmatic breathing (10mins) twice a day for one week was an ineffective method of reducing participant anxiety compared to the control group. There were no significant differences between baseline measures of SAI scores, heart rate, or salivary α-amylase concentration between

sessions. However, there was a significant reduction in salivary α-amylase measures between sessions regardless of participant group (intervention or control). When α-amylase concentrations were organised by task presentation order, we were able to see that there were no within session differences (Figure 5-1). There was however, a significant α-amylase reduction between sessions, suggesting that participants were less anxious during their second lab visit. This reduction may have been due to familiarity with the laboratory environment and researchers, however we argue that this general familiarity is not the only mediating factor in the improvement of stepping performance, as there were no significant reductions of anxiety within sessions over the course of the experiment.

We did not see any response in the self-reported state anxiety inventory scores to task complexity or to session. We suggest that this is due to the individuals' anxiety of the task in the first session being relatively low to begin with, and the limited possible reduction in scores from the first to second sessions.

Heart rate also showed no change between sessions or task difficulties, this may be due to the variability of heart rate as a measure between subjects as discussed in Chapter 4.4.1, and its suitability as a consistent measure between older adults following physical walking tasks.

5.4.2 Progressive Muscle Relaxation and Diaphragmatic Breathing

Although there were no group differences between the intervention and control groups, our self-reported measure of pre- and post-relaxation exercises in the intervention group showed that participants did feel more relaxed following the exercises. However, we

found no evidence that this acute state relaxation significantly reduced overall self-reported anxiety over the course of a week (see section 5.3.4).

5.4.3 Improvements to Stepping Performance

There was a significant reduction in target box hit frequency from the first session to the second session, and a reduction in mediolateral step variability during the most complex task difficulty in session 2 (Figure 5-2). We suggest that these improvements in stepping performance are influenced by the reduced anxiety we observed in the second session. This supports our previous research that stepping performance is somewhat influenced by state anxiety, and when observing an increase in anxiety we have shown corresponding responses in performance (Chapter 4). However, these improvements could also be due to familiarity with the task since the measured reduction in anxiety was not specifically due to our relaxation intervention. Young and Hollands (2010) previously used a similar protocol to the one presented in this study to measure the effects of training specific gaze behaviours during precision stepping in older adults. They showed that control participants who received no training, but were familiar with the task from a previous session, elicited no significant changes in mediolateral step variability, or target box hit frequency. We therefore suggest that while task familiarity during these adaptive locomotion tasks definitely plays a role, the improvements in stepping performance during the second session are partially mediated by the observed reduction in physiological anxiety. However, since we failed to manipulate anxiety through relaxation techniques in order to compare to a control group, we cannot draw a definite conclusion as to the role that reduced anxiety plays compared to the effects of learning. Furthermore, the lack of correlation between salivary α-amylase and stepping

performance indicators add strength the argument that improvements were due to familiarity

We also observed a main effect of difficulty on toe-first stepping technique. The technique was more prevalent in more complex trials, however showed no response to a reduction of anxiety or task familiarity (Figure 5-3). This supports our previous findings that toe-first stepping is selected during trials when the attentional demand of future stepping constraints is higher (Chapter 4). The timing of gaze transfer was moderately negatively correlated with toe-first stepping occurrence, suggesting that the technique was more common with earlier gaze transfer. We previously suggested that toe-first stepping could be used as a method of verifying the foot position within the target. This correlation suggests that when foveal visual information was not available, this method was used, presumably as a clearer peripheral stimulus to maintain stepping accuracy. We also observed a moderate correlation of SAI scores with toe-first stepping, however there was no correlation with salivary α-amylase, which showed greater fluctuations throughout the study. Therefore the nature of the relationship between anxiety and stepping strategy remains unclear. We propose that task difficulty and increased planning requirements are the main factors driving adoption of the toe-first strategy.

5.4.4 Gaze Transfer

We found a significant delay between the timing of gaze transfer during TO, and more complex trials (section 5.3.3). This supports previous research suggesting that earlier gaze transfer occurs at increasing task difficulties in order to allow additional time for step planning (Chapman & Hollands, 2006; 2007, Chapter 4). We also found a negative correlation of gaze transfer time and M/L stepping error (Figure 5-4), which contradicts

our stated hypothesis, and previous findings by Young and Hollands (2010). However, the r^2 value of this correlation was 0.14, suggesting that only 14% of the variability between gaze transfer and M/L stepping error was accounted for. In addition to this, the participants in the Young and Hollands study were more high-risk than the participants in the current study, thus partially confounding a direct comparison.

We did not observe a significant delay in gaze transfer with reduced anxiety. Young and Hollands (2010) found that instructing participants to delay gaze transfer improves stepping performance, and the extent of this gaze transfer was correlated with state anxiety. In the current study we provide further evidence to our previous findings (Chapter 4) that early gaze transfer is not the mechanistic explanation for the effect of state anxiety on stepping errors. Instructing participants to delay gaze could have decreased anxiety by instilling a sense of confidence about stepping into the target box, and the consequent improvements to stepping performance could have been due to a combination of this decreased anxiety and improved online feedback. We suggest that appropriate allocation of attention and gaze fixations in general might be more pertinent than the specific timing of gaze transfer from the current stepping target. In the next chapter we explore age-related differences in visuospatial mapping prior to and during walking, and its consequent effect on anxiety.

5.4.5 Conclusions

In this study we demonstrated that reduced task-specific physiological anxiety is associated with an increased stepping performance in older adults, although effects due to learning must also be considered, as our initial study design was unsuccessful. We did not identify relaxation exercises as a useful intervention to reduce stepping error for

older adults. The relationship between gaze transfer time from current stepping targets and anxiety remains unclear, however we suggest that anxiety influences the broader allocation of visuospatial mapping as a whole, which we explore in further detail in the next chapter.

Chapter 6

Effects of route previewing on gaze behaviour, anxiety and stepping performance during adaptive locomotion.

6.1 Introduction

Evaluation of the environment to identify obstacles and traversable paths is essential for walking individuals to safely move through our cluttered world. Visual information is continuously gathered and processed along with proprioceptive and vestibular feedback in order to maintain balance and generate the most appropriate motor response to our locomotive needs (Uiga et al., 2015).

A close relationship between saccade onset timing and swing phase initiation has been demonstrated in young individuals walking a path of illuminated stepping targets (Hollands & Marple-Horvat, 2001). This consistent coupling of oculomotor and locomotor movements is thought to represent a feedforward control process that relies on visual information describing target location prior to step initiation in order to pre-programme step trajectory. Once step trajectory is initiated it remains constant during the lead foot swing phase (Lyon & Day, 2005) with visually-guided fine-tuning when precision stepping is required during the final part of the swing (Reynolds & Day, 2005). However, older adults, particularly those deemed to be at a high risk of falling, show greater latencies in both onset of gaze refixation towards a new target, and trajectory deviations when adjusting their steps to target translocation during the swing phase (Young & Hollands, 2012a). Therefore, this age-related reduction in ability to make online stepping adjustments is a result of delays in central processes in addition to any musculoskeletal decline.

As we age, our visual sampling strategy (i.e. the times at which we look at environmental features) changes; presumably to allow more time to plan steps (Di Fabio et al., 2003a; 2003b; Chapman & Hollands, 2007; Zietz & Hollands, 2009; Young & Hollands, 2012b). For example, Chapman and Hollands (2007) compared the timing of gaze transfer from a stepping target in two groups of older adults, deemed to be at a high-risk and a low-risk of falling, and in young adults during a precision stepping task. They found that high-risk adults transferred gaze to future stepping constraints earlier than the low-risk group and young adults. This early gaze transfer occurred before heel contact with the stepping target and the extent of early gaze transfer correlated with increased mediolateral foot placement variability. These findings are in line with those of Reynolds & Day (2005) who found that visual occlusion of a pre-planned step at foot-off can lead to decreased step accuracy and increased step variability. This decline in stepping performance indicates that visual information is used in an online manner to fine-tune foot placement during target stepping.

Gage et al. (2003) showed that anxiety induced by manipulating the postural threat posed to participants (i.e. raising the height of the walking surface) led to decreased performance on a secondary task. They concluded that anxiety led to a greater allocation of attentional resources to the walking task. Furthermore, it has been recently shown that high-risk older adults prematurely transfer their gaze from current stepping targets toward future obstacles. This early gaze transfer is correlated with state anxiety, and there is a consequent reduction of stepping performance (Young et al., 2011). Instructing older adults to delay gaze transfer until after foot contact during a precision stepping task can improve stepping performance (Young & Hollands, 2010). However, in a fixed laboratory environment there are no unexpected variables to adapt to, and

instructing older adults to fixate their current steps during daily activities might not be a practical method of reducing falls risk when external factors require attention.

When planning a strategy for obstacle avoidance, Patla and Vickers (1997) showed that during a 10-metre walk with a single obstacle, participants primarily visually sampled the upcoming obstacle during the approach phase. Gaze direction was also focussed on future step areas when stepping over the obstacle, rather than the concurrent task. This gathering of visual information before stepping allows time to plan appropriate responses to stepping constraints. In the current study, we ask how allowing increased planning time will affect precision stepping and gaze behaviour during an obstacle avoidance task.

Crowdy et al. (2002) have shown that route rehearsal by saccadic eye movements improved locomotor performance in cerebellar patients, however the improvements shown in this study might be due to an increase in oculomotor function, rather than better spatial mapping. To our knowledge, no previous studies have examined the effect of visual route previewing of stepping obstacles on stepping accuracy and variability in a healthy older population. A prolonged planning phase could reduce the attentional load of concurrent stepping and planning, and allow greater focus on stepping precision and maintaining balance.

We hypothesise that altered gaze behaviour observed in older adults is due to an anxiety-mediated reduction in the amount to which they pre-plan their locomotor adjustments.

This study aimed to assess if 1) previewing the route results in changes to older adult gaze behaviour during walking to more closely resemble that of younger adults, 2)

whether changes to gaze behaviour are mediated by state anxiety, and 3) whether changes to gaze behaviour are accompanied by improvements in stepping accuracy.

We predicted that route previewing would reduce the instances and extent of premature gaze transfer from the stepping target in older adults and that this would result in more accurate and less variable stepping. We also expected altered gaze behaviour to be accompanied by a reduction in anxiety and increased self-confidence.

6.2 Methods

6.2.1 Participants

Nine healthy young adults and nine community-dwelling healthy older adults were recruited to take part in this study. Young adults were volunteer PhD students from The University of Birmingham's Sport & Exercise Sciences department (23 – 29 years old). Older adults (65 – 87 years old) were recruited from local assisted living homes, and from poster advertisements placed around the local area. Older adults were compensated £20 for their time plus travel expenses. All participants received a study information sheet prior to attending the lab and signed consent forms on arrival stating that they understood the study, what was required of them, and that they could drop out at any time. Full ethics approval was granted by The University of Birmingham Ethics Committee for the study.

Participants were excluded if they had any self-reported musculoskeletal or neurological impairment, or if they were on prescription medication for anxiety or vestibular problems. The use of corrective lenses was allowed in this study if the participant usually wore them for everyday locomotion, however participants were excluded if they wore bifocals or varifocals due to incompatibility with the Dikablis head-mounted eye-tracker, and their suitability for lower-field walking tasks (Davies et al., 2001; Lord et al., 2002).

A series of visual and psychophysiological tests were completed prior to any walking trials to ensure participants were suitable to take part (Table 6-1, see Chapter 2.3 for details on each test).

Table 6 – 1: General Participant Characteristics and Test Scores

Measure: Mean (Std dev)	Young Adults *(n = 9)*	Older Adults *(n = 9)*
Age *(years)*	25.44 (1.81)	77 (8.29)
Height *(cm)*	177.44 (7.30)	162.67 (10.22)
Weight *(kg)*	75.24 (8.50)	67.60 (9.00)
Body Mass Index	23.54 (1.45)	25.56 (2.67)
Shoe Length *(cm)*	29.11 (2.42)	27.11 (1.62)
Shoe Width *(cm)*	10.44 (1.16)	9.83 (0.87)
Snellen Visual Acuity *(min score)***:**		
Left Eye Only	≥20/30	≥20/50
Right Eye Only	≥20/30	≥20/50
Both Eyes	≥20/20	≥20/40
Pelli-Robson Contrast Sensitivity Score *(max 2)***:**		
Left Eye Only	1.73 (0.13)	1.48 (0.19)
Right Eye Only	1.78 (0.12)	1.5 (0.20)
Both Eyes	1.88 (1.11)	1.74 (0.19)
Berg Balance *(/56)*	56 (0)	52.78 (6.51)
TUG Test *(secs)*	7.45 (0.36)	11.11 (2.33)
FES-I *(/48)*	1.33 (1.00)	5.22 (7.07)
ABC *(%)*	98.19 (2.11)	88.46 (19.10)
Trail Making A *(s)*	21.98 (4.13)	47.66 (24.67)
Trail Making B *(s)*	42.12 (6.10)	148.77 (142.7)
Δ Trail Making *(s)*	20.14 (4.26)	101.29 (112.29)
Mini-Mental State *(/30)*	29.78 (0.44)	27.33 (1.94)
GHQ-28 *(/21 each)***:**		
Somatic Symptoms	4.44 (2.65)	4.56 (2.92)
Anxiety/Insomnia	4.22 (2.86)	5.44 (2.65)
Social Dysfunction	4.22 (2.44)	5.78 (0.97)
Severe Depression	0.33 (1.00)	0.56 (1.33)

6.2.2 Data Collection

An adapted version of the Vicon lower-body plug-in gait model was used in this study with an additional 2 markers on the medial and lateral sides of each foot, and the toe markers were moved forward to the upper front edge of each shoe. Additional details of marker placement can be found in Chapter 2.5. A 100Hz 13-camera Vicon MX motion capture system was used to record body kinematics (Oxford Metrics, England).

A head mounted Dikablis monocular eye-tracker was used to record spatial and temporal gaze behaviour, sampling at 25Hz. The Dikablis system generated a video image of the visual scene with gaze direction superimposed as a crosshair for each trial. Saccadic timings were recorded using a BlueGain EOG Biosignal Amplifier (Cambridge Research Systems, England), sampling at 1000Hz across separate vertical and a horizontal channels. This signal was synced to the Vicon kinematic recordings via a near infrared input channel using a custom Matlab script (The Mathworks Inc., United States, see Chapter 2.6). Heart rate was recorded using an Oregon Scientific strapless heart rate monitor (Oregon Scientific, UK).

6.2.3 Protocol

The general protocol for each session follows the same principles mentioned in previous chapters (see Chapter 2.2 for more detail). There were three trial difficulties used in this study, these were: (1) no obstacles following the target box (Target Only – TO), (2) one obstacle following the target box (One Obstacle – OO), and (3) two obstacles following the target box (Both Obstacles – BO). Participants completed 6 trials of each difficulty in two separate sessions on the same day, and were allowed four familiarisation trials of each difficulty prior to starting the recorded trials. In each session, participants were required to

stand on a start line facing away from the course, then turn 180° to face the course with their eyes shut and, when instructed, either open their eyes and start immediately ('Go' trials), or open their eyes and preview the route for 10 seconds before being told to start walking ('Preview' trials). When previewing the route, participants were told to plan their steps and examine the course in order to step most accurately and avoid the obstacles.

Preview and Go trials were completed in separate sessions on the same day, and their order was randomised and counterbalanced across all participants. The three trial difficulty blocks within each session (TO, OO and BO) were also completed in a random order.

Following each set of 6 trials, participants' heart rate was recorded and they were asked to complete a State Anxiety Inventory (SAI) of 6 questions, and the Immediate Anxiety Measurement Scale (IAMS) in relation to how they felt during the trials they had just completed. These responses were later compared against baseline measures taken at the start of the session following the familiarisation trials.

6.2.4 Data Analysis

Step accuracy was calculated in both mediolateral and anteroposterior planes with relation to the orientation of the target box using the foot markers and markers placed on the corners of the target box (see Chapter 2.5.1). Both the mean (step accuracy) and the standard deviation (step variability) of target box steps were analysed.

Occurrences of the right foot visibly touching or hitting the target box were recorded as frequency per set of 6 trials.

Foot contact and toe off events within the target box were identified using the heel and toe markers' vertical acceleration profile as explained in Chapter 2.5.1. This method allowed differentiation of the target box stepping strategy used by each participant on a trial-to-trial

basis. Participants either made floor contact with their heel or toe first. The percentage of toe-first steps was recorded for each set of 6 trials.

Stance duration inside the target box was also calculated as the time between foot contact and toe-off.

A 3 x 2 x 2 (task difficulty x preview condition x age) mixed design ANOVA was used to identify any main effects or interactions of stepping characteristics relating to the target box. Leading and trailing foot toe clearance on the near obstacle was measured for trials where the near obstacle was present.

Spatial and temporal visual behaviour analysis was carried out using the D-Lab Eye-Tracking suite (Ergoneers GmbH, Germany). Blink artefacts were removed prior to analysis using the software's in-built algorithm. Three areas of interest (target box, near obstacle and far obstacle) were marked out on-screen in relation to real-world adjacent visual markers identified by the software, and fixation periods within these areas were calculated. Fixation was classified at 3 frames of video, which is equivalent to 120ms and falls within the normally accepted range of fixation period (Patla & Vickers, 1997). Preview and walking sections were separated into different outputs. Two dependent variables were extracted from these data: (1) total duration spent fixating an area, and (2) percentage of the trial or section spent fixating an area. Mixed-design repeated measures ANOVAs were used to analyse the Dikablis eye-tracking data. Within subject differences of task difficulty was removed from ANOVA analysis as each difficulty had a different number of visual targets to fixate, and comparisons between these would be invalid. Therefore, independent t-tests were used to analyse between-subject differences in preview fixation periods on the target box, near obstacle and far obstacles. The Bonferroni correction was applied to all p values analysed in the t-tests.

Saccadic timings were calculated by temporally synchronising the EOG signal to the Vicon data, then by using the previously identified foot contact time as a reference for the appropriate saccadic eye movement (see Chapter 2.6.1), averaged for each set of 6 trials, and analysed in a 3 x 2 x 2 repeated measures ANOVA.

The anxiety score from the SAI was scored out of a possible 12 (see Chapter 2.3.3). The Immediate Anxiety Measurement Scale (IAMS) was also used. The questionnaire directly asks participants to rate their anxiety, and was excluded from the studies presented in Chapters 4 and 5 due to the explicit nature in which it asks participants to rate their anxiety levels, which might have alerted participants to our anxiety manipulations. Any changes in anxiety in the current study would be due to indirect influences; therefore it was included in order to examine self-reported anxiety and self-confidence in greater detail. IAMS scores were split in to two sections. Section A was on a Likert scale of 1 – 7 and related to cognitive anxiety, somatic anxiety and self-confidence. Section B described on a scale of -3 to +3 whether that person found their relative presence or lack of each item in section A to be debilitative or facilitative. These scores were also based on change from baseline levels and gave 6 variables for each of the 6 sets of trials. Change from baseline for heart rate data following each set of trials was also calculated. SAI, IAMS and heart rate data were all analysed using a 3 x 2 x 2 repeated measures ANOVA.

Correlation analysis comparing at least one non-parametric variable (IAMS, SAI, target hit frequency and toe-first stepping percentage) was carried out using Spearman's Rank Correlation Coefficient. If both variables were parametric (stepping error and variability, stance duration, gaze transfer time and target fixation time) then Pearson's Product-Moment Correlation Coefficient was used. All correlation analyses were two-tailed. *P*

values were adjusted using the Bonferroni correction for multiple comparisons; only correlations with a p value less than .003 are reported.

6.3 Results

A summery of the results can be found in Table 6-2. All values presented in this section are means ± standard error unless otherwise stated.

6.3.1 Anxiety

There was a main effect of session on self-reported IAMS self-confidence change from baseline score ($F_{(1,\ 16)} = 6.84$, $p < .05$). Self-confidence was significantly higher in 'preview trials' compared to 'go trials' (.44 ± .27 and .13 ± .30 respectively *(mean ± standard error)*, Figure 6-1).

There were no main effects for somatic and cognitive anxiety IAMS scores (Table 6-2), however there was a significant age x session interaction for cognitive anxiety direction change from baseline ($F_{(1,\ 16)} = 4.75$, $p < .05$). Older adults rated their current level of cognitive anxiety (regardless of value) to be more beneficial to their stepping performance during 'preview trials' than during 'go trials' (0.26 ± 0.32 and -0.37 ± 0.31 respectively), young adults showed no difference between sessions (Figure 6-2b).

There was a main effect of task difficulty on heart rate change from baseline ($F_{(1,\ 16)} = 3.78$, $p < .05$). Post hoc tests showed that heart rate during TO trials (0.06 ± 1.11bpm) was significantly lower than the OO (2.1 ± 1.2bpm) difficulty, but not from BO (1.6 ± 1.4bpm).

There were no between-subject or within-subject significant differences in scores on the state anxiety inventory.

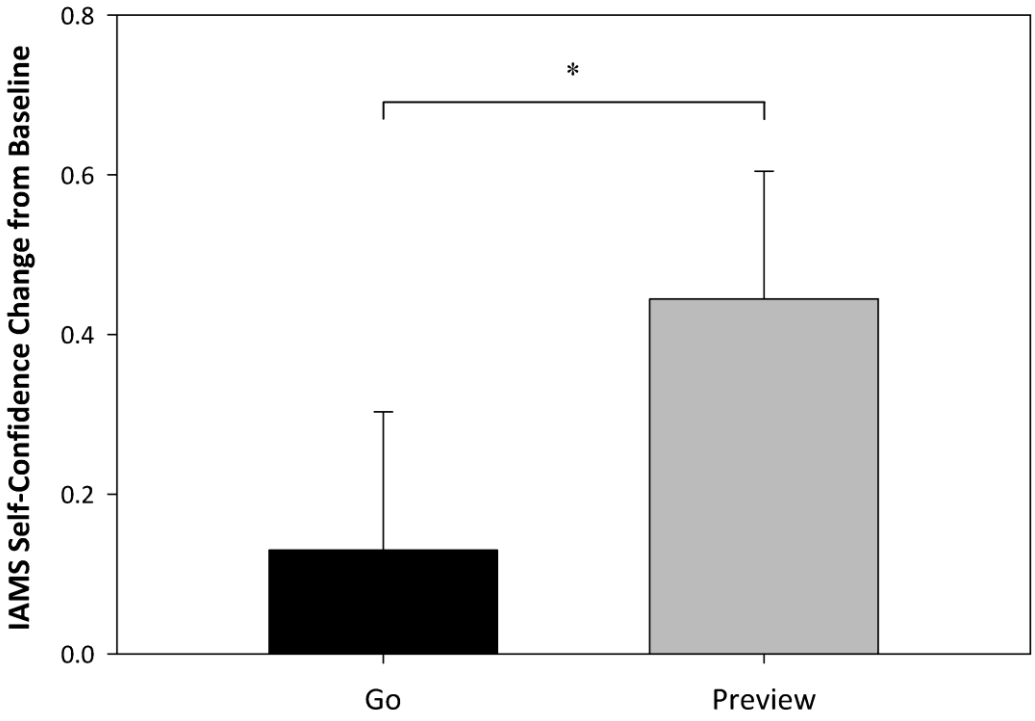

Figure 6-1 IAMS self-confidence scores as a change from baseline for each session and both age groups. Error bars represent standard errors (SE). * Sig. session difference $p < .05$

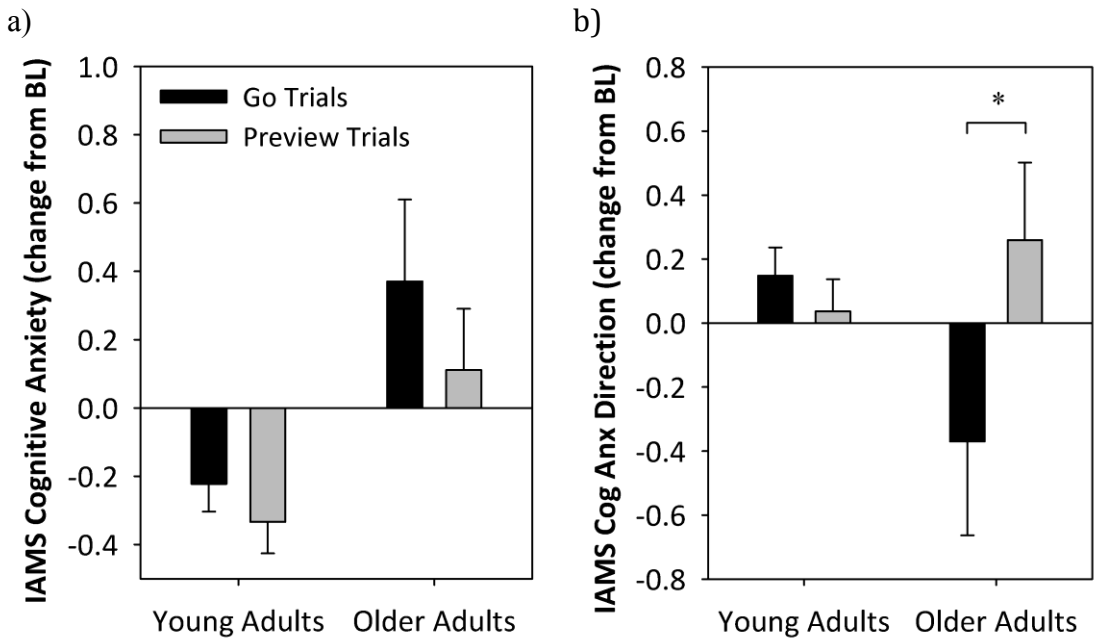

Figure 6-2 a) IAMS cognitive anxiety change from baseline for age and session. b) The change from baseline measures of the psychological direction that participants perceived their cognitive anxiety to be assisting them with their stepping performance. If it was facilitating performance the score was positive, and if it was debilitating performance the score was negative. Graph a) has been included to show the levels of anxiety to which graph b) was scored. * main effect of session within the age group, *p* < .05. Error bars show standard error.

6.3.2 Kinematic Measurements

There was a main effect of age ($F_{(1, 16)} = 8.58$, $p = .01$) and difficulty ($F_{(1, 16)} = 120.43$, $p < .001$) on trial walk duration. Older adults took significantly longer to complete the course than young adults (9.96 ± 0.57 and 7.62 ± 0.57s respectively). Increasing task difficulty produced longer walk durations (TO = 8.13 ± 0.39s, OO = 8.69 ± 0.39s and BO = 9.54 ± 0.42s). All walk duration under different difficulties were significantly different from each other ($p < .001$).

There were also main effects of age, session and difficulty on mean walking speed ($F_{(1, 16)} = 3.78$, $p < .05$, $F_{(1, 16)} = 5.74$, $p < .05$, and $F_{(2, 32)} = 125.62$, $p < .001$). Young adults were significantly quicker than older adults (0.93 ± 0.04 and 0.74 ± 0.04ms^{-1} respectively), 'preview trials' were slower than 'go trials' (0.82 ± 0.03 and 0.86 ± 0.03ms^{-1} respectively), and each task difficulty was significantly different from the other two, with decreasing speeds as difficulty increase (TO: 0.90 ± 0.03ms^{-1}, OO: 0.84 ± 0.03ms^{-1}, BO: 0.77 ± 0.03ms^{-1}, $p < .001$). Walking speed was added as a covariate to the indicated analyses below, to account for any changes in speed between groups or conditions.

6.3.2.1 Mediolateral and Anteroposterior Stepping Accuracy and Variability

Repeated measures ANCOVA showed a main interaction of session and difficulty on mediolateral (M/L) stepping variability within the target box ($F_{(2, 30)} = 4.115$, , $p < .05$) . Compared to the 'go trials', 'preview trials' showed significantly less M/L stepping variability in each individual task difficulty (Figure 6-3).

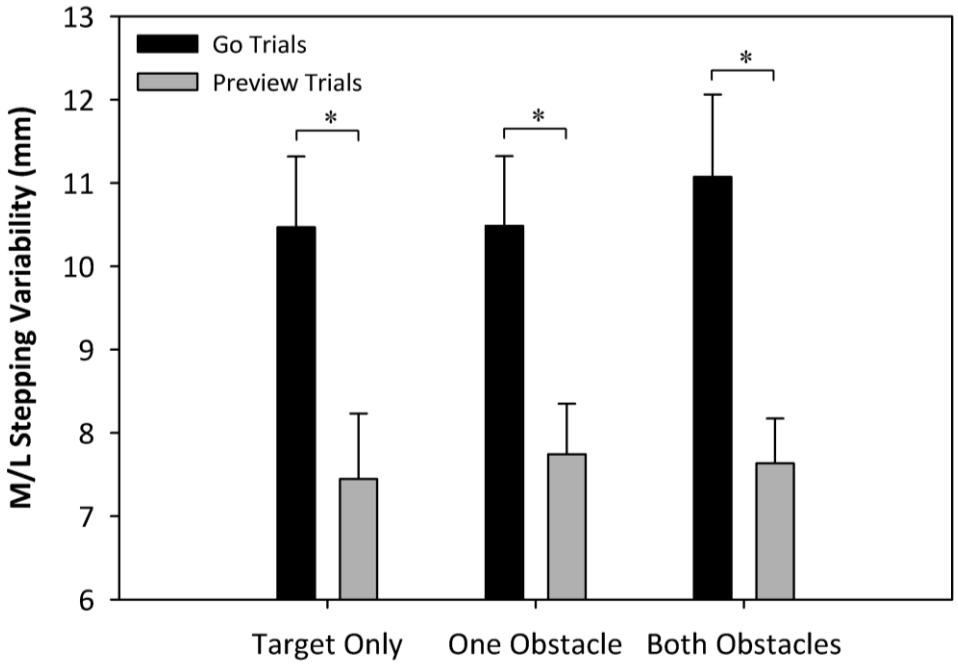

Figure 6-3 Mediolateral stepping variability of each session within each task difficulty. * Sig. difference between sessions, $p < .01$. Error bars represent standard error (SE).

There were no significant differences between age groups, sessions or difficulties in mean M/L stepping error, however there was a main effect of age on anteroposterior (A/P) stepping error ($F_{(1, 15)} = 7.08$, $p < .05$). Older adults (-23.0 ± 3.3mm) stepped significantly further back than young adults (-9.3 ± 3.3mm). There was also an interaction effect of age and session on A/P stepping error ($F_{(1, 15)} = 5.30$, $p < .05$). Post hoc tests revealed a significant difference between young and older adults during go trials, and older adults stepped with significantly less error in 'preview trials' compared to 'go trials' (Figure 6-4). There was no significant effect of any variable on A/P stepping variability.

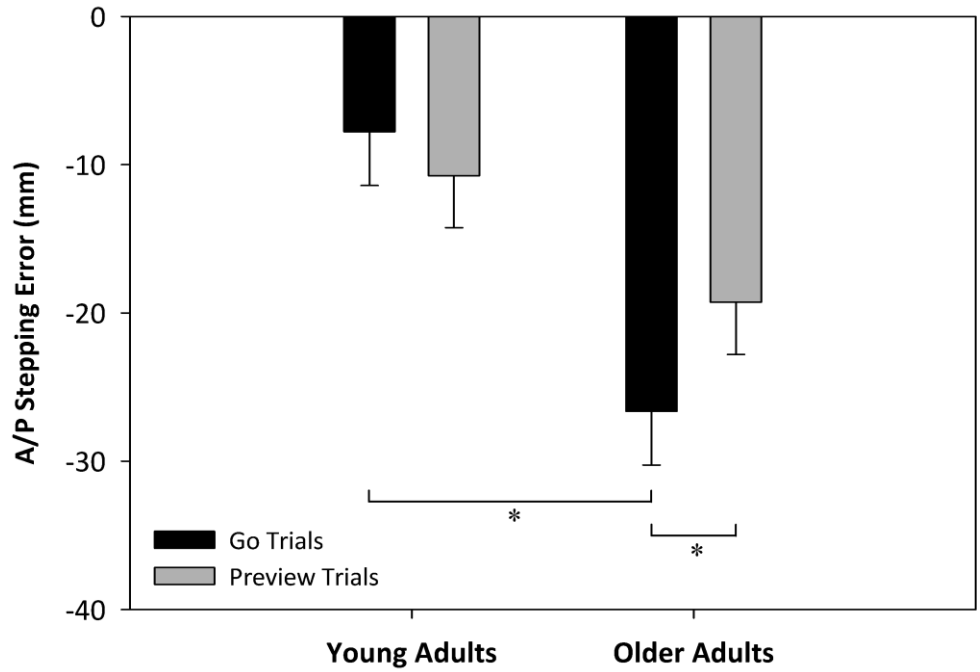

Figure 6-4 Anteroposterior stepping error in each session for young and older adults. Negative numbers indicate posterior stepping. * $p < .05$ for indicated conditions and groups. Error bars represent standard error.

6.3.2.2 Target Box Hit Frequency

When walking speed was added as a covariate, we found no significant differences between age group, session or task difficulty on target box hit frequency.

6.3.2.3 First Obstacle Toe Clearance

An independent t-test showed older adults to be significantly shorter than young adults ($t_{(16)} = 3.53$, $p < .005$), therefore a repeated-measures ANCOVA with height (valued at 170.6cm) and walking speed as covariates was used to compare differences in obstacle toe clearance in OO and BO task difficulties. There was a main effect of difficulty on lead toe clearance ($F_{(1, 14)} = 5.49$, $p < .05$) showed slightly greater toe clearance during OO trials (15.6 ± 0.9mm) than BO trials (15.4 ±.08mm) when adjusted for height and walking speed. There were no significant differences for group, session or difficulty on trailing toe clearance with height and walking speed as covariates.

6.3.2.4 Target Box Step Technique

Some participants approached the precision stepping task using a 'toe-first' strategy rather than the usual 'heel-first' strategy generally observed in normal locomotion (heel contact). Converting the frequency of 'toe-first' steps in each set of trials to a percentage, a repeated-measures ANCOVA revealed a main effect of age on the technique used ($F_{(1, 15)} = 4.788$, $p < .05$). Older adults used the 'toe-first' technique in 69.4 ± 13.1% of trials, whereas young adults only used this approach in 24.4 ± 13.1% of trials. However, previewing the route did not change the step technique used in young or older adults (Figure 6-5).

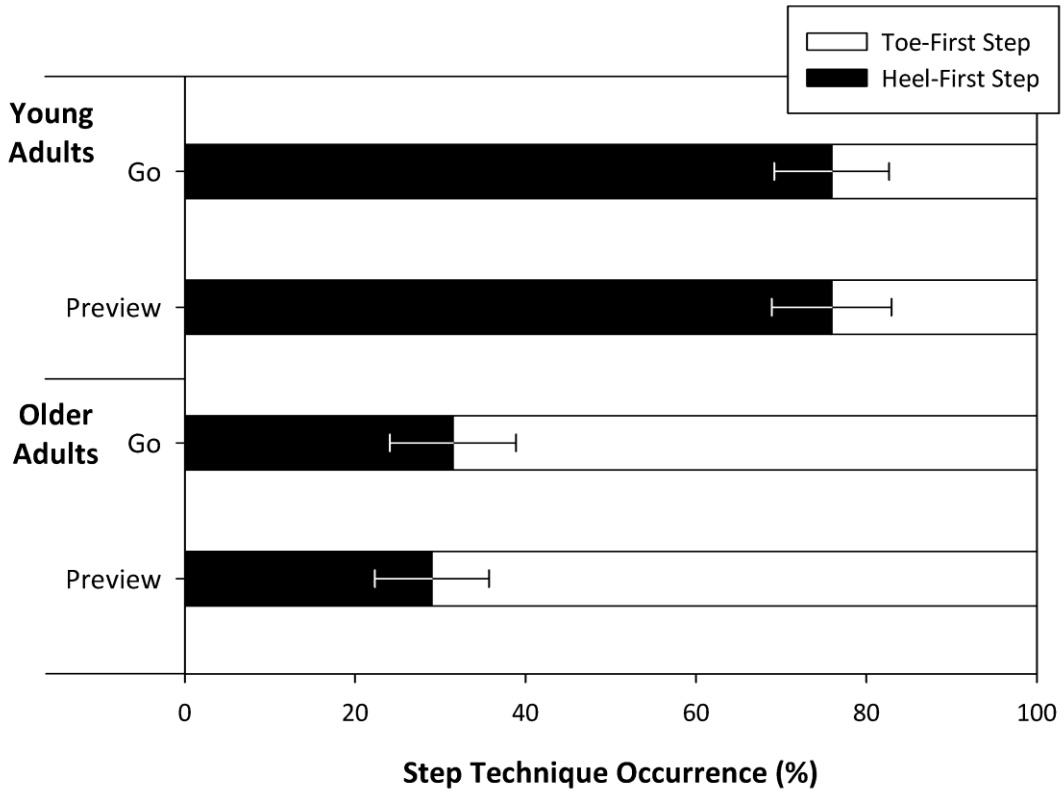

Figure 6-5 The occurrence of heel-first and toe-first foot contact in the target box as a percentage of each session. There was a significant difference of age, but no significant within-subject variations. Error bars represent standard error.

6.3.3 Gaze Behaviour

6.3.3.1 Target Box and Obstacle Fixations While Previewing

Task difficulty was excluded from gaze fixation analysis due to the nature of the task. Previewing trials with more obstacles require participants to fixate more visual targets; therefore comparisons between these task difficulties would be invalid.

There were slight variations in preview times due to the reaction times of verbally signalling participants to start walking, however these variations were not significantly different between age groups ($t_{(52)}$ = 0.50, p = .62). Independent t-tests using the Bonferroni correction for multiple comparisons showed no significant differences of age on target box, near obstacle, or far obstacle fixation times. Figure 6-6 shows fixation differences between young and older adults.

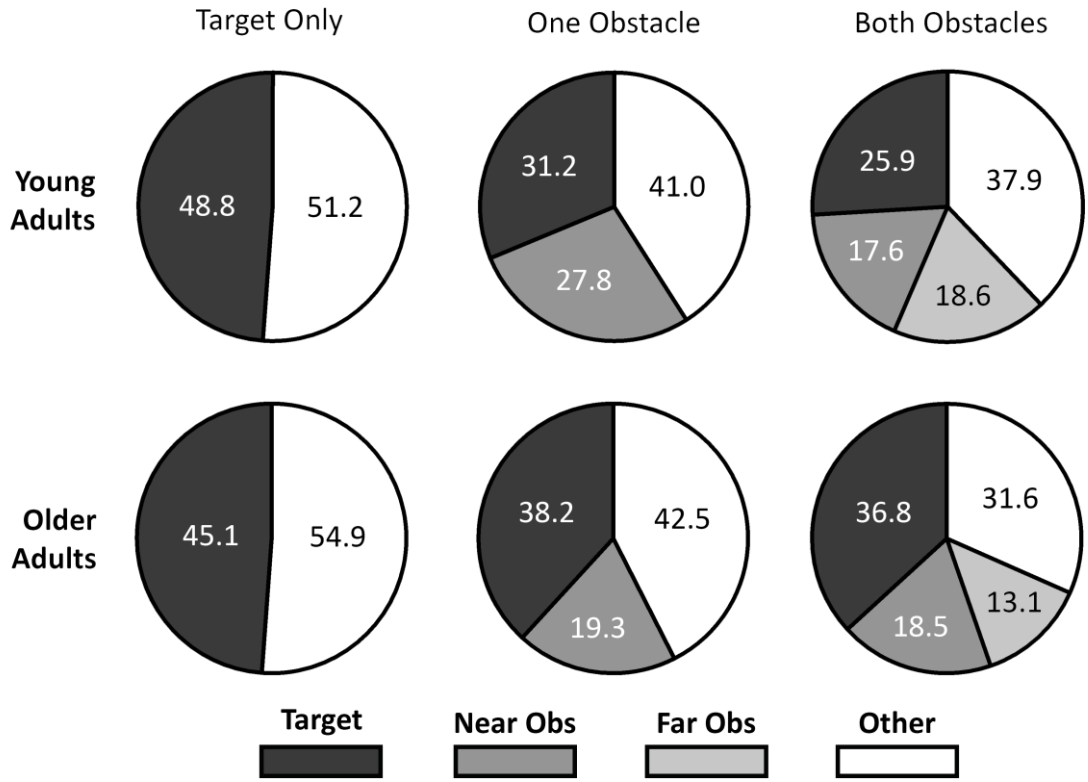

Figure 6-6 Pie charts summarising the percentage of preview time spent fixating the target, near and far obstacles (where present). Values represent percentage of preview time.

6.3.3.2 Target Box Fixations While Walking

In order to compare the relative fixation times due to the difference between young and older adults' walk times, total target fixation was calculated as a percentage of total walk time. There was a main effect of session on target fixation percentage ($F_{(1, 16)} = 11.67$, $p < .01$), with 'preview trials' resulting in a longer fixation percentage than 'go trials' (26.0 ± 1.0% and 22.8 ± 1.1% respectively). This time-relative fixation analysis reveals that during

preview trials older adults fixate the target box for a similar percentage of walk time as young adults (Figure 6-7).

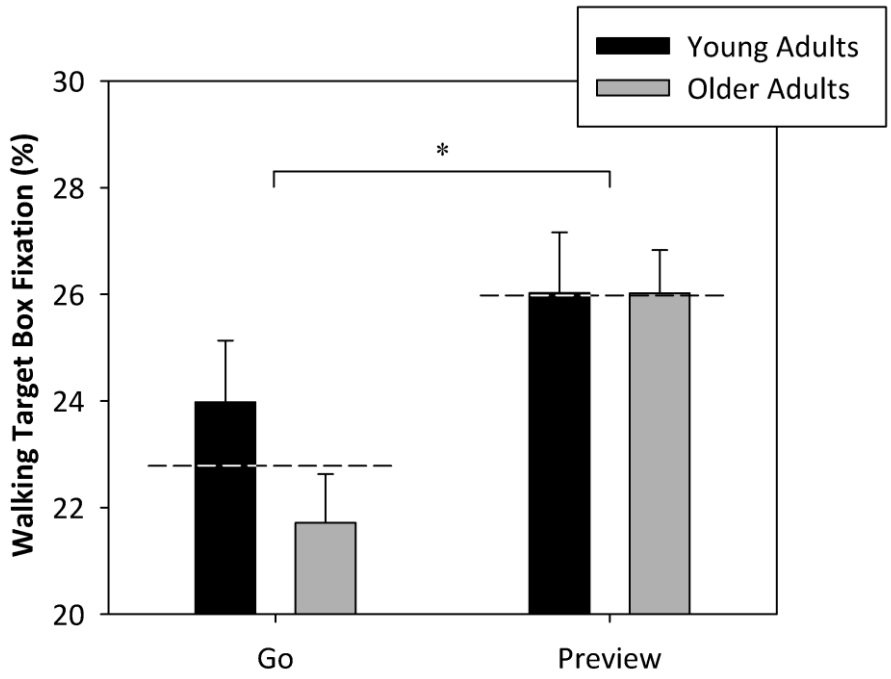

Figure 6-7 Total target box fixation period while walking and as a percentage of total walk time for young and older adults in both sessions. Dashed lines represents collapsed mean for each session. * Sig. difference between sessions, $p < .05$. Error bars represent standard error.

There was also a main effect of difficulty on target box fixation time ($F_{(2, 32)} = 44.65$, $p < .001$). Post hoc analysis revealed that the target box was fixated for longer in the TO (27.7 ± 1.0%) trials compared to OO (23.6 ± 1.1%) and BO trials (22.0 ± 0.8%) $p < .001$).

6.3.3.3 Obstacle Fixations While Walking

As expected there was a main effect for difficulty on near obstacle total fixation time between OO (12.0 ± 0.8%) and BO (8.9 ± 0.7%) conditions ($F_{(1, 16)} = 28.04$, $p < .001$). TO trials were not included as there was no near obstacle present to fixate on.

There were no significant differences between far obstacle fixations for age group, session or difficulty.

6.3.3.4 Gaze Transfer Time From Stepping Target

The start of saccadic eye movements were identified from the vertical EOG trace when angular velocity was over $100°s^{-1}$. Temporal differences between saccade initiation and foot contact are reported. Negative numbers indicate that gaze transfer took place before foot contact, and positive numbers indicate that it took place after (Figure 6-8).

There was a main effect of age on gaze transfer time with respect to foot contact in the target with walking speed as a covariate ($F_{(1, 15)} = 7.44$, $p < .05$). Older adults (-105 ± 41ms) transferred gaze significantly earlier than young adults (71 ± 41ms).

Standard deviation of gaze transfer time was used as a measure of gaze transfer variability. When walk speed was added as a covariate, there was a main effect for age ($F_{(1, 15)} = 6.44$, $p < .05$). Older adults had a higher gaze transfer standard deviation (167 ± 21ms) compared to younger adults (84 ± 20ms) meaning that older adults' had a more variable saccade time relative to foot contact. There was also a main effect of session on gaze transfer variability with walk speed as a covariate ($F_{(1, 15)} = 10.88$, $p < .01$). Interestingly, participants had greater gaze transfer variability during 'preview trials' (131 ± 16ms) than during 'go trials' (120 ± 11ms).

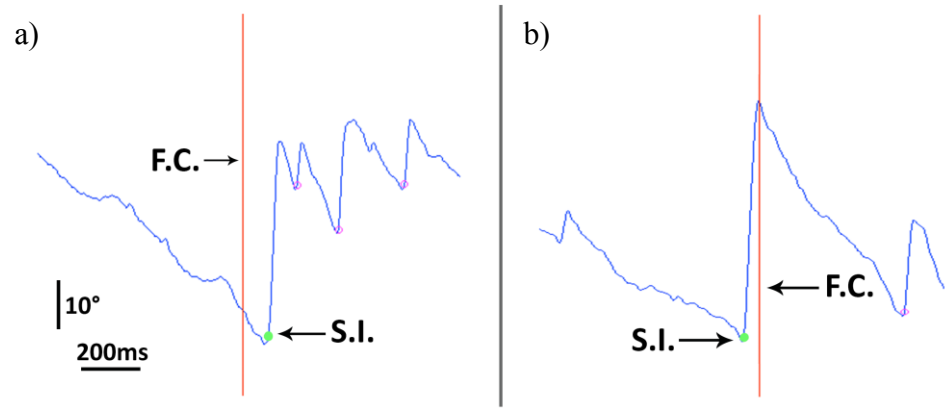

Figure 6-8 Example EOG data for a young adult (a) and an older adult (b). The x-axis represents time, and the y-axis represents eye rotation within the head. The vertical red line represents foot contact (F.C.) in the stepping target. The green dot represents saccade initiation (S.I.), identified as when the rotational velocity of the eye surpassed 100°s^{-1}. Figure a) shows an example of gaze transfer occurring after foot contact, figure b) shows and example of gaze transfer occurring before foot contact.

6.3.4 Anxiety, Gaze Behaviour and Stepping Performance Correlations

The following sections show correlations between variables of different types for older adults and young adults separately. Correlations between similar variables (i.e. SAI and IAMS as measures of anxiety) are not shown.

6.3.4.1 Older Adults

A/P stepping error was correlated with IAMS cognitive anxiety scores ($r_{s\ (54)}$ = .43, p = .001, Figure 6-9a), and with target fixation duration during walking ($r_{(54)}$ = .50, p < .001, Figure 6-9b) and target fixation during preview ($r_{(27)}$ = .58, p = .001).

Gaze transfer time was correlated with IAMS somatic anxiety scores ($r_{s\,(54)} = -.49$, $p < .001$, Figure 6-9c). Target fixation percentage during preview and walking was also positively correlated ($r_{(27)} = .65$, $p < .001$, Figure 6-9d).

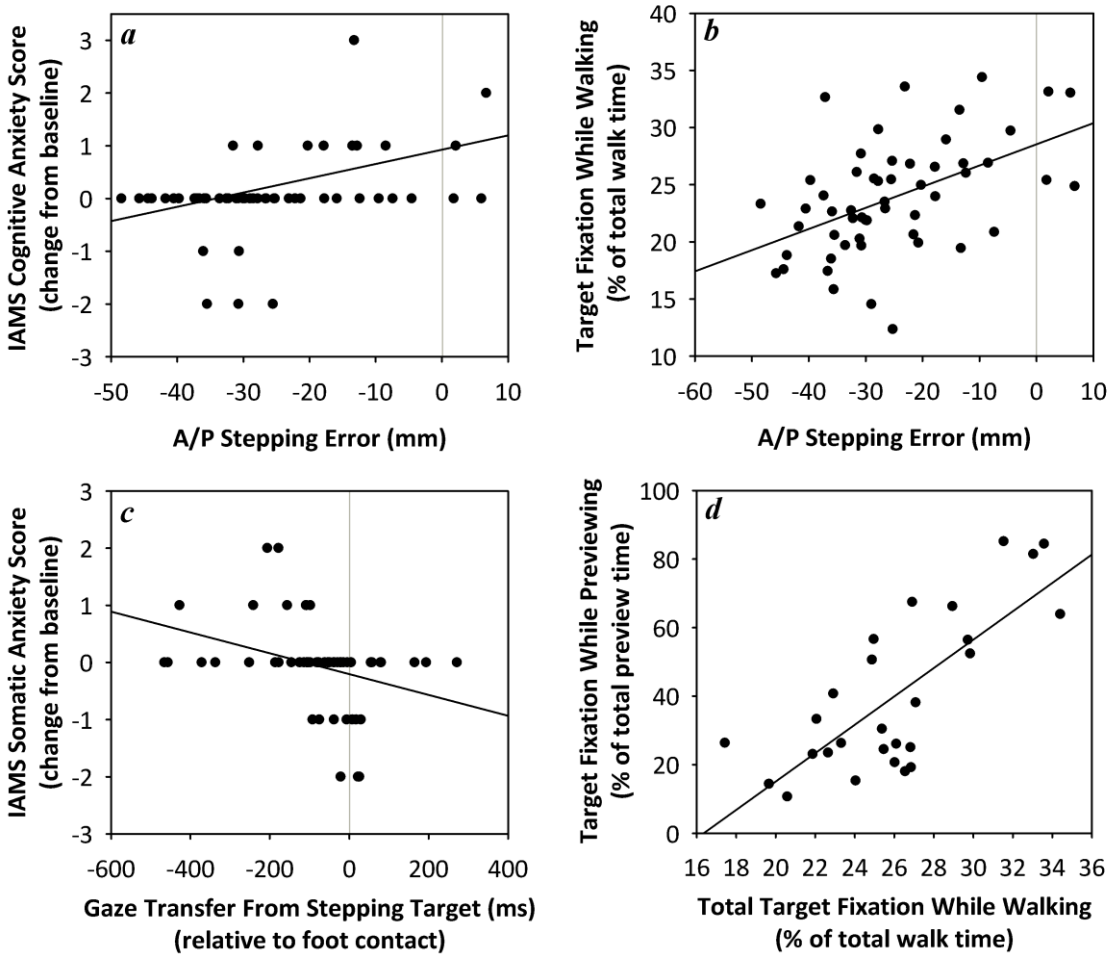

Figure 6-9 Older adult correlations between: a) mean anteroposterior stepping error and IAMS cognitive anxiety score change from baseline, b) mean anteroposterior stepping error and the percentage of total target fixation while walking relative to walk time, c) gaze transfer time (saccade initiation) from the current stepping target and IAMS somatic anxiety score change from baseline, and d) percentage of total target fixation while walking and percentage of total target fixation while previewing.

6.3.4.2 Young Adults

A/P stepping error was correlated with toe-first stepping technique ($r_{s\,(54)}$ = -.43, p = .001, Figure 6-10a), and target box hit frequency was correlated with SAI scores ($r_{s\,(54)}$ = .54, p < .001). Time spent fixating the target during preview was correlated with walking target fixation time ($r_{(54)}$ = .62, p = .001, Figure 6-10b).

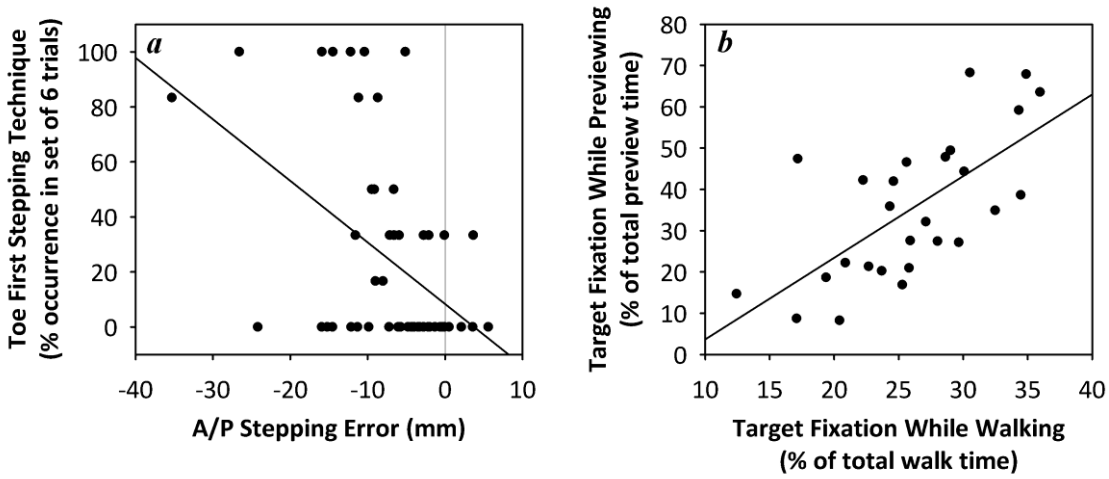

Figure 6-10 Young adult correlations between a) mean anteroposterior stepping error and the percentage of trials in which the toe-first stepping technique was used, and b) percentage of total target fixation while walking and percentage of total target fixation while previewing.

Table 6-2 Means and standard errors for anxiety measures, gaze behaviour and stepping performance.

means ± standard deviation	Go		Preview	
	YA	OA	YA	OA
Anxiety Measures				
IAMS Cognitive Anxiety	-0.22 ± 0.42	0.37 ± 1.24	-0.33 ± 0.48	0.11 ± 0.93
- Direction	0.15 ± 0.46	-0.37 ± 1.52 [4]	0.04 ± 0.52	0.26 ± 1.26
IAMS Somatic Anxiety	-0.19 ± 0.40	-0.11 ± 0.58	-0.26 ± 0.45	0.00 ± 0.96
- Direction	-0.04 ± 0.44	-0.04 ± 0.98	0.00 ± 0.39	0.07 ± 1.52
IAMS Self-Confidence [1]	0.30 ± 0.72	-0.04 ± 1.65	0.37 ± 0.63	0.52 ± 1.55
- Direction	0.07 ± 0.27	0.11 ± 1.09	0.07 ± 0.27	0.26 ± 1.35
SAI	0.04 ± 1.45	-0.04 ± 1.74	-0.15 ± 1.06	-0.41 ± 2.52
Gaze Behaviour				
Saccade Timing *(ms)* [2]	50 ± 138	-77 ± 114	44 ± 142	-86 ± 174
Saccade Variability [1 2] *(ms)*	89 ± 51	151 ± 109	96 ± 78	166 ± 152
Walking Target Fixation [1] *(%)*	23.98 ± 6.00	21.71 ± 4.74	26.02 ± 5.92	26.02 ± 4.20
Stepping Performance				
A/P Stepping Error *(mm)*	-6.66 ± 6.74 [3]	-27.76 ± 12.64 [4]	-7.38 ± 8.22	-22.64 ± 13.58
A/P Stepping Variability *(mm)*	14.71 ± 6.48	14.43 ± 5.77	6.09 ± 5.66	7.31 ± 5.89
M/L Stepping Error *(mm)*	-7.83 ± 8.06	-7.40 ± 10.87	-8.99 ± 6.59	-11.36 ± 7.92
M/L Stepping Variability *(mm)*	9.32 ± 2.80	12.03 ± 4.47	3.52 ± 3.94	4.28 ± 4.84
Stance Duration *(s)*	0.77 ± 0.07	0.87 ± 0.11	0.82 ± 0.08	0.96 ± 0.22
Toe First Stepping [2] *(% of trials)*	24.07 ± 35.00	68.52 ± 38.49	24.07 ± 36.49	70.99 ± 34.77
Leading Foot Toe Clearance *(mm)*	18.77 ± 4.98	12.49 ± 2.17	17.67 ± 5.83	13.17 ± 4.21
Trailing Foot Toe Clearance *(mm)*	17.95 ± 6.40	10.92 ± 4.24	15.35 ± 5.29	9.60 ± 7.05
Target Hit Frequency *(per 6 trials)*	0.22 ± 0.51	1.07 ± 1.17	0.04 ± 0.19	0.63 ± 0.97
Walk Time	7.47 ± 0.89	9.58 ± 2.14	7.77 ± 0.82	10.33 ± 2.80

[1] = sig. overall difference between 'Go' and 'Preview' trials

[2] = sig. overall difference between age groups

[3] = sig. difference between age groups within the same session

[4] = sig. difference between sessions within the same age group

N.B. Raw values only – changes to the due to covariance analysis are not presented

6.4 Discussion

This study investigated the effects of previewing a route prior to walking on anxiety levels, stepping performance, and gaze behaviour in young and older adults performing an adaptive locomotor task. Improvements in these measures following route previewing would suggest that the effects of anxiety on visually guided walking is mediated by reduced visuomotor planning due to inadequate visual scanning of the environment during walking. We observed a significant increase in self-confidence during preview trials, as well as a directional change in the facilitatory perception of cognitive anxiety for older adults (older adults felt that their anxiety levels were more beneficial to their performance). These changes were accompanied by a reduction in mediolateral stepping variability for both groups (Figure 6-3) and a reduction of anteroposterior stepping error for older adults (Figure 6-4), as well as and increase in target fixation duration during walking (Figure 6-7). We also showed a negative correlation between gaze transfer time and somatic anxiety in older adults, indicating that earlier gaze transfer from the current stepping target occurred more when participants were more anxious (Figure 6-9c).

6.4.1 Previewing Effects on Anxiety

During preview trials we measured a significant increase in the IAMS self-confidence change from baseline score across all participants (Figure 6-3). This indicates that during preview trials participants were more confident about the walking task, presumably due to the increased spatial information acquired allowing a spatial map to be formed. Zettel et al. (2007) have previously shown that during unexpected perturbations, previous spatial information can be used to make appropriate motor corrections to maintain balance. Our results suggest that this spatial mapping can be utilised from the preview time to allow

increased focus on the task at hand, hence increasing self-confidence. We also showed that older adults perceived their current level of cognitive anxiety to be more beneficial to their stepping performance (Figure 6-4); a trait that has been previously shown to be beneficial to putting performance in golfers (Chamberlain & Hale, 2007). There were no significant differences in IAMS somatic or cognitive anxiety, or state anxiety inventory scores between sessions or task difficulties. We suggest that the absence of a significant change in anxiety, compared to the measured increased in self-confidence is due to the possible variance available for each measure at baseline. If a participant reported low anxiety during the 'go trials', the amount that anxiety scores can reduce during 'preview trials' is limited. The same could be said for self-confidence, however due to the novelty of the task, most participants did not report maximum self-confidence during the 'go trials'. Furthermore, both the young and older adults in this study would classify as being at a low-risk of falling (Berg et al., 1992; Podsiadlo & Richardson, 1991), and therefore would not exhibit as much anxiety regarding this task as previously found in high-risk older adults (Young et al., 2011).

We also found a main effect of task complexity on heart rate, indicating that participants had less physiological arousal in TO trials compared to OO trials; this might be due to greater exertion from more stepping obstacles. As mentioned in previous chapters, heart rate is a very crude measure of sympathetic CNS activity, and must be interpreted with caution as a measure of anxiety, especially as there were no accompanying changes in self-reported anxiety measures.

6.4.2 Previewing Gaze Behaviour

There were no main effects of age on target or obstacle fixation times during route previewing. However when interpreting mean total percentage of fixation time (Figure 6-6) we can see a trend that older adults fixated with a bias towards more immediate stepping constraints (a greater percentage of time fixating the target box) when compared to younger adults. This trend has previously been identified in high-risk older adults with increased state anxiety compared to low-risk individuals (Young et al., 2011; Young & Hollands, 2012b) and supports the idea that there is an age-related prioritisation of more immediate stepping constraints, even prior to initiating locomotion.

6.4.3 Walking Gaze Behaviour

There was an increase in target box fixation as a percentage of total walk time following preview trials (Figure 6-7). This suggests that during previewing time participants were able to gather and store spatial information about the course (Zettel et al., 2007), and consequently allow a longer fixation time on more immediate constraints. It has previously been shown that balance and locomotion are more attentionally demanding for older adults than for young adults (Brown et al., 1999; Li et al., 2012). We observed that following preview trials, younger and older adults fixated the target for similar proportions of their total walk time. It is possible that previewing the route alleviates some of the older adults' cognitive load during walking, resulting in gaze behaviour that more closely resembles that of younger adults.

We also found effects of task difficulty on target box and near obstacle fixation time. Target box fixation duration was significantly reduced in OO and BO trials compared to TO presumably because there are more constraints to look at in the more complex tasks.

This trend was also observed in near obstacle fixation time, as participants fixated the near obstacle more during OO than BO trials. These results demonstrate that increasing the number of stepping constraints splits the attentional load as would be expected.

We found a main effect of age on gaze transfer time relative to foot contact which was independent of walking speed; older adults transferred gaze significantly earlier than younger adults. This finding is supported by the current literature and suggests that older adults prioritise gathering information about future stepping constraints over visually guiding ongoing stepping actions (Chapman & Hollands, 2006; 2007). We also found that older adults exhibited a higher variability in the timing of gaze transfer from the target box compared to young adults (see section 6.3.3.4).

6.4.4 Stepping Performance

As expected, we found that young adults walked significantly faster than older adults throughout the study (Kerrigan et al., 1998). Therefore we used walking speed as a covariate for analysis of stepping-related variables in order to account for any speed-related differences in the data. We found a significant interaction effect of session and task difficulty on mediolateral stepping variability (Figure 6-3). Post hoc analysis revealed that mediolateral stepping variability was significantly decreased in all task complexities during preview trials. We also found an interaction of age and session that revealed that older adults significantly reduced their anteroposterior stepping error following previewing. This provides evidence that allowing more time to gather spatial information about the task results in improved stepping performance. We suggest that this is due to improved spatial awareness about where the target and obstacles are, which allows greater focus on the

current stepping tasks, as is supported by our finding that previewing increased target fixation during walking.

We also found a main effect of task difficulty on leading toe clearance. However, as previously mentioned in Chapter 4, comparisons of toe clearance between task complexities could be influenced by the design of the course. There is a relatively small stepping area between the two obstacles during BO trials that may alter the foot trajectory; therefore comparisons between task difficulties are difficult to draw clear conclusions from.

There was a difference between age groups in percentage of toe-first stepping trials. We found that young adults used this strategy significantly less often than older adults. We suggest that it is used as a method of trying to judge central stepping from the distance between the inside front of the target box and the front of the stepping foot. However, correlations between toe-first stepping prevalence and anteroposterior stepping error in young adults suggest that this technique might lead to more posterior stepping. If this study were repeated with a target that did not impose any postural threat, such as a box marked on the floor with tape, or a singular mark on the floor, we would not expect to see such a high adoption rate of this toe-first stepping technique. We propose that older adults exercise an increased caution when stepping over the rear edge and into the target area, as a potential trip or fall may be more challenging to recover from compared to their younger counterparts. Guiding a foot to the floor with the toe does not initially commit as much pressure to the step compared with a normal heel strike (Dufek & Bates, 1991), and allows for better visual guidance, and easier withdrawal of the foot should an unexpected perturbation occur underfoot. However, the benefits of adopting this toe-first stepping technique appear to be limited, if not detrimental to stepping accuracy, and future research

should examine the mechanisms and potential benefits of this selection process in further detail.

6.4.5 Conclusions

We have shown evidence that previewing a walking route allowed increased allocation of attentional resources to current steps, which produced greater online visual guidance of the foot and increased stepping accuracy. We suggest that this is due to improved spatial mapping of the environment and stepping constraints. We have also shown that preview time increases self-confidence (an aspect of anxiety), and suggest that this, along with a greater spatial map of the environment, is driving this improved allocation of gaze.

Chapter 7

General Discussion

This thesis was based on previous work that has shown that older adults display different gaze behaviour to younger adults during everyday tasks such as standing and walking from a seated position (Di Fabio et al., 2001), stepping over and on to obstacles (Di Fabio et al., 2003b; Chapman & Hollands, 2006b), and negotiating stairs (Zietz & Hollands, 2009). In particular it builds on the literature relating to suboptimal visual sampling strategies that impair stepping performance in older adults (Chapman & Hollands, 2007). Young et al. (2011) found that there is a relationship between the timing of gaze transfer from a current stepping target, and state anxiety in high-risk older adults. They found that self-reported anxiety was strongly correlated with the timing of gaze transfer, and suggested that high-risk older adults' prioritisation of future stepping constraints (Chapman & Hollands, 2007) was based on this anxiety-driven allocation of attention. We hypothesized that there were causal relationships between increased levels of anxiety, sub-optimal gaze behaviour and increased falls risk in older adults walking through complex terrain. This thesis aimed to elucidate the causal nature of these relationships by studying the effects of manipulating individuals' levels of anxiety (Chapters 4 and 5) and the extent that they previewed the route ahead (Chapter 6), on eye movements and stepping characteristics. The effects of exercises aimed at reducing anxiety and promoting optimal gaze behaviour on stepping performance were assessed.

7.1 Experimentally increasing anxiety

The first study presented in this thesis investigated whether the use of social evaluative threat during adaptive locomotion could raise state anxiety in young adults, with the intention of subsequent use on older adults. This proof of concept study aimed to see if we could (i) experimentally increase anxiety, (ii) find an appropriate physiological measure of anxiety, and (iii) show consequent effects of this increase anxiety on stepping. Social evaluative threat is a term used to describe an increase of anxiety that has been instilled from a form of social evaluation; a common method of experimentally increasing anxiety in this way is the Trier Social Stress Test (Kirschbaum et al., 1993). This involves making participants make unplanned speeches and perform mental arithmetic in front of an audience. In Chapter 3 we adapted this test to instil a more task-specific form of anxiety about stepping performance on a group of young adults. We used a panel of judges to monitor and provide feedback on walking performance during various complexities of short adaptive locomotion tasks. We also used salivary α-amylase, a biomarker of sympathetic nervous system activity, to measure physiological changes of anxiety. In this study we measured a moderate response in self-reported cognitive anxiety during judged trials, and showed a modest correlation between this cognitive anxiety and mediolateral stepping variability, with an increase in variability during the judged trials (Figure 3-3). Although the increase in anxiety during social evaluative threat trials was non-significant, these results were promising, given that young adults generally show less mediolateral variability than older adults during adaptive locomotion (Chapman & Hollands, 2006b), and show fewer anxiety-mediated errors in walking performance during increased anxiety (Brown et al., 2006). The implications of our study suggested that social evaluative threat could be used in further research with older adults to test whether anxiety-associated

attentional changes (Gage et al., 2003) would alter gaze transfer time. We also found an increase of salivary α-amylase in 5 out of 8 participants, which suggested that this measure might show an augmented response in older adults.

Our next study applied our previously described methods of inducing task-specific state anxiety to an older population (Chapter 4). Using a similar protocol to that of Chapter 3 and Young et al. (2011), we also used electrooculography (EOG) to measure the timing of gaze transfer from the target of an on-going step.

We successfully increased state anxiety during social evaluative trials as measured by self-reported SAI scores. This increase in anxiety was accompanied by increased mediolateral stepping error (Figure 4-3a), however we found no change in gaze transfer time from the current stepping target. This suggests that the increased mediolateral error may not have been due to an inappropriate allocation of attention towards future stepping constraints (Chapman & Hollands, 2007), but may have been due to other factors associated with anxiety, such as postural stiffening. Previous research has shown that postural control is tightened when participants are subject to standing at increasing platform heights, resulting in a decreased centre of pressure variability (Adkin et al., 2000; Tersteeg et al., 2012). This stiffening strategy associated with anxiety is also apparent during locomotion, and produces increased leg muscle activation, especially in older adults, that decreases stepping range (Brown et al., 2002). The anxiety induced in the current study may have caused a similar stiffening strategy during locomotion that consequently produced more medial stepping.

We also found that there was increased anteroposterior error as trial difficulty increased (Figure 4-3b), this was preceded by premature gaze transfer from the stepping target. This

finding suggest that a lack of online visual guidance of foot placement reduced anteroposterior accuracy, and is supported by previous research (Chapman & Hollands, 2006a; 2007; Reynolds & Day, 2005). Due to the relatively low-risk nature of our participant group with regards to falling, we suggest that our measures of anxiety were not able to detect increases of anxiety that have been previously associated with high-risk groups and increased task difficulty (Young et al., 2011). This suggestion is based on our previous finding in young adults (Chapter 3), and we predict that we would have seen an increase in anxiety with more challenging task complexities in older adults. Young et al. (2011) suggested that the anxiety-driven change in the allocation of attention (Gage et al., 2003) directs gaze to future stepping constraints. Another contributing factor to this anxiety-based stepping inaccuracy could be postural stiffening as previously mentioned (Adkin et al., 2000; Brown et al., 2002). More medial and posterior steps indicate a tighter control of posture during the step that may have contributed to the errors that we identified. We were unable to identify changes in anxiety between task complexities, but did show that increased task difficulty produced earlier gaze transfer and decreased anteroposterior accuracy.

To summarise, we were able to increase task-specific self-reported anxiety through use of social evaluative threat in older adults, and observed associated changes in mediolateral stepping accuracy that are indicative of a stiffening strategy. However, we did not find an associated earlier gaze transfer with increased anxiety, and suggest that gaze transfer in low-risk older adults is mediated more by a combination of task complexity and anxiety, than anxiety alone.

7.2 Reducing task-specific anxiety during locomotion

In Chapter 5 we experimentally reduced task specific anxiety in order to further understand the relationship between anxiety, gaze transfer and stepping performance. We initially intended to reduce task anxiety through use of diaphragmatic breathing and progressive muscle relaxation techniques; however, we found that these were ineffective in decreasing task specific anxiety compared to a control group. We did observe a reduction in salivary α-amylase (a measure of sympathetic nervous activity and anxiety (Nater et al., 2005)) between sessions for all participants, which still allowed us to test our original hypothesis, despite the ineffectiveness of our intervention. However, effects of learning must also be taken in to account when interpreting the results of this study as the control group was combined with the intervention group.

We found that reduced anxiety was associated with a reduction in the number of target box hits (Figure 5-2), suggesting that participants' stepping performance improved under conditions with less anxiety. However, these improvements may also have had influence from previously stored information about the task due to participant familiarity. We did not find that this improvement in stepping performance was accompanied by a delay in the timing of gaze transfer from the current stepping target, as would be expected if premature gaze transfer offered the explanation for the effects of anxiety on reduced stepping performance.

The older adults tested in this study could be considered to be at a relatively low risk of falling, as is evident from their Berg balance scores (Table 5-1). Whereas high-risk individuals are thought to exhibit earlier gaze transfer in order to plan for future steps (Chapman & Hollands, 2007), there may still be a limit to how late older adults in general

can delay their gaze transfer when compared to young adults. Yordanova et al. (2004) analysed the strength and timing of event related potentials at different stages of information processing in the brain, and demonstrated that a behavioural age-related slowing during sensorimotor tasks originates in the motor cortex, suggesting a cognitive decline with age. Therefore this cognitive decline might have created a ceiling effect that limited the possible lateness at which older adults could transfer gaze while still safely planning for further steps. It is possible then, that the reduced-anxiety related stepping-performance improvement we identified in Chapter 5 could be due to a reduction in extent to which the stiffening strategy discussed earlier in relation to increased anxiety is employed (Brown et al., 2006; Adkin et al., 2000). This means that upon returning for the second session of testing, participants were less anxious and more relaxed about the stepping task, and consequently showed improved performance regardless of any changes in gaze behaviour. However, we must also consider that this improved stepping performance may also be due to task familiarity.

7.3 The effects of previewing on stepping performance

Our results from Chapters 4 and 5 suggest that it is likely that previously identified relationships between anxiety and stepping performance are mediated by allocation of attention to environmental constraints, rather than solely mediated by gaze transfer time from the stepping target. We therefore used gaze tracking in Chapter 6 to further explore the relationship of stepping constraint fixation time between young and older adults, and how allowing a route preview time might alter gaze behaviour during walking.

Our results showed that following previewing trials, all participants' had greater self-confidence (Figure 6-1), and older adults found that their current level of cognitive anxiety

was more facilitative to their performance following previewing (Figure 6-2b). Although there was no significant decrease in older adults' previewing cognitive anxiety compared to control trials, there was some reduction (Figure 6-2a). This reduction presumably was part of the reason for their increase in their perception of how their current level of cognitive anxiety was beneficial to their performance.

Previewing the route increased target box fixation duration while walking. This increase suggests participants were able to utilise the preview time to successfully generate a spatial map of stepping constraints, which facilitated greater focus on more immediate stepping demands while walking. Zettel et al. (2007) have previously demonstrated in both young and older adults, that visual scanning of an unfamiliar environment creates a spatial map, which is then utilised during an unexpected balance perturbation to produce compensatory steps to regain balance without online visual guidance of the foot. We suggest that our experimental preview time allowed participants sufficient time to create a spatial map of the walkway, and retain it while completing the trial. This knowledge of the course layout then increased self-confidence, and reduced attentional demands, allowing better allocation of attention towards the execution of ongoing actions rather than planning future actions. This attentional strategy was evidently beneficial to stepping performance as all participants showed reduced mediolateral stepping variability, and older adults showed reduced anteroposterior stepping error.

The practical applications of route previewing for older adults in day-to-day life are very promising, however and the extent to which spatial map can be retained might be affected by age and interference from external sources. Lustig et al. (2001) showed that there is a decline in functional working memory as we age. This might transfer to retention of spatial maps during locomotion, especially in high-risk groups that exhibit higher anxiety, as this

increases the attentional demand required for locomotion (Gage et al., 2003). We therefore suggest that further research in to the effects of previewing in high-risk older adults, and under conditions of social evaluative threat needs to be carried out in order to ascertain whether the advantages of previewing can ameliorate the negative effects of anxiety. If previewing still produces a more optimal allocation of attention toward current stepping tasks (Chapter 6) under conditions of increased anxiety, then the negative effects of anxiety on locomotion (Chapter 4) can be at least partially explained by a disruption to cognitive processes associated with spatial mapping. More work needs to be done exploring the acquisition of these spatial maps in high-risk elderly, in order to develop an intervention that improves their retention by decreasing task-specific anxiety, and ultimately reduces the risk of falls in older adults.

7.4 Limitations

7.4.1 Anxiety measures

Throughout the studies presented in this thesis, anxiety was measured using various psychological and physiological measures. In Chapter 3 we found a moderate, but non-significant increase for judged trials in IAMS cognitive anxiety measures, but no such increase for the anxiety/tension subsection of the POMS, SAI, or salivary α-amylase (Table 3-1). Using the same protocol with older adults in Chapter 4, we measured a significant increase in self-reported SAI, but not for salivary α-amylase (Table 4-2). In Chapter 5 there was a reduction in salivary α-amylase between sessions, but not for the SAI (Table 5-2). And in Chapter 6 we found a significant increase in IAMS self-confidence, but no corresponding reductions in IAMS cognitive or somatic anxiety, and no reduction in SAI (Table 6-2).

This inconsistency between anxiety measures is a limitation to the research presented in this thesis. Each questionnaire offered a different way for participants to record their levels of anxiety. The IAMS used a very direct method of asking participants to rate aspects of their anxiety on a 7-point Likert scale, and showed the most promise as a reliable indicator of anxiety. However, due to this direct questioning it was not used in Chapters 4 and 5, as it was important that participants did not think the primary purpose of these studies was to manipulate anxiety. The SAI was chosen as a substitute as it asked participants questions relating to anxiety on a 4-point Likert scale, but not to rate their anxiety directly. This questionnaire showed promise when anxiety was increased in older adults due to experimental manipulation, however in the later chapters it did not show much change when participant anxiety was presumably reduced. We suggest that this was due to a combination of a ceiling effect limiting the possible reduction from a relatively low initial anxiety level, and the lower 4-point resolution of the scale when compared to the 7-point IAMS. The POMS was used in the first experiment, however, due to its length (32-items) it became apparent that participants were treating it as a box ticking exercise rather than thinking about each item following each set of trials, and was therefore dropped from further studies.

Salivary α-amylase was measured as a physiological indicator of anxiety in all but the final study presented in this thesis. While it has shown promise as a reliable measure of sympathetic nervous activity, and shown increases in response to acute psychological stressors (Rohleder et al., 2004; Nater et al., 2005; Nater & Rohleder, 2009), there is still some doubt in the reliability of these findings due to inconsistent sampling methods, participant variability, and its usefulness as a measure of anxiety (Bosch et al., 2011). While every effort was made in the studies presented in this thesis to maintain consistent

sample collection and analysis, fluctuations due to participant physical fitness and non-anxiety related emotional responses might have influenced our results. We did find a significant reduction in post-trial salivary α-amylase when participants visited the laboratory for a second time, and we suggest this was due to familiarity with the environment reducing the anxiety of participants. However we measured no significant changes in self-reported anxiety so we cannot verify that that was the reason.

A method that has previously been used as a measure of anxiety in walking older adults is galvanic skin conductance (Gage et al., 2003; Young et al., 2011). While this method of measurement is a reactive indicator of anxiety, it has shown limited practicality as a measure of low-level anxiety in low-risk older adults during similar adaptive locomotor tasks to those presented here (Young et al., 2011). For this reason it was not used as a measure of anxiety in the studies presented in this thesis. However, due to the relatively non-invasive methodology, and the ability measure galvanic skin conductance while walking, future studies should consider this as an alternative physiological anxiety measure to salivary α-amylase.

7.4.2 Low-risk older adults

The studies presented in this thesis only tested low-risk older adults due to participant availability and ability. Some high-risk participants were tested in Chapter 5, however due to the severe nature of their mobility impairments the data was confounded by having to assist them throughout the trials, also blocking Vicon markers recording limb position in the process. In order to safely test these high-risk individuals, a harness would have been necessary to stop potential falls from occurring. In addition to this, a mobile laboratory

would also have been useful in order to test individuals that did not feel safe commuting to the university, however this was not available to us at the time of testing.

7.4.3 Reducing anxiety

The anxiety reduction intervention presented in Chapter 5 did not work effectively and thus compromised the quality of the conclusions drawn. With the collapsed data across intervention and control groups, there is a confound of learning effects. While we have argued that anxiety levels were reduced in the second session, there is no direct way we can distinguish between effects of anxiety and effects of learning on stepping performance measures. Future studies should try a more intensive course of relaxation techniques, combined with cognitive therapy from a trained therapist over a number of weeks in older adults exhibiting a fear of falling. We expect that these techniques might show more promising results as is found in adults suffering from anxiety disorders (Dendato & Diener, 1986; Bastani et al., 2005).

7.4.4 Task specificity and the implications of changes to stepping performance

The design of the protocol presented in these experiments is very specific to these studies. While it is a useful method of drawing conclusions relating to the potential mechanisms of how anxiety and previewing influence gait and gaze, few direct real world applications of these findings can be implemented due to the varying conditions of everyday life. During normal walking, it is unlikely that anyone would keep their gaze fixated on their current steps, however these methods are useful for exploring the cognitive pathways that are used when stepping precisely. In addition to this, the stepping error and variability we measured is relatively small and would be unlikely to cause a stepping perturbation during day-to-

day tasks, nonetheless it is useful to measure these changes in low-risk individuals to understand how trips or falls might occur.

7.5 Summary

The work presented in this thesis has provided support that increased anxiety increases stepping errors in older adults. These errors were not directly attributable to the timing of gaze transfer from specific targets as has been suggested in high-risk older adults (Young et al., 2011). We then provided some evidence that decreased task-related anxiety improved stepping performance which was again, independent of timing of gaze transfer from targets. We therefore suggest that the mechanism by which anxiety influences stepping performance is likely to be due changes in the allocation of attention to environmental features relevant to safe progression. In our final study we assessed how previewing the walking path would address this attentional capacity deficit and allow better development of a visuospatial map. We found that previewing the route increased self-confidence, presumably as more time had been allowed to generate a spatial map of the path. This confidence was associated with longer fixation durations on relevant stepping constraints. This change in visual behaviour resulted in lengthened visual fixation on the stepping target which presumably facilitated online guidance of step placement, and consequently improved stepping performance. These findings suggest that: 1) there is an anxiety-induced age-related change in gaze behaviour that decreases the ability to generate spatial maps of our surroundings and 2) that route previewing counteracts the effects of, and ameliorates, this anxiety. Further research should aim to see how experimentally induced anxiety effects the quality and usefulness of this increased timeframe in which spatial maps are produced, and the consequent changes in allocation of attention during locomotion.

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