EXAMINING LINKS BETWEEN ANXIETY, ATTENTIONAL FOCUS, AND ALTERED CONTROL OF LOCOMOTION

A Thesis Submitted for the Degree of Doctor of Philosophy

by

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Abstract

The present programme of research sought to explore how fall-related anxiety, and resulting changes in attention, influence the control of adaptive locomotion. Six interrelated studies were conducted to achieve this aim. Studies 1–3 were conducted with young adults. In Study 1, we demonstrated that the maintenance of effective visuomotor control during adaptive gait requires cognitive resources. The results of Study 2 extended these findings and indicated that fall-related anxiety – through the likely mediator of heightened conscious movement processing – reduces the cognitive resources available for processing concurrent tasks during adaptive locomotion. Study 3 (Experiment 1) described that young adults anxious about falling display visual search patterns indicative of reduced feedforward planning. Study 3 (Experiment 2) indicated that these anxiety-related changes in visual search are a likely consequence of altered prioritisation resulting from the conscious processing of discrete stepping movements; rather than simply a reduction in the cognitive resources available for maintaining effective visual search. Studies 4–6 were conducted with older adults. Study 4 described that anxious older adults at a high risk of falling will direct attention towards worries/ruminations related to falling – in addition to consciously processing stepping movements. Study 5 provided evidence of a link between fall-related anxiety and the maladaptive visual search behaviours reported previously in high-risk older adults. Finally, Study 6 indicated that the anxiety-related visual search behaviours reported in Study 5 are likely underpinned by heightened attention directed towards consciously processing stepping movements. The present programme of research provides evidence of a link between fall-related anxiety, and associated changes in attention, and altered visuomotor control of adaptive locomotion. The findings presented herein support the importance of considering attentional mechanisms when inferring how fall-related may influence an individual’s risk of falling.

Dedication

To Chloe, for everything.

To Mum and Dad. You guys are the best.

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List of Thesis Publications

Chapter 3 published as: Ellmers, T. J., Cocks, A. J., Doumas, M., Williams, A. M., & Young, W. R. (2016). Gazing into thin air: The dual-task costs of movement planning and execution in adaptive gait. *PLOS ONE, 11,* e0166063. IF: 2.77

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Chapter 8 submitted as: Ellmers, T. J., Cocks, A. J., Kal, E. C., & Young. W. R. (Manuscript submitted). Conscious movement processing, fall-related anxiety, and the visuomotor control of locomotion in older adults. *The Journals of Gerontology: Series B, Psychological and Social Sciences*. IF: 3.42

List of Other Publications

Chow, V. W. K., **Ellmers. T. J.,** Young, W. R., Mak, T. C. T., & Wong, T. W. L. (2019). Revisiting the relationship between internal focus and balance control in young and older adults. *Frontiers in Neurology, 9,* 1131. IF: 3.55

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Ellmers, T. J., Machado, G., Wong, T. W. L., Zhu, F., Williams, A. M., & Young, W. R. (2016). A validation of neural co-activation as a measure of attentional focus in a postural task. *Gait and Posture, 50,* 229–231. IF: 2.27

List of Presentations

Invited Lectures

2017, December – *Examining links between anxiety, attentional focus and altered control of balance and gait in young and older adults*. School of Sport Health and Applied Science Research Seminar Series 2017/18, St Mary's University, Twickenham

Invited Conference Symposia

2019, June – *From basic science to clinical practice: Anxiety, attentional focus and the control of posture and gait.* International Society for Posture and Gait Research (ISPGR) World Congress, Edinburgh, Scotland.

2017, August – *Enhancing the efficacy of exergames for rehabilitation*. The 9th International Conference on Virtual Worlds and Games for Serious Applications, Athens, Greece.

Oral Conference Presentations

Ellmers, T. J., Paraskevopoulos, I., Williams, A. M., & Young, W.R. (2017). *Recalibration of perceived postural capabilities mediates post-intervention improvements in older-adult functional balance.* Paper presented at the International Society for Posture and Gait Research (ISPGR) World Congress, Fort Lauderdale, USA.

Ellmers, T. J., Paraskevopoulos, I., Williams, A. M., McIntyre, A., & Young, W.R. (2016). *The psychological factors mediating post-intervention improvements in functional balance in older-adults.* Paper presented at the North American Society for the Psychology of Sport and Physical Activity (NASPSPA) Conference, Montreal, Canada.

Ellmers, T. J., Cocks, A. J., Williams, A. M., & Young, W. R. (2015). *The dual-task costs of movement planning and execution in adaptive gait.* Paper presented at the International Society for Posture and Gait Research (ISPGR) World Congress, Seville, Spain.

Poster Conference Presentations

Ellmers, T. J., Cocks, A. J., & Young, W. R. (2017). *Exploring thoughts and attentional focus of older adult fallers under anxiety.* Poster presented at the International Society for Posture and Gait Research (ISPGR) World Congress, Fort Lauderdale, USA.

Chapter 1: Introduction to the Programme of Research

Older adult falls are a major public health concern. They are the leading cause of injury, and mortality from injuries, among those aged 65 years and older (Centers for Disease Control and Prevention, 2016). One-third of adults aged 65 years and above fall at least once annually, with this figure increasing to 50% for those aged 80 years and older (Lord, Ward, Williams, & Anstey, 1993; Tromp et al., 2001). Falls, and fall-related injuries, can affect older adults in numerous ways, including reduced mobility, activity restriction, and loss of independence (Białoszewski et al., 2008; Hadjistavropoulos, Delbaere, & Fitzgerald, 2011). All of factors can increase the likelihood of further falls occurring. Indeed, once an older adult experiences their first fall, there is a 66% chance that they will suffer a second fall within a year (Nevitt, Cummings, Kidd, Black, 1989).

In 2013, the UK annual health costs from fall-related injury exceeded £2.3 billion (National Institute for Clinical Excellence, 2013). However, with the percentage of the worldwide population aged 60 years and older estimated to almost double to 21.5% by the year 2050 (United Nations, 2015), the cost of hospitalisation following older adult falls is also expected to rise. Accordingly, identifying factors that make certain older adults more susceptible to falls is an important public health challenge and represents the necessary first step in the development of methods designed to reduce the economic and societal burden of falls in older adults.

1.1 Causes of Falls in Older Adults

Older adults most commonly fall while walking (Berg, Alessia, Mills, & Tong, 1997; Blake et al., 1988; Robinovitch et al., 2013), with trips, slips and misplaced steps accounting for the large majority of incidences (Berg et al., 1997; see Figure 1.1). These findings suggest that older adult falls may frequently represent an inability to adapt foot placement in response to environmental demands usually specified by visual information, such as a hazardous object occurring in the walking path.

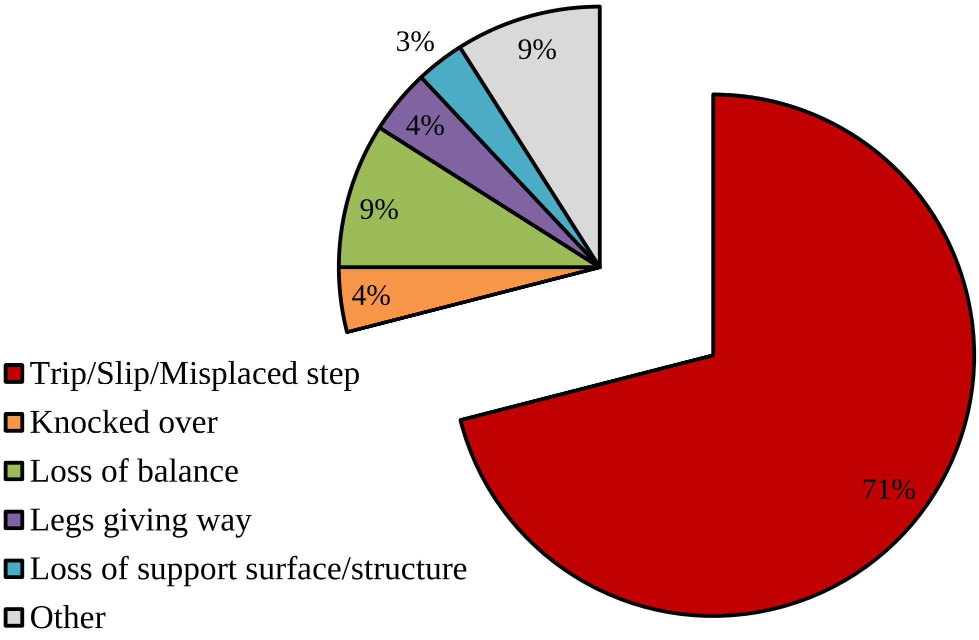

Figure 1.1. Frequency of different causes of older adult falls (adapted from Berg et al., 1997).

While other senses, such as the proprioceptive and vestibular system, play an important role in the reactive control of balance (i.e., detecting and subsequently reacting to a loss of stability), the visual system allows us to identify threats to our balance and proactively adapt our stepping movements to avoid the site of potential perturbation altogether (Patla, 1997, 1998). Unsurprisingly, decline in visual function is a well-established predictor of older adult fall risk (Beurskens & Bock, 2012; Lord, 2006; Lord & Dayhew, 2001). However, falls in older adults relating to an inability to adapt one’s movements in response to an environmental hazard are unlikely to be fully attributable to age-related decline in visual function. For example, despite a general absence of visual deficits, Hollands and colleagues (Chapman & Hollands, 2006b, 2007; Young, Wing, & Hollands, 2012) have reported “maladaptive” patterns of visual search during adaptive gait (i.e., gaze behaviours causally associated with increased stepping errors; Young & Hollands, 2010) in older adults who are deemed to be at a high-risk of falling. Specifically, such individuals will prioritise the planning of future stepping actions, at the expense of guiding on-going actions (e.g., prematurely transferring their gaze away from an environmental constraint they are currently navigating, in order to fixate future obstacles). The magnitude of these premature gaze transfers associated with increased stepping errors and, therefore, reduced safety.

While an individual's ability to effectively negotiate an environmental hazard will undoubtedly also be dependent on their physical functioning, these high-risk gaze behaviours – and subsequently increased stepping errors – are more frequently attributed differences in psychological processing. Specifically, researchers have speculated that these maladaptive behaviours may result from heightened fear of falling and subsequent changes in attentional focus (i.e., Staab, 2014; Young & Williams, 2015; Young et al., 2012).

1.2 Fall-Related Anxiety and Increased Fall Risk

Anxiety, defined as "an aversive emotional and motivational state occurring in threatening circumstances" (Eysenck, Derakshan, Santos, & Calvo, 2007, p. 336), is a common occurrence in our daily lives. It can influence how we think (e.g., worrisome thoughts), how we feel (e.g., racing heart or restlessness), and, ultimately, how we behave (e.g., "choking" under pressure or attempting to avoid the source of anxiety [Nieuwenhuys & Oudejans, 2012]). However, there is also a large degree of individual difference when it comes to the situations which can trigger anxiety. For an individual to become anxious, they must first appraise the situation as being a threat to their current goals (Lazarus, 1991); which can account for individual differences in anxiety responses. Indeed, researchers often distinguish between state and trait anxiety (Spielberger, 1972), with state anxiety referring to the current level of anxiety felt, which in turn is influenced by an individual's trait anxiety (a trait propensity to perceive a situation as threatening and respond with state anxiety [Eysenck, 1992]). It is worth noting that fear and anxiety are traditionally viewed as related, yet distinct constructs (Rachman, 1998). For example, an individual may always be fearful of public speaking (i.e., a trait characteristic), but yet would only experience anxiety in anticipation of, or during, the public speech itself (i.e., a state response). However, within the domain of gait and posture, fear of falling is treated as both a trait characteristic (e.g., Delbaere et al., 2010; Hadjistavropoulos et al., 2011) and a state response (e.g., Huffman, Horslen, Carpenter, & Adkin, 2009; Young et al., 2012; Zaback, Cleworth, Carpenter, & Adkin, 2015). For example, a healthy, active individual may have little concern about falling in their everyday life, yet may still become fearful of falling when walking on a slippery, unstable surface; although an individual’s trait fear of falling will likely influence the degree to which they perceive a situation as threatening their balance, thus mediating, to some degree, the state anxiety response (Hadjistavropoulos et al., 2011). Accordingly, fear of falling is treated as both a trait and state construct within this thesis.

Fall-related anxiety, or fear of falling, is common in community dwelling older adults, with estimations of its frequency ranging from 29%–77% (Hadjistavropoulos et al., 2011). The relationship between fear of falling and increased fall risk is well documented (Friedman, Munoz, West, Rubin, & Fried, 2002; Hadjistavropoulos et al., 2011; Young & Williams, 2015), and heightened anxiety is related to a 53% increase in the likelihood that an older adult will fall (Hallford, Nicholson, Sanders, & McCabe, 2017). Research highlights fear of falling as both a consequence and a predictor of falls (Friedman et al., 2002), indicating that once an older adult has fallen, they may become trapped in a vicious cycle of heightened anxiety, which then increases their likelihood of future falls.

Traditional conceptualisations of the relationship between fear of falling and increased falls are based on the notion that individuals who are anxious about falling are more likely to avoid activities during which they could fall, such as walking down stairs or visiting a crowded shopping area (e.g., Brummel-Smith, 1989). These conceptualisations propose that it is then this activity avoidance that increases the likelihood of falling, with these individuals becoming deconditioned to walking outside, thus resulting in the development of poorer balance. However, rather than indirectly increasing fall risk – as proposed by these traditional conceptualisations – recent research instead suggests that fall-related anxiety may lead directly to behavioural adaptations which increase the likelihood of a fall occurring (e.g., Hadjistavropoulos et al., 2011; Young & Williams, 2015). Despite preliminary research that supports this notion (e.g., Young et al., 2012), the specific mechanisms and behaviours through which fall-related anxiety may reduce safety during walking remain largely unknown.

1.3 Thesis Overview

This thesis seeks to explore how fall-related anxiety, and associated changes in attentional focus, influence the (visual) planning and execution of dynamic stepping movements during human gait. The adaptive locomotor movements examined in this body of work will primarily concern precision stepping; whereby the walker has to adapt their movements to step accurately onto a target. To understand how these psychological factors alter the production of such movements, it is first necessary to evaluate causal changes in a healthy young adult ‘model’ unaffected by countless confounding factors related to age or fall risk (such as cognitive decline or deficits in visuomotor processing). Consequently, the first half of the thesis evaluates changes in young adults during manipulations designed to induce either fall-related anxiety or altered attentional focus (Chapters 3–5), before attempting to translate these findings to an older adult population (Chapters 6–8).

These experimental chapters are presented as progressively linked, yet standalone, papers adapted from work that has either been published in, or submitted to, peer-reviewed journals (see previous page xvii for information detailing this published work). Thus, while this thesis presents a progressive narrative through subsequent chapters, each experimental chapter is also intended to represent an independent, standalone study. Consequently, each experimental chapter features its own self-contained introduction, which summarises the relevant literature needed to contextualise that particular study.

1.4 Structure of the Thesis

This General Introduction is followed by a critical review of the literature relevant to this programme of research (Chapter 2). The Review of Literature discusses topics such as: the relationship between anxiety and perceptual-motor performance within the broader context; visuomotor control of balance and gait, and; current evidence illustrating behavioural adaptations made when anxious about falling. Particular focus is placed on discussing these results with reference to existing psychological theories. Finally, the Review of Literature introduces the specific aims and hypotheses of the thesis.

Chapter 3 explores the impact of reduced attentional resources on the visual scanning behaviours of young adults during adaptive locomotion. As this walking path featured various stepping constraints, this study allows us to assess whether movement planning during adaptive gait requires attentional resources.

Chapter 4 investigates whether fall-related anxiety reduces the attentional resources available for carrying out tasks concurrent with walking in young adults. This study also explores potential mechanisms through which fall-related anxiety might reduce attentional resources; namely, increased internal focus of attention/conscious movement processing.

Chapter 5 is a multi-experiment study. Experiment 1 examines the effects of fall-related anxiety on how young adults visually scan a walking path containing a series of stepping constraints. This experiment also explores how these changes in visual search might subsequently impact stepping behaviours when negotiating these constraints. Experiment 2 scrutinises possible attentional mechanisms underpinning these anxiety-related behavioural changes. Previous chapters highlight that fall-related anxiety can lead to both heightened conscious movement processing and reduced attentional resources. Therefore, Experiment 2 investigates whether visual search behaviours comparable to those reported in Experiment 1 are observed during conditions of: (a) internal focus of attention/conscious movement processing; and (b) reduced attentional resources.

Chapter 6 employs a retrospective verbal reports protocol to provide a detailed account of the changes in attentional focus that occur when older adults are anxious about falling. This chapter also seeks to determine whether a previous fall alters how older adults allocate attention when anxious.

Chapter 7 explores the extent to which the maladaptive patterns of visual search observed previously in high-risk older adults can be attributed to increased fall-related anxiety. Specifically, this chapter compares visual search strategies between low- and high-risk (e.g., repetitive fallers, poor balance ability, etc.) older adults during an adaptive gait task at ground level (i.e., low levels of postural threat). It then seeks to establish whether any observed “high-risk” patterns of gaze behaviour (and associated behavioural consequences) can be induced in the low-risk participants during conditions of experimentally induced fall-related anxiety (walkway elevated 0.6 m without a safety harness).

Chapter 8 explores whether anxiety-related alterations in visual search observed during Chapter 7 are a likely consequence of either: (a) heightened conscious movement processing; or (b) other anxiety-related changes in attention (such as a gaze bias for external threatening stimuli).

Finally, Chapter 9 provides a general discussion that both summarises and connects the findings from the eight experimental chapters. The theoretical and applied implications of this work are then presented. This chapter culminates in the presentation of new conceptual model (*The Gait-Specific Model of Threat Perception*) that seeks to account for how fall-related anxiety alters the visuomotor control of locomotion. Particular importance is placed on describing the situations in which these anxiety-related changes might reduce safety when walking. Limitations of this programme of research are also identified, and directions for future work are discussed.

Chapter 2: Review of Literature

This programme of research explores how fall-related anxiety, and subsequent changes in attention, influence the (visuomotor) control of locomotion. Given the broad scope of the research areas needed to contextualise the experimental work contained in this thesis, the Review of Literature is presented in the format of a narrative review, rather than multiple smaller, structured systematic reviews. This review begins by first examining the relationship between anxiety, attention, and broad perceptual-motor performance (e.g., far-aiming sporting tasks). This general overview then transitions into a critical assessment of the existing research exploring anxiety's influence on: (a) standing balance; (b) walking behaviours; and, more specifically, (c) the visuomotor control of adaptive locomotion. Finally, the theoretical basis of anxiety's effects on locomotor control is also examined.

2.1 Anxiety and Perceptual-Motor Performance

Effective use of perceptual information to plan and guide action – a skill defined as perceptual-motor processing (Nieuwenhuys and Oudejans, 2012) – is crucial for much of daily living. Perceptual-motor processing is required to *effectively*[1] perform actions as varied as reaching for a glass of water, climbing out of the shower, walking along a busy street and kicking a ball. It is well accepted that anxiety can disrupt cognitive processing, with seminal research from the 1980s elucidating the ways in which anxiety can negatively impact performance in a range of cognitive tasks, such as mental arithmetic and memory tasks (Eysenck, 1982, 1985, 1989; Eysenck, MacLeod, & Mathews, 1987). However, the past 25 years have seen researchers also explore the varied and largely detrimental effects that

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[1] Albeit, theoretically, it would be possible to perform such actions in the absence of perceptual information, performance effectiveness will undoubtedly be maximised through the use of such information. Thus, for the purpose of this thesis, perceptual-motor actions will be defined as any action guided by – or optimised through the use of – perceptual information obtained from the environment (Gibson, 1979/1986).

anxiety can have on perceptual-motor behaviour (Eysenck & Wilson, 2016; Janelle, 2002; Nieuwenhuys & Oudejans, 2012; Wilson, 2008); a logical trend when considering the different domains that require effective perceptual-motor processing during high pressured situations (e.g., surgery, military, sport, etc.).

The large majority of what we know about anxiety's influence on perceptual-motor processing is derived from work that has sought to answer why high-pressure sporting situations (e.g., taking a penalty kick in a championship final) often lead to a break-down in perceptual-motor performance. Although there are numerous competing theories that seek to explain the anxiety–performance relationship (see Section 2.5 for a review), it is generally accepted that the disruptive effect of anxiety on perceptual-motor performance is likely underpinned by alterations in attentional allocation (Beilock & Carr, 2001; Eysenck & Wilson, 2016; Masters & Maxwell, 2008; Niewenhuys & Oudejans, 2012).[2]

Nieuwenhuys and Oudejans (2012) view perceptual-motor behaviour as a self-repeating process consisting of: (a) the perception of both task-relevant information and action possibilities (*perception*); followed by (b) the selection of the action (*selection*); and (c) the subsequent use of information to guide movement execution (*action*). While technically distinct, there is some debate as to the overlap between these different processes. This is particularly pertinent to continuous movements, such as walking (rather than tasks requiring a single, discrete perceptual-motor action; e.g., a golf-putt), whereby these processes will likely be ongoing and occur simultaneously. (See Section 2.4.1 for further discussion.)

The first two processes (perception and selection) within Nieuwenhuys and Oudejans (2012) conceptual framework can be broadly categorised as "action planning",

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[2] While attention is a challenging construct to define, for the purpose of this thesis, the term will be used to refer to the selective processing (i.e., the prioritisation or inhibition) of information (Carrasco, 2011).

while the third process (action) can be categorised as “action execution/control”. In *The Integrated Model of Anxiety and Perceptual-Motor Performance*, Nieuwenhuys and Oudejans (2012) suggest that anxiety influences each of these processes. The sections that follow will, in turn, describe the evidence that highlights the influence of anxiety on perception, selection and action during perceptual-motor performance.

2.1.1 *(Action) Perception*

In ecological psychology (Gibson, 1979/1986), perception refers to “…the active pickup of information specifying affordances, that is, the behavioral possibilities offered by the environment (also called action possibilities or behavioral potential)” (Pijpers, Oudejans, Bakker, & Beek, 2006, p. 132). Indeed, perceptual-motor actions are often performed in complex environments, which require the performer to effectively prioritise task-relevant stimuli and ignore various distracters. However, research illustrates that anxiety can impair the efficiency of visual scanning behaviours prior to movement execution (for a review, see Janelle, 2002). In general, anxious individuals have been shown to be more easily distracted by task-irrelevant, threatening information (Nieuwenhuys & Oudejans, 2012; Wood & Wilson, 2010), consequently fixating task-relevant information for shorter durations (Nibbeling, Oudejans, & Daanen, 2012; Wilson, Vine, & Wood, 2009). For example, Wilson, Wood and Vine (2009) found that anxious footballers made earlier and longer fixations towards the goalkeeper when preparing to take a penalty kick, at the expense of fixating on the empty areas of the goal where they wished to kick the ball. Unsurprisingly, these alterations in gaze behaviour resulted in decreased shooting accuracy, with participants shooting significantly closer to the goalkeeper. Research also illustrates that anxious individuals need increased time to detect task-relevant visual information during perceptual-motor actions (Nieuwenhuys, Pijpers, Oudejans, & Bakker, 2008).

In addition to influencing *what* visual information is acquired during perceptual-motor processing, Nieuwenhuys and Oudejans (2012) also suggest that anxiety may influence *how* this information is perceived, with anxious individuals argued to be more likely to interpret neutral situations or stimuli as threatening. This suggestion is supported by research from perceptual psychology which describes how individuals in heightened emotional states (including fatigue and anxiety) are more likely to perceive action possibilities as threatening or challenging (Proffitt, 2006). As such, it is possible that a reciprocal relationship exists between anxiety and altered attention, whereby anxious individuals perceive situations/stimuli as posing greater threat, which leads to further anxiety and threat-related interpretations. Taken together, these results indicate that anxiety can influence the information that individuals direct their attention towards and acquire, and how this information is subsequently perceived.

2.1.2 *Selection*

As anxiety can influence the perception and interpretation of information during perceptual-motor actions, it has been argued that anxious individuals may subsequently fail to identify action possibilities or select alternative, threat-related actions (Nieuwenhuys & Oudejans, 2012). For example, Pijpers et al. (2005, 2006) observed marked differences in action selection when anxious individuals traversed a climbing wall. Specifically, increases in anxiety (when climbing at height) led to a reduction in perceived maximal reaching height, with anxious individuals observed using more handholds to complete the climb (i.e., selecting handholds that were closer to their body; Pijpers et al., 2006). Anxious individuals also performed more exploratory movements (i.e., information-gathering movements, such as moving their hand towards a handhold, to see whether or not it could be reached). They grasped the handholds for longer durations and made smaller, more hesitant movements (Pijpers, Oudejans, & Bakker, 2005).

These findings imply that anxious individuals, when performing perceptual-motor tasks, will select more cautious behaviours – as indicated by the execution of smaller movements over shorter distances. Follow-up research suggests that these anxiety-related alterations in action selection are unlikely be a sole consequence of individuals failing to perceive the visual information needed to select alternative actions. Rather, this research highlights that the selection of cautious behaviours may persist even when anxious performers acquire similar visual information, as during conditions of low anxiety (Nieuwenhuys et al., 2008). This indicates that these cautious behavioural adaptations may be a consequence of *how*, rather than *what*, task-relevant visual information is perceived (e.g., a threat-related interpretational biases, as described in the previous section; Nieuwenhuys & Oudejans, 2017).

2.1.3 *Action*

Following the selection of the motor response, perceptual-motor actions will typically require perceptual information to coordinate and guide – or at least optimise – the movement. Indeed, research from the domain of sport psychology demonstrates the importance of using vision to programme and fine-tune goal-directed motor responses (Vickers, 2009). For example, successful performance on goal-directed tasks (e.g., a basketball throw, golf-putt or penalty kick) is consistently characterised by a steady fixation of at least 100 ms on a specific target location or object directly prior to movement initiation (Vickers, 1996, 2007, 2009). This a phenomenon is termed *quiet eye* (Vickers, 1996). Maintaining a steady gaze on a task-relevant stimulus requires the performer to display effective attentional control in order to inhibit task-irrelevant distracters – something that is impaired by anxiety (Eysenck et al., 2007; Eysenck & Wilson, 2016). Unsurprisingly, anxiety has been shown to reliably reduce both quiet eye duration and subsequent performance effectiveness (see Payne, Wilson, & Vine, 2019, for a review). For example, Wilson, Vine et al. (2009) found that heightened anxiety reduced quiet eye durations by 34% during a basketball free-throw task, with participants exhibiting increased fixations towards various locations. These changes in gaze behaviour were accompanied by significant reductions in shooting accuracy.

Anxiety has also been shown to influence how movements are controlled and executed, irrespective of any changes in visual information used to plan and guide the action. It is well accepted that heightened anxiety during perceptual-motor actions can cause the performer to direct their attention internally, towards the conscious processing of movements, which would otherwise be “automatic” (see Masters & Maxwell, 2008, for a review; also see Section 2.5.2 for a more thorough description of “self-focus” theories of anxiety-related performance breakdown). Masters and Maxwell (2004) argued that motor output is likely to be disrupted if an expert performer uses “conscious, explicit, rule-based knowledge…to control the mechanics of movements” (p. 208).

This assumption is well-supported in the literature. Research demonstrates that attempting to consciously control or monitor perceptual-motor performance can lead to decreased movement fluency, ineffective/superfluous muscle activation, poorer movement coordination and increased pre-, and overall, movement times in a wide range of different motor tasks (Castaneda & Gray, 2007; Gray, 2004; Jackson, Ashford, & Norsworthy, 2006; Lohse & Sherwood, 2012; Masters & Maxwell, 2008; Wulf, 2013). These findings have led researchers to conclude that such conscious movement strategies can impair both efficiency and effectiveness when performing well-learned motor skills (Masters & Maxwell, 2008). As the development of expertise within the domain of motor performance is characterised by an increased reliance on implicit, ‘automatic’ processes (Masters & Maxwell, 2008), Eysenck and Wilson (2016) argue that attending to explicit movement cues represents another way in which anxiety can cause performers to become distracted by task-irrelevant information.

2.1.4 Eye Movements: Perception, Selection or Action?

While the previous sections categorise eye movements as distinct processes pertaining to either the gathering of perceptual information or the coordination of an ongoing action, the difficulty of classifying gaze behaviours within such distinct categories should be acknowledged. For example, determining whether a visual fixation towards a target during an aiming task is related to the process of gathering of information (i.e., *perception*) or the co-ordination of the motor action itself (i.e., *action*) is often difficult; given that such eye movements could be deemed to relate to each of these processes. Thus, although eye movements cannot solely be used as an indication of any one of these processes (*perception*, *selection* or *action*), given the temporal sequence of eye movements in relation to the rest of the task, it is, nonetheless, possible to infer different processes from eye movement data.

2.2 Visuomotor Control of Human Locomotion

Locomotion, whether performed by humans or other legged animals, is an integral aspect of independent living. It allows for the hunting and gathering of food, the searching of shelter or water, and the navigation of terrains that would be untraversable with wheeled vehicles (Patla, 1997). However, maintaining balance during human locomotion presents many challenges. During quiet standing (i.e., standing still), balance is maintained by ensuring that the vertical projection of the centre of mass (COM) remains within the base of support. However, during locomotion, each step is initiated with the COM moving beyond this base, thus producing a self-generated perturbation to balance, which the central nervous system (CNS) needs to accommodate to ensure that stability is maintained (Winter, 2009). Another challenge reflects the need to adapt movement patterns in response to environmental constraints that threaten balance (Higuchi, 2013). For example, a task as simple as walking along a street is likely to present various constraints that need to be navigated, such as stepping over an uneven paving stone or changing direction to avoid an oncoming pedestrian.

Modifying gait-related movements to accommodate these changes is referred to as “adaptive locomotion” (Higuchi, 2013, p. 1). Research demonstrates that the visual system is paramount in the initiation of these proactive movement adaptations (Patla, 1997, 1998). Thus, although it is *possible* to walk without using visual information relating to one’s surroundings, adaptive locomotion (and subsequent safety) will be optimised through the use of such perceptual information.

According to Patla (1997), the primary strategies employed during adaptive locomotion to avoid environmental threats to balance are: (a) modifying step length, width or height (e.g., increasing step length to land on a safe foothold or increasing ground clearance to avoid contacting a raised obstacle); (b) changing direction to steer around any constraint that cannot be stepped over, under, or between/through; and (c) terminating gait (i.e., stopping walking altogether). Research indicates that vision is used in an anticipatory manner during adaptive locomotion, allowing avoidance strategies (and subsequent gait adjustments) to be proactively employed a few steps prior to reaching the stepping constraint (Matthis, Barton, & Fajen, 2015, 2017; Matthis & Fajen, 2014). For example, when approaching an obstacle, individuals will often lengthen their stride a few steps before reaching the constraint that needs to be avoided (Moraes, Lewis, Patla, 2004). This allows the walker to step beyond the normal spot where their foot would land, successfully stepping over the obstacle without having to stop and take an extra step (Moraes et al., 2004). Similarly, recent research from Matthis and colleagues (Matthis et al., 2015, 2017; Matthis & Fajen, 2014; Matthis, Yates, & Hayhoe, 2018) suggests that vision is used in an anticipatory manner allowing adaptive avoidance strategies to be employed at least two steps prior to navigating the constraint itself.

2.2.1 On-line Control vs. Feedforward Planning

Visuomotor control of locomotion can be largely classified as either *on-line* or *feedforward*. On-line control refers to the use of visual information to guide the step as the action is ongoing, whereas feedforward control refers to the sampling of visual information in a “feedforward” manner to plan future stepping actions (Patla, 1997, 1998). While visual information can be used to make rapid, on-line adjustments once a step has been initiated (Reynolds & Day, 2005), adaptive locomotion is likely to be more stable if movements are guided through feedforward planning rather than relying solely on on-line control to make changes to foot trajectory mid-step (Matthis & Fajen, 2014). Sudden, unexpected changes in foot trajectory during stepping are both energetically inefficient and reduce stability, thereby increasing the likelihood of a fall occurring. The avoidance of such destabilising movement requires effective, feedforward movement planning.

As we walk through our cluttered world, we build a visual-spatial map of our environment (Zettel, Scovil, McIlroy, & Maki, 2007). Feedforward visual sampling allows not only for the identification of potential threats to balance, but also for the subsequent planning and execution of stepping behaviours necessary to avoid tripping. Recent research by Matthis and colleagues describes a “critical phase” for visual control of human locomotion (Matthis et al., 2015, 2017; Matthis & Fajen, 2014). In a series of studies, these authors found that collisions with obstacles became more frequent when participants were constrained to visually previewing only two step-lengths ahead or less. These findings suggest that while walkers *can* use on-line vision to control precision stepping (e.g., Reynolds & Day, 2005) visual information from at least two step-lengths ahead is needed to *effectively* navigate a stepping constraint in a safe, stable manner.

According to Matthis and colleagues (Matthis et al., 2015, 2017; Matthis & Fajen, 2014), such feedforward planning allows for the mechanical state of the body to be adjusted to optimise the trajectory of both the centre of mass and stepping leg, prior to the initiation of the precision step itself. Doing so is argued to both maximise stability and reduce the likelihood of having to produce a potentially destabilising mid-step adjustment. Based on this work, Matthis and colleagues identified the critical phase for visual control of locomotion as occurring specifically during the swing phase of the non-precision-stepping leg (i.e., during the step made with the left foot, if the subsequent step made with the right foot is a precision step over an obstacle; see Figure 2.1). Therefore, while on-line vision is often used to guide precision steps which have been pre-programmed through feedforward planning (e.g., Young et al., 2012), on-line control alone is unlikely to be sufficient to produce an accurate precision step. Consequently, failing to acquire visual information relating to a stepping constraint prior to this critical phase will likely reduce safety during locomotion by virtue of the walker having reduced ability to avoid an obstacle or step accurately onto a target.

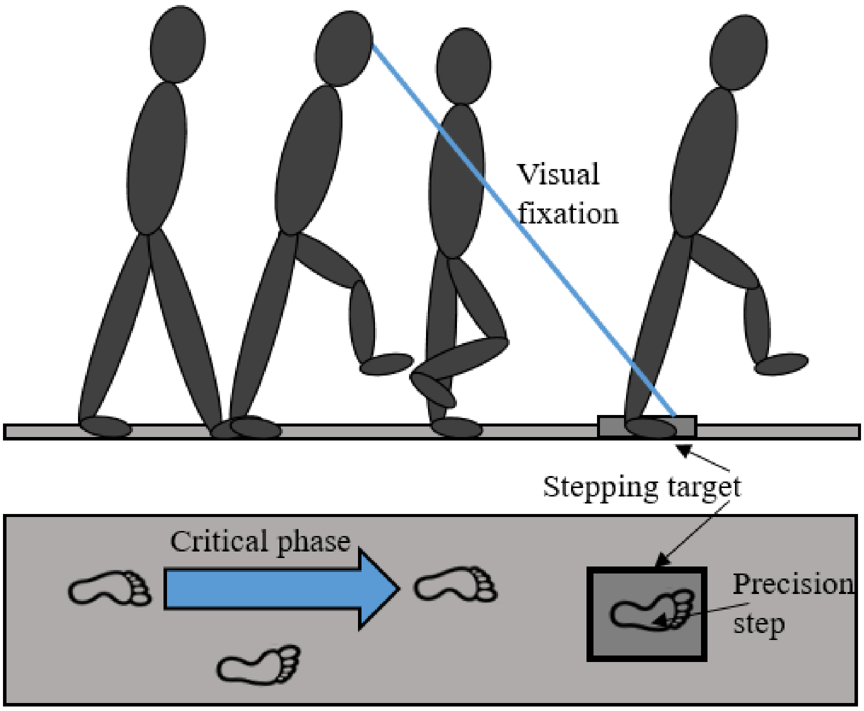

Figure 2.1. A schematic representation of the "critical phase" (blue arrow; i.e., during the swing phase of the step preceding the precision step) for acquiring visual information about an upcoming stepping constraint/precision step (as described by Matthis et al., 2017).

This section illustrates that adaptive locomotion is predominately a visually-guided action, requiring vision to be used in anticipatory, feedforward manner. The question remains, however, whether adaptive locomotion and associated visual search behaviours are susceptible to the same anxiety-related disruptions as other goal-directed perceptual-motor actions described in previous sections.

2.3 Anxiety-Related Changes in the Control of Balance

Investigations of behavioural responses to fall-related anxiety have mostly studied how postural threat, typically induced by raising participants between 1.5 m and 3 m above ground, alters postural control during quiet standing. Typically, when standing on an elevated platform, individuals will display a so-called “conservative stiffening” strategy (reduced range of body movement) aimed at accommodating potential destabilising factors (Adkin, Frank, Carpenter, & Peysar, 2000, 2002; Huffman et al., 2009; Zaback et al., 2015). This stiffening response is achieved by co-contracting tibialis anterior, soleus, and gastrocnemius muscles, resulting in reduced movement at the ankles and decreased postural sway amplitude (Staab, Balaban, & Furman, 2013).

When performing anticipatory postural tasks (such as rising to one’s toes following an auditory cue), individuals who are anxious about falling will similarly exhibit postural movements of reduced magnitude and velocity (Adkin et al., 2002; Zaback et al., 2015). Young and Williams (2015) suggest that such stiffening responses may be a consequence of anxious individuals directing attentional resources towards consciously controlling/monitoring postural movements (much in the same way that consciously processing other “automatic” motor skills can lead to slower, less fluent movements characterised by increased, often superfluous, muscle activity; as described previously in Section 2.1.3). Indeed, fall-related anxiety is causally associated with increased attention directed towards conscious movement processing during static postural control tasks (Huffman et al., 2009; Zaback et al., 2015; Zaback, Carpenter, & Adkin, 2016).

Young and Williams (2015) propose that stiffening strategies may potentially enhance postural stability during the static tasks during which such behaviours are typically assessed. However, postural stiffening is proposed to increase the possibility of falling during dynamic tasks (such as walking along an uneven pavement), where rapid and responsive movements are often required to maintain stability (Young & Williams, 2015). For example, stiffening the lower limbs may reduce an individual's ability to make the rapid reactionary step necessary to regain her/his balance following a trip; a point illustrated by observed impairments in stepping reactions in older adults with fear of falling (Uemura et al., 2012). It has also been suggested that occurrences of anxiety-related stiffening responses may not be confined to the lower limbs during static postural tasks, with "visual stiffening" also proposed to occur during the visuomotor control of anxious gait (Young & Williams, 2015).

Despite this, the large majority of work investigating how fear of falling can influence the control of balance has restricted explorations to static postural tasks. Ergo, comparatively less is known about how fall-related anxiety impacts the visuomotor control of adaptive locomotion. The next section will outline the preliminary research that has been conducted in this area.

2.4 Anxiety and the Perceptual-Motor Control of Locomotion

One clear benefit of Nieuwenhuys and Oudejans' (2012) previously discussed model (Section 2.1) is that it allows for perceptual-motor behaviours to be categorised into different processes *(perception*, *selection* and *action*). However, the boundaries between these categories are less clear during continuous tasks, such as locomotion. Unlike a discrete perceptual-motor action (e.g., a basketball free-throw or a golf-putt), locomotion requires perceptual information to be used concurrently to both plan upcoming (e.g., *perception* and *selection),* and control ongoing, movement (e.g., *action*). Therefore, the boundaries between these processes are often less clear during locomotive tasks. For example, walking across an uneven terrain in a busy, crowded environment will necessitate that the walker simultaneously perceive the information needed to select safe targets for upcoming steps, use this perceptual information to control the movement, and scan ahead to perceive information about future obstacles. In contrast, discrete perceptual-motor tasks have clearer ‘planning’ and ‘control’ phases (subsequently allowing for behavioural observations to be more easily categorised as “perception”, “selection” or “action”). However, if clear (temporal) distinctions are made between perceptual-motor processing required to plan upcoming movement, and the processes needed to control ongoing movement, we propose that it is still possible to classify behaviours observed during locomotion in line with Nieuwenhuys and Oudejans’ (2012) categorisation system.

As per Nieuwenhuys and Oudejans’ (2012) Integrated Model of Anxiety and Perceptual-Motor Performance, the preliminary findings within this area of research will be separated into the following three perceptual-motor processes: (a) *perception* of both task-relevant information and action possibilities (e.g., visual exploration of one’s surroundings to perceive relevant visual information needed to plan the action); (b) *selection* of the action itself (e.g., selecting a longer step-length to step over an obstacle), and; (c) the execution of the *action* itself (e.g., the subsequent use of information to guide movement execution).

2.4.1 *(Action) Perception*

Much like with other visually-guided perceptual-motor skills, preliminary work suggests that fall-related anxiety may similarly disrupt the acquisition of task-relevant visual information needed to select and plan actions during locomotion. For example, research conducted by Kugler, Huppert, Eckl, Schneider, and Brandt (2014) highlights marked differences in how individuals suffering from fear of heights visually explore their surroundings when walking on an elevated balcony (raised 20 m above the ground). When walking at height, individuals with height intolerances restricted their visual exploration of their environment, instead “freezing” their gaze predominantly on the “ground nearby in the heading direction, the handrail, and the goal of the walking path” (Kugler et al., 2014, p. 8).

As individuals require visual information from at least two steps ahead to effectively avoid stepping on an obstacle (Matthis & Fajen, 2014), this limited visual search behaviour will likely reduce safety during locomotion (Brandt, Kugler, Schniepp, Wuehr, & Huppert, 2015).

Similar reductions in visual exploration have also been observed in older adults who are anxious about falling (Young & Williams, 2015), with these behaviours implicated in reducing safety in this population. For example, Young and colleagues (2012) found that when approaching a target followed by a series of obstacles, older adults deemed to be at a low risk of falling displayed a "proactive" pattern of visual exploration, fixating, and transferring their gaze between, subsequent stepping constraints. In contrast, high-risk older adults displayed reduced visual exploration (see Figure 2.2). They directed their gaze predominantly towards the proximal stepping target and spent less time previewing the subsequent constraints – in a manner similar to the reduced visual exploration reported by Kugler et al. (2014) in individuals fearful of falling at height. As the high-risk older adults also reported significantly greater levels of state anxiety, the authors identified this heightened fear of falling as a factor potentially responsible for driving reductions in visual previewing.

Much in the same way that fall-related anxiety has been shown to induce postural stiffening, characterised by reduced swaying movements (see Section 2.3), Young and Williams (2015) refer to this reduced visual exploration as "visual stiffening". Taken together, these findings suggest that fall-related anxiety may disrupt visual search during gait and potentially compromise the perceptual-motor processes necessary for effectively planning future stepping movements (e.g., avoiding a potential trip-hazard).

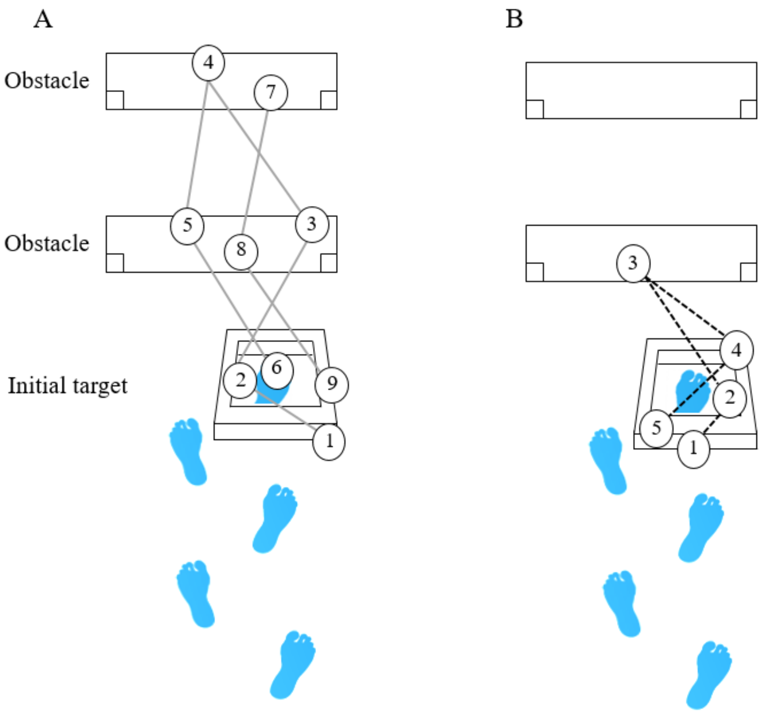

Figure 2.2. Schematic illustration of the “proactive” visual search behaviours displayed by low-risk older adults (A), and the “restricted” visual search displayed by their high-risk counterparts (B), when approaching a series of stepping constraints. Note, the numbers reflect the order of fixations made. Figure reproduced through Creative Commons Licence from: Young, W. R., & Williams, A. M. (2015). How fear of falling can increase fall-risk in older adults: Applying psychological theory to practical observations. *Gait and Posture, 41,* 7–12.

Fear of falling can also influence how acquired information is subsequently interpreted. For example, individuals anxious about falling have been shown to interpret fall-related information as being more threatening, with state anxiety being positively correlated with overestimations of vertical heights when looking down from an 8 m balcony (Stefanucci & Proffitt, 2009). Fear of falling can also lead to individuals perceiving increased postural instability. For example, research illustrates that anxious individuals will often perceive themselves to be swaying at greater magnitudes, despite exhibiting reduced postural sway (Cleworth & Carpenter, 2016). Similarly, despite adopting a more cautious, conservative postural strategy (e.g., smaller, slower, reduced movements), anxious individuals will frequently report decreased postural stability (Adkin et al., 2002). Therefore, as is the case with other perceptual-motor actions, it appears that fall-related anxiety can influence both the information that individuals direct their attention towards and acquire, and how this information is subsequently interpreted.

2.4.2 *Selection*

Research also illustrates that fall-related anxiety can influence the selection of actions; anxious individuals tend to select more cautious movement patterns during locomotion. For example, when traversing a narrow walkway at a 0.6 m elevation, anxious older adults will exhibit decreased walking velocity, shorter steps and increased double-limb support (i.e., they spend longer with both feet planted on the ground between steps; Delbaere, Sturnieks, Crombez, & Lord, 2009; Gage, Sleik, Polych, McKenzie, & Brown, 2003; Hadjistavropoulos et al., 2012). Similarly, when negotiating an obstacle in the presence of increased postural threat, anxious older adults will display shorter crossing steps of reduced velocity (McKenzie & Brown, 2004).

Fall-related anxiety is typically induced by elevating participants above ground level. However, it is unlikely that these cautious behavioural adaptations are a sole consequence of an altered visual environment resulting from elevation, e.g., increased viewing distances from objects at ground level, which may increase postural disturbances (Bles, Kapteyn, Brandt, & Arnold, 1980). For example, Tersteeg, Marple-Horvat, and Loram (2012) elevated participants 3.5 m and used a novel method to remove visual exposure to elevation. This ensured that the visual environment was consistent between low- and high-threat scenarios. The results presented in this study illustrate that cautious behavioural adaptations induced through elevation (e.g., reduced gait velocity and increased time spent in double-limb support) persist even in the absence of visual exposure to the threat (i.e., the drop). Consequently, the authors propose that the selection of cautious behaviours during anxious gait are driven largely by threat-related interpretations of the environment, rather than being a direct consequence of the altered visual environment itself. This suggests that anxious individuals will select conservative movement patterns in an attempt to avoid a fall occurring.

2.4.3 *Action*

As illustrated in Section 2.2.2, while adaptive locomotion relies largely on feedforward vision to plan and programme movement adaptations, precision stepping (e.g., stepping over an obstacle or towards a target) also requires some degree of on-line vision to guide movement execution (e.g., Young et al., 2012). Much in the same way that anxiety can disrupt how vision is used to guide other perceptual-motor skills (e.g., reduced quiet-eye effectiveness, as described previously in Section 2.1.3), preliminary research suggests that fall-related anxiety can similarly disrupt the on-line visual control of adaptive locomotion. For example, in the study described in Section 2.4.1, Young et al. (2012) also described how the high-risk, anxious older adults exhibited premature transfers of gaze away from stepping constraints (i.e., they transferred their gaze away from the stepping target prior to completing the step). This behaviour has been shown to be causally associated with increased stepping errors (Young & Hollands, 2010). Similar premature transfers of gaze away from stepping constraints, and subsequent poorer stepping accuracy, have also been reported in an older adult 2-3 weeks following their first fall. These changes in gaze behaviour and stepping performance occurred despite no recorded alterations in cognitive or physical functioning, with the single exception of increased fear of falling (Young & Hollands, 2012b).

As with the “automatic” sporting tasks outlined in Section 2.1.3, preliminary research suggests that fall-related anxiety may similarly induce a more conscious form of movement control and monitoring during adaptive locomotion (Young, Olonilua, Masters, Dimitriadis, & Williams, 2015). Young and Williams (2015) suggested that this anxiety-induced conscious movement processing can manifest itself as less efficient motor patterns, characterised by both increased (and potentially superfluous) muscle activation and stiffer, less fluent overall movements. Indeed, much like during static postural tasks, it appears that fall-related anxiety may indeed induce a stiffening response during locomotion. For example, when traversing a walkway under conditions of increased postural threat, anxious older adults have been shown to walk with a stiffer gait pattern, reducing both the range of motion and angular velocities in their knees, hips and ankles (Brown, Gage, Polych, Sleik, & Winder, 2002). Altered patterns of more superfluous muscle activation were also reported in these anxious individuals. Finally, research highlights that fear of falling is associated with increased gait variability (Ayoubi, Launay, Annweiler, & Beauchet, 2015), which itself is a marker of heightened conscious movement processing (Mak, Young, Chan, & Wong, 2019).

Taken collectively, these results suggest that individuals who are anxious about falling may be less efficient at detecting, acquiring and subsequently using task-relevant visual information to guide adaptive locomotion. There are, however, numerous issues and confounds with this preliminary body of work that limit the conclusions that can be drawn. The next section will outline such issues, as well as potential gaps in the literature.

2.4.4 Limitations of Existing Literature

Albeit causal links between fall-related anxiety and conservative gait adaptations have been established (i.e., as described in Section 2.4.2), the conclusions drawn regarding how anxiety influences visual search during adaptive locomotion remain largely speculative. For example, the current literature is restricted to cross-sectional data describing behaviours observed in either older adults with high fall-risk who also report increased anxiety (i.e., Young & Hollands, 2012b; Young et al., 2012), or individuals with visual intolerances for heights (Kugler et al., 2014). As the anxious older adults studied by Young et al. (2012) were also deemed to be at high-risk of falling, it is possible that these anxiety-related changes may reflect differences in physiological, rather than psychological, functioning. Indeed, Chapman and Hollands (2010) found that older adults at high-risk of falling require greater time to initiate, plan and execute stepping adjustments. Similar results have also been presented by Young and Hollands (2012a), indicating impaired visuomotor processing in high-risk older adults. Therefore, it is possible that the previously observed “reductions” in visual search – whereby anxious/high-risk older adults fixate initial stepping constraints for longer durations and transfer their gaze between these constraints less – may reflect age-related deficits in visuomotor processing rather than being a direct consequence of anxiety.

There are also a number of issues with the tasks and/or experimental manipulations used in this previous research. For example, as Young et al. (2012) did not specifically manipulate anxiety, but rather task complexity, which resulted in heightened fear of falling in a high-risk sub-group. Therefore, one must be cautious when attributing these changes in visual search to increased fall-related anxiety and not, for example, group differences in ability to navigate the more challenging stepping task. While fear of falling was directly manipulated in the study presented by Kugler et al. (2014), the gait task employed in this research was not adaptive in nature; participants walked on an even flat surface, rather than having to navigate stepping constraints. Consequently, as this task did not require vision to be used in an anticipatory manner, there would have been little negative behavioural outcome of reduced feedforward movement planning. The question therefore remains whether anxious individuals will display similar patterns of restricted feedforward planning when traversing a walking path that requires adaptive locomotion.

2.5 Theoretical Accounts of Altered Visuomotor Control of Locomotion

It is possible that altered patterns of visual search observed during anxious locomotion may be a consequence of anxious individuals prioritising visual stability when walking, e.g., attempting to stabilise the visual image/optic flow on the retina (Kugler et al., 2014) and/or reducing potentially destabilising head movements associated with feedforward visual search (Young & Williams, 2015). However, anxiety-related changes in attentional processing are frequently implicated as an underlying cause of these behaviours (e.g., Staab, 2014; Young & Williams, 2015). As with sporting tasks that also require perceptual-motor processing, three main theoretical stances have been proposed to account for the altered visual search observed during anxious gait (Young & Williams, 2015):

1. *Distraction* theories postulate that anxiety disrupts performance by directing attention towards threatening, task-irrelevant cues, thus reducing the attentional resources available for processing task-relevant information (Wine, 1971). These task-irrelevant cues can be either internal (worries or disturbing thoughts relating to the consequences of failure) or external (i.e., threatening task-irrelevant distracters, such as a soccer player facing the opponent crowd behind the goal when tasked with a penalty kick).
2. In contrast, *self-focus* theories hold that anxiety causes the performer to direct conscious attention towards monitoring or controlling previously “automatic” movement processes (Baumeister, 1984). In broad terms, distraction theories suggest that anxiety leads to performance breakdown as a result of directing too little on-line attention towards movement execution, while self-focus theories postulate that performance decrements are a consequence of directing excessive on-line attention towards movement.
3. Finally, *integrated perspectives* – as the name suggests – propose an interplay between distraction and self-focus factors.

2.5.1 *Distraction Perspectives*

Within the domain of posture and gait research, the two most commonly referenced distractions theories are Processing Efficiency Theory (PET; Eysenck & Calvo, 1992), and its successor, Attentional Control Theory (ACT; Eysenck et al., 2007). According to PET, anxiety disrupts attentional processing by shifting attention towards task-irrelevant threatening information; namely, worrisome or disturbing thoughts. Processing these ruminative thoughts is then argued to compromise the capacity of working memory thus reducing the cognitive resources available for performing other processes necessary for successful task performance. Anxious individuals can use compensatory self-regulatory strategies to overcome these distractions. Nonetheless, doing so is cognitively taxing, requires increased mental effort, and further reduces the cognitive resources available for directing attention towards the primary task. Indeed, PET argues that anxiety negatively impacts *processing efficiency* – the level of cognitive resources needed to obtain a given level of performance – to a greater degree than it does *performance effectiveness*. However, performance effectiveness is proposed to decline in situations whereby the anxious performer is unable to recruit sufficient cognitive resources.

ACT builds on the hypotheses presented in PET, and provides a more detailed account of how anxiety can disrupt attentional processing.[3] According to ACT, anxiety's impact on attention results from the disrupted balance between the goal-directed ("active" top-down attention influenced by prior experience and knowledge) and stimulus-driven attentional systems ("passive" bottom-up attention driven by salient and threatening stimuli; Corbetta & Shulman, 2002). This disrupted balance is argued to impair both the inhibition and the shifting functions of attention. As a consequence, anxious individuals are less able to *inhibit* preferential attention from being directed towards internal or external task-irrelevant threat-related distractions (and subsequently divert attention back towards task-relevant cues), in addition to having a reduced ability to *shift* attention between different tasks/sub-tasks. As

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[3] Although ACT is traditionally viewed as a distraction theory, recent developments to this theory – specifically its application to the context of sport – have led some researchers to place ACT within the context of integrated perspectives (see section 2.5.3 for further detail).

with PET, ACT posits that the influence of the stimulus-driven attentional system can be overridden through the employment of cognitively taxing compensatory strategies.

Providing support for distraction theories, Young and Williams (2015) suggested that anxiety-related reductions in visual exploration may reflect an inability to plan future actions as a result of preferentially processing internal worries. Specifically, Young and Williams (2015) proposed that focusing on thoughts/worries about falling may reduce balance safety during complex gait tasks (such as obstacle avoidance) by impairing an individual's ability to store a visual-spatial map of their surroundings (Zettel et al., 2007). Indeed, research has demonstrated that fall-related anxiety can impair attentional processing efficiency in older adults, reducing the cognitive resources available for carrying out other concurrent tasks while walking (Gage et al., 2003; Uemura et al., 2012). This may include the storing of such visual-spatial map (Young & Williams, 2015). Anxiety-related reductions in the capacity to store a spatial map are likely to impact on tendencies to proactively scan the environment. After all, it is not efficient to acquire information that will be lost before it can be used (Young & Williams, 2015).

As Section 1.2 illustrates, adaptive locomotion requires both feedforward (i.e., looking multiple steps ahead to identify and avoid potential trip hazards; Matthis et al., 2015; 2017; Matthis & Fajen, 2014) and on-line visual control (i.e., visually fixating upon a trip hazard during the step towards it to inform and modulate necessary adjustments; Chapman & Hollands, 2006a; Patla, 1991; Patla & Vickers, 2003). A real-world example of simultaneously using these two strategies could be negotiating an uneven paving stone while approaching a high curb. In this scenario, the individual must prioritise which areas of their environment on which to fixate. While research suggests that low-anxious individuals would likely transfer their gaze frequently between both the uneven paving stone and the curb, before finally maintaining their gaze on the uneven paving stone until they have stepped over it, anxious individuals would likely solely fixate the uneven paving stone until initiating the step around/over it. At this time, having not yet looked towards future stepping constraints (i.e., the curb) these anxious individuals would have an urgent need to fixate on these future areas. Consequently, these individuals would likely transfer their gaze away from the uneven paving stone earlier in their step towards it in order to fixate the curb, resulting in an increased likelihood of producing a misplaced step. Indeed, as described in Section 2.5.3, anxious older adults will often transfer their gaze away from a stepping target prior to foot contact in order to fixate upon upcoming obstacles earlier, due to failing to perceive these constraints during the approach (Young & Hollands, 2012b; Young et al., 2012). This is worrying, given that this behaviour is causally associated with reduced safety during adaptive locomotion (Young & Hollands, 2010).

Similarly, Staab (2014) highlights distraction theories as a potential explanation for the aforementioned anxiety-related changes in visual search. However, rather than implicating internal distracters (such as worries) as an underlying cause of these behaviours, he interprets the altered patterns of visual search in anxious older adults to represent an attentional bias for external threat-related stimuli – with anxious individuals directing preferential attention towards upcoming threats to balance. Therefore, rather than anxiety indirectly disrupting visual search by virtue of reducing the cognitive resources available for carrying out proactive feedforward planning (as proposed by Young and Williams, 2015), Staab’s interpretation indicates that anxious individuals may prioritise processing the immediate threat to their balance at the expense of proactively scanning the walking path beyond this initial constraint. This idea is supported by research suggesting that older adults fearful of falling display an attentional bias toward threatening, fall-relevant stimuli (Brown, White, Doan, & deBruin, 2011).

2.5.2 *Self-Focus Perspectives*

In contrast, researchers have also used self-focus theories to explain how fall-related anxiety may alter visuomotor control of locomotion (Uiga, Capio, Wong, Wilson, & Masters, 2015; Uiga, Cheng, Wilson, Masters, & Capio, 2015; Young & Williams, 2015). The most frequently used self-focus theory within the domain of posture and gait is Reinvestment Theory (Masters & Maxwell, 2008). This theory postulates that anxiety leads the performer to direct conscious attention towards monitoring or controlling previously “automatic” movement processes. Although the control of gait and posture requires some degree of conscious cognitive involvement (Woollacott & Shumway-Cook, 2002), these processes can typically be governed using largely automatic, lower-level processes (Boisgontier et al., 2013; Wulf & Prinz, 2003). As conscious movement control is characterised by increased on-line movement processing (Jackson et al., 2006), it is possible that the reduced visual exploration/feedforward planning observed in anxious individuals (e.g., Kugler et al., 2014; Young et al., 2012) may be a consequence of the prioritisation of the on-line visual information needed to consciously control/monitor individual stepping movements. Relatedly, Beilock and Carr’s (2001) theory of Explicit Monitoring suggests that anxiety “increases the attention paid to skill processes and their *step-by-step* control [emphasis added]” (p. 701). The question remains as to whether adopting “step-by-step control” during locomotion occurs at the expense of visually exploring one’s environment and planning future stepping actions.

Masters and Maxwell (2008) also argue that cognitive resources are required to consciously attend to the process of moving. This in turn limits the resources available for other processes, which may include the visual search necessary to attend to information in the external environment (Young & Williams, 2015). Therefore, it is possible that conscious movement strategies may also limit the resources available for carrying out concurrent processes, such as the visual-search necessary for detecting trip-hazards or the storing of a spatial map (Young & Williams, 2015). Indeed, Clark (2015) suggested that if the cognitive resources needed for locomotion in complex environments are:

> "...encumbered by the [conscious] control of the basic walking pattern, there is a heightened risk that hazards may be overlooked or ignored. The individual may be less likely to notice a slick puddle on the floor or may misjudge the speed or direction of surrounding pedestrians, resulting in slips, trips, collisions and falls." (Clark, 2015, p. 2)

This is supported by research which describes that, much in the same way as performing a cognitive dual-task while walking can reduce an individual's ability to perceive environmental cues (Hyman, Boss, Wise, McKenzie, & Caggiano, 2009; Hyman, Sarb, & Wise-Swanson, 2014), consciously monitoring and controlling movement may similarly impair the perception of external information during locomotion (Uiga, Capio et al., 2015; Young et al., 2016). Consequently, Uiga, Cheng et al. (2015) propose that such conscious movement strategies may increase fall risk by virtue of these individuals being less likely to perceive external information necessary for successful locomotion. However, as this research did not directly assess gaze behaviour, the question remains whether the conscious processing of movement disrupts visual search itself, or merely impairs an individual's ability to store this information within working memory.

2.5.3 *Integrated Perspectives*

The term "integrated perspective" is derived from Nieuwenhuys and Oudejans' (2012) model which describes the influence of anxiety on perceptual-motor processing (described in Section 2.1). In addition to describing the effects that anxiety can exert on various aspects of perceptual-motor performance (e.g., perception, selection and action), Nieuwenhuys and Oudejans also speculate on the psychological processes that underpin such changes. Specifically, this model proposes that anxious performers will direct preferential attention towards task-irrelevant distractions. However, Nieuwenhuys and Oudejans (2012) argue that during perceptual-motor tasks typically governed by automatic, lower-level processes (e.g., locomotion), such task-irrelevant distractions may also include the direction of attention towards movement execution – given that consciously processing such information is not typically required for successful performance. This assumption is supported by research demonstrating that consciously processing movement during gait can distract attention away from other task-relevant processes, such as extracting relevant visual information from one's walking environment (Uiga, Capio et al., 2015). Such theoretical perspective highlights that distraction and self-focus need not be viewed as mutually exclusive.

Relatedly, as noted in Section 2.5.1, recent developments to ACT have also allowed this theory to be placed within the context of integrated perspectives. Attentional Control Theory: Sport (ACTS; Eysenck & Wilson, 2016) was developed in an attempt to apply ACT to the context of perceptual-motor performance. This theory posits that anxiety disrupts the balance between the goal-directed and stimulus-driven attentional systems. Accordingly, anxious individuals are less able to inhibit the diversion of attention away from task-relevant cues towards internal or external task-irrelevant threat-related distractions (as per distraction accounts). Consequently, attention is biased towards "detecting the source of the threat and deciding how to respond" (Wilson, 2008, p. 195) – with ACTS proposing that anxious individuals may be less able to inhibit such responses from being initiated and/or controlled via potentially disruptive conscious, on-line mechanisms (as per self-focus accounts).

Specific to the domain of posture and gait, Young and Williams (2015) have also presented a model that integrates both distraction and self-focus accounts to describe how fall-related anxiety may influence balance (see Figure 2.3). Specifically, this model proposes that fall-related anxiety may induce both preferential processing of task-irrelevant threat-related distracters (primarily worries/ruminative thoughts; i.e., distraction perspective) and the direction of attention internally towards movement processes (i.e., self-focus perspective), with both alterations in attention speculated to influence perceptual-motor behaviour differently. For example, an inability to disengage from processing worrisome thoughts is speculated to impair the retention of visual-spatial information during walking, which in turn is suggested to impact the walker's proclivity for proactive scanning behaviours/feedforward planning. It is, however, worth noting that a large number of the behavioural associations presented by Young and Williams (2015) are speculative in nature. Thus, albeit this model provides a theoretical basis to contextualise previous observations, future work is needed to further scrutinise these speculative predictions.

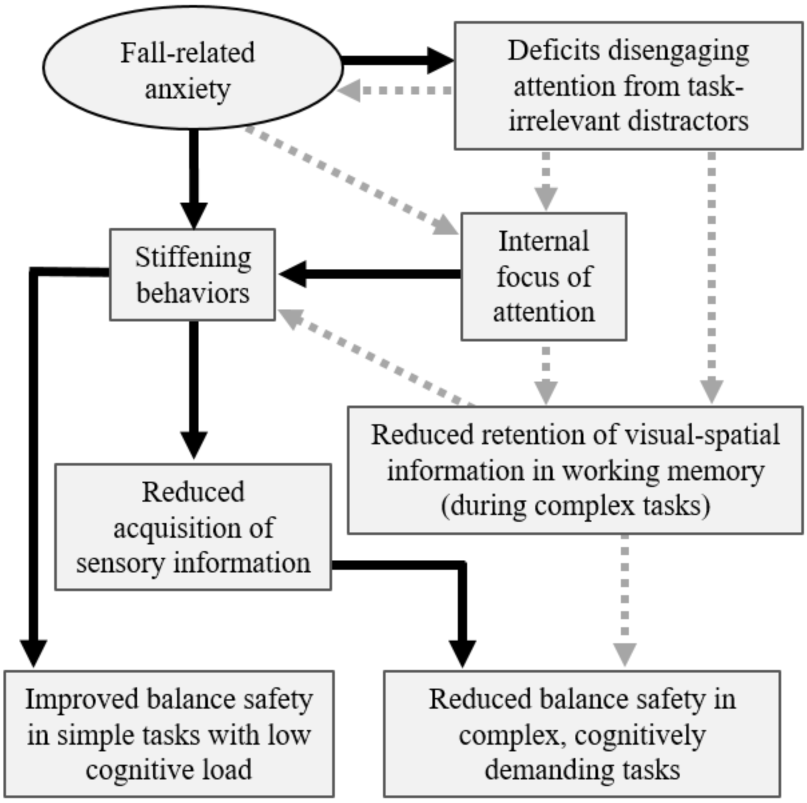

Figure 2.3. Schematic diagram of Young and William's (2015) model which proposes how fall-related anxiety can influence the control of posture and gait. Note. Solid black lines indicate associations strongly supported in the literature, and dotted lines represent speculative links. Figure reproduced through Creative Commons Licence from: Young, W. R., & Williams, A. M. (2015). How fear of falling can increase fall-risk in older adults: Applying psychological theory to practical observations. *Gait and Posture, 41,* 7–12.

2.6 Rationale for the Present Work

Despite these contrasting theoretical accounts, little attempt has been made to explore the specific psychological factors that underpin anxiety-related changes in perceptual-motor processing during locomotion. Instead, researchers have typically attempted to retrospectively apply psychological theory to existing findings (e.g., Young & Williams, 2015). Consequently, very little is known about how consciously processing one's movement – or any other proposed anxiety-related changes in attention (e.g., worrisome thoughts or compensatory strategies) – influence the visuomotor control of locomotion. For example, while evidence exists for a causal link between fall-related anxiety and heightened conscious movement processing when walking (Young et al., 2016), this research did not evaluate how these changes in attention influence visual search or stepping behaviours. Relatedly, despite a large number of theoretical interpretations implying that fall-related anxiety may reduce the attentional resources available for carrying out feedforward visual search (due to either worries or conscious movement processing), to date, no research has addressed whether attention is required to maintain effective visual search during locomotion.

In addition to these gaps in the literature, we can draw only limited conclusions from the existing body of work regarding how fall-related anxiety may influence the visuomotor control of locomotion. For example, the existing literature can be critique on the basis of: (a) studying either clinical populations suffering from comorbidities likely to confound observations, e.g., visual intolerances to height (Kugler et al., 2014) or age-related deficits in visuomotor processing (Young et al., 2012); (b) featuring simple locomotive tasks requiring limited feedforward planning (Kugler et al., 2014); or (c) failing to directly manipulate fall-related anxiety (Young et al., 2012). There is, therefore, both a need to establish the specific ways in which fall-related anxiety can impact visuomotor control of locomotion, as well as to examine the attentional mechanisms that underpin any such changes in visuomotor behaviour.

2.7 Applied Importance of the Present Work

The relationship between fear of falling and increased fall risk is well documented (Friedman et al., 2002; Hadjistavropoulos et al., 2011; Young & Williams, 2015). While Section 2.4 describes a causal relationship between fall-related anxiety and altered behaviours during walking, it remains unclear how such changes might jeopardise safety in older adults anxious about falling. It is well documented that older adults deemed to be at a high risk of falling often display “maladaptive” visual-search behaviours likely to reduce safety during walking. For example, when approaching a stepping target followed by a series of obstacles, high-risk older adults will fixate upon the immediate stepping target earlier, and for longer durations, at the expense of previewing subsequent stepping constraints (Young et al., 2012). As this strategy limits the amount of visual information acquired relating to subsequent constraints, these individuals will then transfer their gaze away from this initial stepping target earlier (i.e., before the step into the target had been completed), in order to fixate upon the constraints that follow (Chapman & Hollands, 2006b, 2007; Young et al., 2012). Such behaviours are casually linked to increased stepping errors and, by extension, reduced safety (Young & Hollands, 2010).

Previous conceptualisations of these “high-risk” behaviours have highlighted deficits within visuomotor processing as an underlying mechanism (e.g., Chapman & Hollands, 2006b). However, if these behaviours are a consequence of differences in psychological, rather than physiological, functioning (e.g., anxiety-related anxiety, as proposed by Young & Williams, 2015), then it might be possible to use low-cost therapeutic techniques grounded in psychological theory to reduce the potential negative impact of these high-risk behaviours.

2.8 Aims of the Thesis

The present body of work was designed to investigate the relationship between fall-related anxiety, subsequent changes in attentional focus, and altered patterns of (visuomotor) control during locomotion in young adults; before attempting to translate these findings to an older adult cohort.

Specifically, the first aim was to provide a detailed account of the changes in attention that occur when fearful of falling (Chapter 4, 5 and 6), and to explore how these changes influence an individual's ability to carry out concurrent tasks/processes during walking (Chapter 3, 4 and 5).

The second aim was to examine possible causal links between fall-related anxiety and altered visuomotor control of adaptive locomotion, in both a healthy young adult model unaffected by countless confounding factors related to either age or clinical disorders (Chapter 5), and in older adults deemed to be at an increased risk of falling (Chapter 7).

The final aim of the thesis was to explore the attentional factors that may underpin any observed anxiety-related alterations in gaze behaviour (Chapter 5, 6, 7 and 8). Specifically, this aim seeks to examine whether any anxiety-related changes are a consequence of: (a) heightened conscious movement processing (i.e., support for "self-focus" theoretical perspectives); (b) a bias for threatening stimuli, whether internal worries/rumination or a gaze bias for external threatening stimuli (i.e., support for "distraction" theoretical perspectives); (c) reduced cognitive resources (resulting from either conscious movement processing or anxiety-related worries/rumination); or (d) a combination of the aforementioned factors (i.e., support for previously described "integrated" theoretical perspectives).

Chapter 3: Gazing into thin air: The dual-task costs of movement planning and execution during adaptive gait

Study 1 was published in *PLOS ONE*

(see Section List of Thesis Publications)

3.1 Introduction

As we walk through our cluttered world, we rely predominantly on visual information for effective navigation (Patla, 1997, 1998; Higuchi, 2013). An effective visual search strategy allows for the identification of hazards and for the feedforward planning and execution of safe stepping behaviours to avoid tripping. Stepping and eye movements exhibit a robust spatiotemporal relationship in healthy younger adults (Hollands & Marple-Horvat, 1996, 2001; Hollands, Marple-Horvat, Henkes, & Rowan, 1995), with this relationship being disrupted during the ageing process (Chapman & Hollands, 2006b, 2007; Young & Hollands, 2012b; Young et al., 2012). In general, when navigating a series of stepping constraints younger adults fixate on a target momentarily prior to initiating the step towards it, with their gaze maintained on this target until the step has been completed (Chapman & Hollands, 2006b, 2007; Young & Hollands, 2012b; Young et al., 2012). However, older adults – particularly those deemed to be at a high risk of falling and/or those with higher levels of fall-related anxiety – transfer their gaze away from the target prior to the step being completed (Chapman & Hollands, 2006b, 2007; Young & Hollands, 2012b; Young et al., 2012).

Young et al. (2012) have also reported that when approaching a target followed by a series of obstacles, older adults deemed to be at a low risk of falling will display a ‘proactive’ pattern of visual search, fixating on, and transferring their gaze between, these subsequent stepping constraints. However, high-risk older adults spent less time previewing these subsequent constraints and instead spent more time fixating the initial target. Adopting this less-variable pattern of visual search behaviour, whereby the individual focuses on the initial target and fails to fixate on future constraints, is likely to compromise an individual's ability to generate a "spatial map" of their environment (Zettel et al., 2007). As a result, it has been suggested that the aforementioned early transfer of gaze away from the target (i.e., prior to the step being completed) may be a consequence of high-risk older adults failing to acquire this visual information during the initial approach (Young & Williams, 2015). Given that this early transfer of gaze is causally linked to a higher incidence of stepping errors (Young & Hollands, 2010), there is a clear need to identify the underlying mechanisms mediating this apparently maladaptive visual search strategy.

It has been suggested that the altered visual search behaviour observed in high-risk older adults may be caused by inefficiencies in attentional processing (Young & Williams, 2015). It is well established that effective, safe locomotion requires cognitive input (Al-Yahya et al., 2011; Yogev-seligmann, Hausdorff, & Giladi, 2008). Cognitive impairment is associated with increased fall-risk in older adults (Muir, Gopaul, & Montero Odasso, 2012) and walking while carrying out a secondary task negatively impacts measures of gait performance in both young (Schwebel et al., 2012; Stavrinos, Byington, & Schwebel, 2011) and older adults (Agmon, Belza, Nguyen, Logsdon, & Kelly, 2014; Beurskens & Bock, 2012, 2013; Bock, 2008). However, this dual-task interference, or dual-task costs (DTCs), appear to be most pronounced in high-risk older adults (Lundin-Olsson, Nyberg, & Gustafson, 1997; Muir-Hunter & Wittwer, 2015; Nagamatsu et al., 2011). Furthermore, the inability to maintain locomotion while holding a conversation and instead "stopping walking when talking" is a reliable predictor of older adult fall-risk (Beauchet et al., 2009). These findings indicate that the ability to allocate attention efficiently between locomotion and a concurrent task may be impaired in high-risk older adults. It has also been suggested that the less-variable pattern of visual search behaviour observed in high-risk (and high-anxious) older adults may be a consequence of these individuals possessing insufficient cognitive resources to store a “spatial map” of their surroundings (Young & Williams, 2015). However, to our knowledge, no researchers have looked to investigate how increased cognitive load impacts visual search behaviour during locomotion.

Trait psychological factors can also influence attentional processing during gait. Under certain conditions, such as injury or accident (including older adult falls; Wong, Masters, Maxwell, & Abernethy, 2008), performers may attempt to consciously monitor and control movements that are regulated by primarily “automatic”, lower-level processes (Masters & Maxwell, 2008). Such conscious processing often leading to a disruption in performance (e.g., Jackson et al., 2006). This phenomenon is frequently described as “reinvestment”, with an individual’s propensity to consciously monitor and control their movements argued to be a dimension of personality (see Masters & Maxwell, 2008, for a review). In addition to disrupting the automaticity of motor performance, researchers have indicated that reinvestment can influence the allocation of attention during gait. Much in the same way as performing a cognitive dual-task while walking can reduce an individual's ability to perceive environmental cues (Hyman et al., 2009, 2014), researchers have demonstrated that consciously processing movement may similarly impair the perception of external information during locomotion (Uiga, Capio et al., 2015; Young et al., 2016).

Masters and colleagues (Masters & Maxwell, 2008) have argued that cognitive resources are required to consciously attend to the process of moving. This process in turn limits the resources available for other processes, which may include the visual search necessary to attend to information in the external environment (Young & Williams, 2015). It has also been suggested that conscious movement processing may impair the retention of an environmental “spatial map” (Young & Williams, 2015), with older adults who “stop walking when talking” displaying both greater propensity to consciously control their movements and poorer retention of visuo-spatial information (Young et al., 2016).Yet, little is known about how reinvestment influences visual search behaviour; nor whether consciously processing movement does indeed disrupt attentional processing during adaptive locomotion.

The primary aim in this present research was to investigate how increased cognitive load influences visual search during adaptive gait. A healthy younger cohort was selected as the most appropriate sample to investigate this research question, so as to avoid any potential confounding age-related factors, such as cognitive decline. Therefore, we examined whether the previously detailed less-variable patterns of visual search behaviours observed in high-risk older adults can be induced in a healthy younger adult cohort walking while simultaneously carrying out a cognitive dual-task. The secondary aim in this present research was to evaluate if participants with higher scores on a measure of trait-reinvestment exhibited reduced ability to visually preview the environment during locomotion during either baseline (no dual-task) or conditions of cognitive load.

We predicted that individuals would be less likely to proactively scan their environment and instead fixate for longer durations on single points during the walkway when concurrently processing a cognitive dual-task. Therefore, we expected a reduction in the number of task-relevant “inside” fixations (fixations towards areas within the walking path) during conditions of cognitive load. As literature demonstrates how a propensity to consciously process movements is associated with a reduction in the ability to allocate attention between concurrent tasks during locomotion (Uiga, Capio et al., 2015; Young et al., 2016), we predicted that changes in visual search behaviour under cognitive load would be most pronounced in high-trait-reinvesters. Finally, researchers have demonstrated that walking while simultaneously performing a cognitive dual-task can impair performance in both the motor- and cognitive-task in younger adults, relative to a single-task baseline condition (Beurskens & Bock, 2012). Therefore, we predicted significant DTCs for both the motor- and cognitive-task. As consciously attending to the process of movement requires cognitive resources and may limit the resources available for other processes (Masters & Maxwell, 2008), we predicted these DTCs to be greatest in high-trait-reinvesters.

3.2 Method

3.2.1 Participants

Fourteen young adults (male/female: 9/5; mean ± SD age: 26.36 ± 2.59 years) participated in the research. Participants were free from any musculoskeletal or neurological impairment. Participants requiring the use of eyeglasses for daily locomotor activities were excluded due to incompatibility with the gaze tracking equipment. However, the use of contact lenses was permitted. Ethical approval was obtained by the local ethics committee at the lead institution and the research protocol was carried out in accordance with the principles laid down by the Declaration of Helsinki. All participants provided written and informed consent.

As this is the first study to explore visual search during conditions of cognitive load, it was not possible to conduct a power analysis for visual search variables. Instead, a power analysis was conducted to determine the number of participants required to detect a significant effect of cognitive load on motor and cognitive performance. Previous research has reported large effect sizes for comparable variables during cognitively loaded adaptive gait (e.g., Bock, 2008). Consequently, a power analysis conducted with G*Power (Faul, Erdfelder, Buchner, & Lang, 2009) determined that between 6 and 13 participants would be required to obtain 80% power (Cohen, 1988).

3.2.2 Procedure

On arrival, participants were fitted with reflective markers placed on the sternum and mid-foot of both feet (Young et al., 2012), and then with a Mobile Eye-XG portable eye-tracking system (ASL, Bedford, MA). The eye-tracking system records participants’ gaze by contrasting the pupil and corneal reflection, allowing the superimposition of a point of gaze crosshair on a video of the environment recorded from a scene camera. Once calibration was complete, gaze data were recorded wirelessly at 30 Hz. The eye-tracker features an integrated microphone, which was used to record audio (also at 30 Hz). Kinematic data were collected at 150 Hz using an eight camera Motion Analysis system (MotionAnalysis, Santa Rosa, California).

The experimental set up described below is highly comparable to that previously used by Young et al. (2016). Participants walked over a 6 by 5 grid of 19 black and 11 white wooden blocks (stepping surface of each block = 40 cm x 40 cm, height of each block = 30 cm, total length of the walking path = 4.4 m). The white blocks were arranged to form one-of-four different non-linear routes that participants were instructed to traverse at a comfortable pace, without stepping on the black blocks (Figure 3.1). Each non-linear pattern contained a different combination of straight sections and two left and two right apexes. Two white blocks on each pattern were marked with an ‘X’ (the fifth and the tenth block of each pattern). These formed participants’ precision stepping targets. Participants were instructed to step on the middle of the ‘X’ with the middle of their foot (i.e., place the mid-foot markers of their swing foot as close to the centre of the target as possible). The protocol was designed to mimic the common task of walking on a pavement, targeting paving stones perceived to be stable and safe. At the start of each trial, participants stood behind a 2.3 m-high screen (preventing them from seeing the walkway). When instructed to “Go”, participants walked around the screen, up a ramp (120 cm long), along the white blocks, and down a second ramp. They then walked off the ramp to the left side and returned behind the screen in anticipation of starting the subsequent trial.

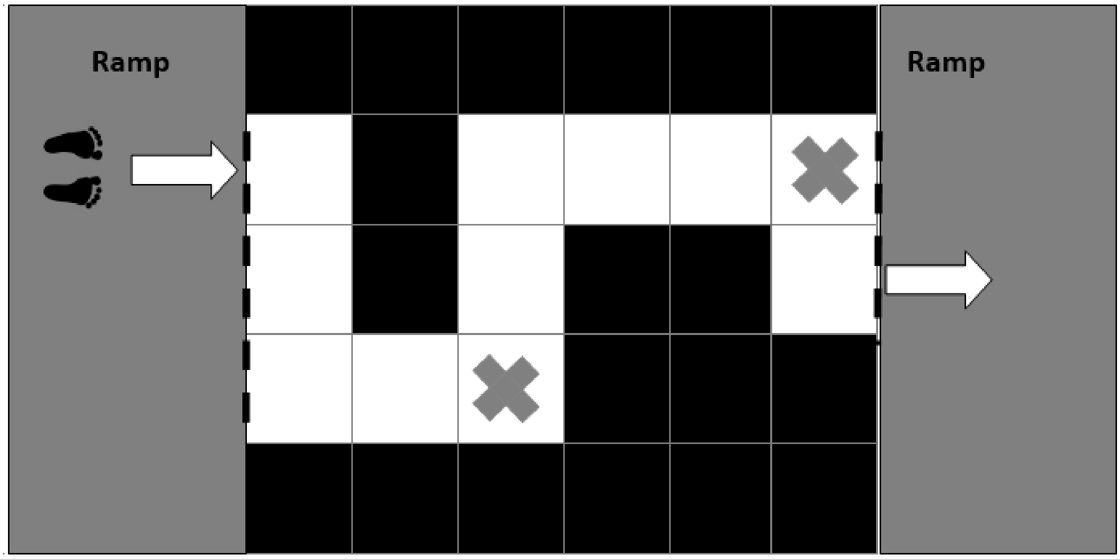

*Figure 3.1***.** Schematic of an example path and direction of walking. The arrows indicate the route that participants took (returning on the left side of the walkway in all trials). Blocks marked with an ‘X’ were participants’ precision stepping targets. Dotted black lines indicate the points between which the time to complete the walking task was calculated.

3.2.3 Experimental Conditions

Participants completed walks under two conditions: Baseline and Cognitive Load (dual-task). The Cognitive Load condition consisted of walking while concurrently subtracting out loud from a randomised number (between 90 and 110) in 7s. Participants were presented with this randomised number directly prior to commencing the walking trial, to ensure that they had not already begun subtracting mentally. Once participants had been presented with this randomised number, their first verbalised response was the subtracted target value (i.e., first verbalisation of 93 if the randomised number presented was 100). Participants were instructed to allocate an equal amount of attention towards both the walking and the arithmetic task. Participants completed eight blocks of two walking trials (16 trials total). Each experimental block consisted of one Baseline and one Cognitive Load trial, presented in a randomised order. The walking route was rearranged after each block, with each pattern presented twice. Pattern presentation was randomised.

After each trial, participants completed the Rating Scale of Mental Effort (RSME; Zijlstra, 1993). The RSME was used as a manipulation check, to measure perceived mental effort, in order to ensure that the cognitive load manipulation was successful in increasing cognitive demand. The RSME was presented as a single continuum scale ranging from 0 to 150, with nine validated reference points along the scale (e.g., “Absolutely No Effort”, “Some Effort”, “Extreme Effort”, etc.). Researchers have demonstrated that the scale provides a valid and reliable indicator of mental effort (Veltman & Gaillard, 1996).

3.2.4 Reinvestment

The Movement Specific Reinvestment Scale (MSRS; Masters, Eves, & Maxwell, 2005) was used to assess participants’ trait-reinvestment. This 10-item questionnaire consists of two 5-item subscales: conscious motor processing (trait-CMP; e.g., “I am always trying to think about my movements when I carry them out”) and movement self-consciousness (trait-MSC; e.g., “I’m self-conscious about the way I look when I am moving”). Items are rated on a 5-point Likert scale (0 = *extremely uncharacteristic*; 4 = *extremely characteristic*). Total MSRS scores range from 0–40, with higher scores reflecting a higher propensity for reinvestment. Both subscales have good internal validity and test-retest reliability (Masters et al., 2005).

3.2.5 Dual-Task Assessments

To quantify participants’ ability to execute two tasks concurrently, we calculated dual-task costs (DTCs) according to the customary formula (McDowd, 1986):

Cognitive DTC (%) = 100 * (single-task score - dual-task score)/single-task score

Motor DTC (%) = 100 * (dual-task score - single-task score)/single-task score

Thus, higher DTCs reflect poorer performance under dual-task conditions.

Cognitive DTCs. Cognitive performance was defined as the number of correct arithmetic calculations verbalised. Dual-task scores were calculated during trials where participants performed the cognitive task while walking (Cognitive Load trials). Single-task scores were calculated while participants performed the cognitive task from a seated position behind the screen. During the single-task condition, participants were given 30 seconds to subtract as many times as possible in 7s from a randomised number. The number of correct digits verbalised during Cognitive Load trials were then compared to those verbalised during a proportional period of time during single-task. For example, if a participant completed a Cognitive Load walking trial in 15 seconds, the number of correct arithmetic calculations verbalised here was compared to the number verbalised in the first 15 seconds during single-task. Verbalisations were recorded from the eye-tracker’s integrated microphone, and then analysed in Adobe Premiere Pro CC (Adobe Systems, San Jose, CA).

Motor DTCs. Performance on two separate motor tasks was calculated: (1) Time to complete the walking trial (defined as the time taken in seconds between the sternum marker crossing over the threshold of the first wooden block of the walking path and then crossing from the last wooden block onto the second ramp following the completion of the trial; see Figure 3.1); and (2) Absolute stepping error (total distance in mm between the mid-foot marker and the middle of the precision stepping accuracy target, regardless of axis). Prior to the commencement of the first trial in each block of trials, a static trial was recorded to identify the coordinates of both stepping targets. This procedure consisted of a reflective marker being placed in the middle of each target; the coordinates of which were then later used as a reference against the position of the mid-foot markers during each walking trial. As markers were placed in the middle of both feet, the co-ordinates of the mid-foot marker nearest the middle of the precision stepping accuracy target was used to calculate stepping accuracy. Motor performance data were processed using a low pass Butterworth filter at 5 Hz and then analysed using custom algorithms in MATLAB version 7.11 (MathWorks, Natick, MA). For both variables, single-task performance was calculated during trials of Baseline walking, while dual-task scores were calculated during trials where participants performed the cognitive task while walking (Cognitive Load trials).

3.2.6 Gaze Behaviour

For this study – and all other studies in the present programme of research which similarly explore visual search – fixations were defined as a gaze that endured on a single location (≤ 1° visual angle) for 100 ms or longer (Patla & Vickers, 1997). It was reasoned that participants would need to fixate on both the white and black blocks within the walking path, as well as the ramp leading to, and from, the walkway, in order to acquire the relevant visuospatial information about their walking path. While black blocks were not part of the walking path, in that participants were instructed to avoid walking on these, participants still needed to acquire relevant visuospatial information about the location of these blocks in order to avoid stepping onto them; much in the same way that participants switch their gaze between both areas of the walking path on which they wish to step, and those which they wish to avoid, during obstacle avoidance (Young et al., 2012). However, other areas of the surrounding environment, such as the laboratory floor beyond the walking path or the laboratory walls, were deemed to contain no visual information necessary to aid the completion of the walking task. Therefore, fixations were classified as either task-relevant “inside” fixations (any area of the environment necessary for safely navigating the walkway: the first and second ramp, and any white or black stepping block within the walking path (Figure 3.2a)) or task-irrelevant “outside” fixations (any area of the surrounding environment that was not either a ramp, or white or black stepping block (Figure 3.2b)).

Trials in which the point of gaze crosshair disappeared for the duration of four frames or more were discarded. Participants with 50% or greater trial-discard rate were excluded from all analyses. This procedure resulted in 3 participants being excluded from the analyses. Gaze data was analysed between the point when participants stepped from behind the screen and initiated gait towards the first ramp, and the point when participants stepped from the final block of the walkway onto the second ramp. As the Motion Analysis system was not able to begin capturing data until participants stepped from the first ramp onto the walking path, we used the ASL eye-tracking videos to identify these points. As participants' heads were pitched down at an angle that also captured their feet during the approach of the second ramp, this allowed for a reliable visual inspection of the frame in which the foot contacted the ramp.

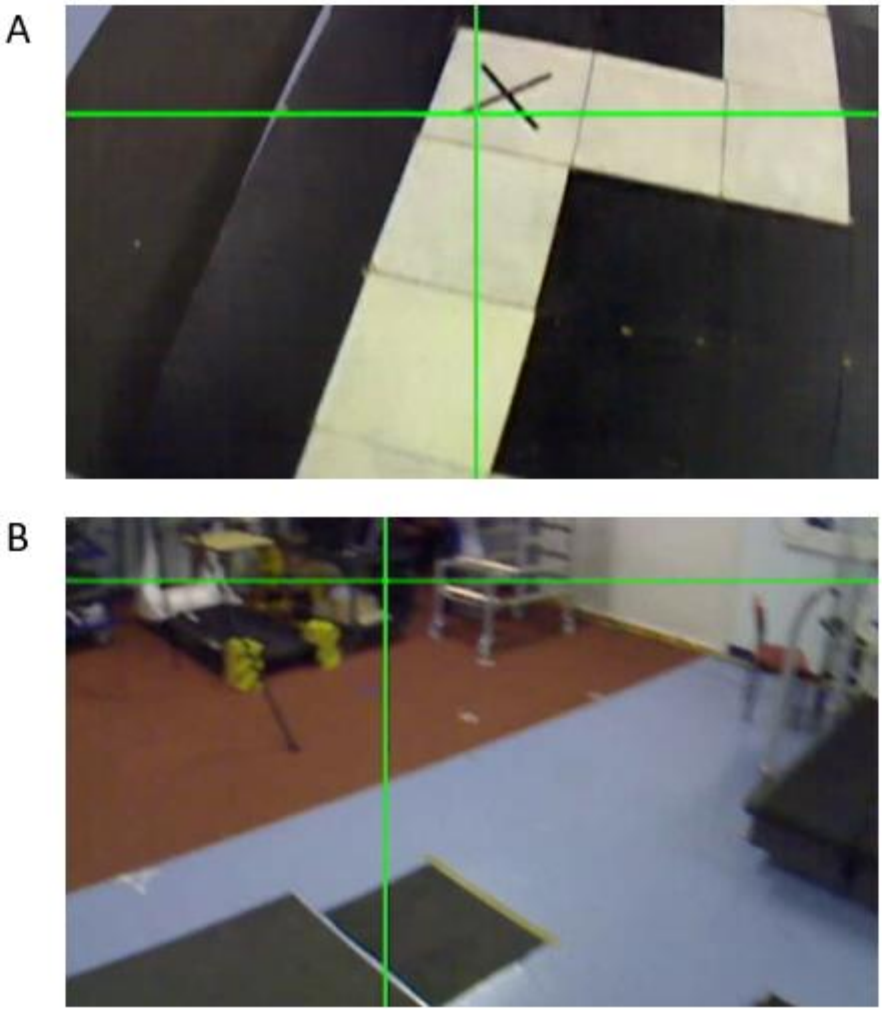

Figure 3.2. An example of a task-relevant "inside" fixation, whereby the participant fixates on an area within their walking path (A), and a task-irrelevant "outside" fixation, whereby the participant fixates on an area outside of their walking path (B).

3.2.7 Temporal Relationship between Cognitive Load and Visual Search

While it was hypothesised that individuals would adopt a less-variable pattern of visual search under conditions of Cognitive Load, preliminary analysis revealed a very different pattern of behaviour. Instead of reducing the variability of their visual search and dwelling on single points for longer periods of time, participants frequently disengaged their gaze from the walking path altogether to fixate on task-irrelevant “outside” areas. Due to these unforeseen changes in visual search behaviour, we conducted a supplementary analysis evaluating the temporal interaction between task-irrelevant fixations and the verbalisations involved in performing the cognitive secondary task. For this temporal analysis, patterns of visual search were compared in four separate temporal time-bins: (a) 10 frames (330 ms) prior to verbalising the first digit in an arithmetic pair; (b) 10 frames prior to verbalising the second digit in an arithmetic pair; (c) 10 frames post-verbalisation of the second digit in an arithmetic pair; and (d) 11-20 frames post verbalisation of the second digit in an arithmetic pair.

Both gaze data and audio verbalisations were analysed frame-by-frame using Adobe Premiere Pro CC (Adobe Systems, San Jose, CA). Ten-frame windows were selected to allow for the classification of distinct, non-overlapping time-bins. Presumably, cognitive processing would be required in both time-bins immediately prior to verbalising both digits. However, after the verbalisation of the second digit, we presumed that the necessary processing for this arithmetic pair was complete, allowing participants to redirect cognitive resources towards visually scanning their walking path. It was unfeasible to include a post-verbalisation time-bin for the first digit in an arithmetic pair because, in several participants, the verbalisation of both digits occurred in such quick succession that the two time-bins (following the first digit, and preceding the second) would often overlap. Therefore, the second digit of the arithmetic pair was identified as containing the most appropriate time-bins for a post-verbalisation comparison, and patterns of visual search in a time-bin post verbalisation of the first digit were not investigated. The percentage of time spent fixating task-irrelevant areas was calculated for each of the four time-bins detailed above.

3.2.8 Statistical Analysis

Manipulation check. A paired-samples *t*-test was used to determine whether the Cognitive Load manipulation was successful in increasing cognitive demand, as determined by RSME scores. Effect size is reported as Cohen's *d*.

DTCs. Separate paired-samples *t*-tests were used to determine whether there was a significant decrease in raw performance scores for either the cognitive task or the motor task (stepping error) during Dual-Task trials, when compared to single-task. A Wilcoxon test was used to determine whether there was a significant decrease in raw performance scores for time to complete the walking trial during Dual-Task trials. The use of a non-parametric test was deemed necessary here (and elsewhere in this chapter) as data were non-normally distributed. Separate paired-samples *t*-tests were then used to determine whether any DTCs observed for either the cognitive task or the motor task (stepping error) were significant, when compared to zero (which represented identical Single- and Dual-Task performance). A Wilcoxon test was used to determine whether any DTCs observed for time to complete the walking trial were significant, when compared to zero. Effect size is reported as Cohen's *d*, unless the assumption of normality is violated, whereby effect size is reported as $r=Z/\sqrt{N}$ (Fritz, Morris, & Richler, 2012).

Gaze behaviour. A paired-samples *t*-test was used to investigate the effect of Cognitive Load on the number of task-relevant "inside" fixations. These data were normalized to trial length, with the number of fixations presented as the average number of fixations per second. Separate Wilcoxon's tests were used to investigate the effect of Cognitive Load on the duration (as a percentage of overall fixation durations) of task-relevant "inside" fixations, and on both the number (/per second) and duration (as a percentage of overall fixation durations) of task-irrelevant "outside" fixations, as these data were non-normally distributed.

Temporal relationship between cognitive load and visual search. A repeated measures ANOVA was used to investigate the percentage of time spent fixating task-irrelevant areas during each temporal time-bin. Effect size is reported as partial eta squared (ηp^2). Any significant effects were followed up by pairwise comparisons with Bonferroni adjustments.

Correlations. Separate bivariate correlations were run between three measures of trait-reinvestment (trait-MSRS; trait-CMP; trait-MSC) and each of the aforementioned variables. As multiple gaze data variables were not normally distributed (the duration of task-relevant "inside" fixations for Baseline trials; the number of task-irrelevant "outside" fixations for Baseline trials, and; the duration of task-irrelevant "outside" fixations for Baseline trials), Spearman's correlation were used for these comparisons. All other data were analysed using Pearson's correlation.

3.3 Results

3.3.1 Manipulation check.

Participants reported significantly higher levels of mental effort during Cognitive Load trials (*M* = 53.24, *SD* = 22.25), compared to Baseline (*M* = 10.21, *SD* = 6.44), *t*(10) = -7.45, *p* < .001, *d* = 2.63. There were no significant correlations between RSME scores and any measures of trait-reinvestment (trait-MSRS; trait-CMP; trait-MSC; *p*s > .44).

3.3.2 Dual-Task Assessments

Cognitive DTCs. Participants verbalised significantly fewer correct arithmetic calculations when completing the cognitive task while walking (*M* = 3.70, *SD* = 1.41), compared to when sitting (*M* = 4.91, *SD* = 1.45), *t*(10) = -3.99, *p* = .002, *d* = 0.85, with these

DTCs (Figure 3.3) being significant, *t*(10) = -3.38, *p* = .004, *d* = 1.44. There were no significant correlations between cognitive DTCs and any measures of trait-reinvestment (trait-MSRS; trait-CMP; trait-MSC; *p*s > .78).

Motor DTCs. During Cognitive Load, participants took significantly longer to traverse the walkway (Baseline, *M* = 4.58 s, *SD* = 0.95; Cognitive Load, *M* = 5.45 s, *SD* = 1.95), *Z* = -2.93, *p* = .002, *r* = 0.88, and had poorer stepping accuracy (Baseline, *M* = 58.83 mm, *SD* = 35.54; Cognitive Load, *M* = 68.07 mm, *SD* = 37.95), *t*(10) = -3.16, *p* = .005, *d* = 0.25. These DTCs were significant for both time to complete the walking trial, *Z* = -2.93, *p* = .002, *r* = 0.88, and absolute stepping accuracy, *t*(10) = -2.28, *p* = .025, *d* = 0.95. These data are presented in Figure 3.3. There were no significant correlations between motor DTCs and any measures of trait-reinvestment (trait-MSRS; trait-CMP; trait-MSC; *p*s > .29).

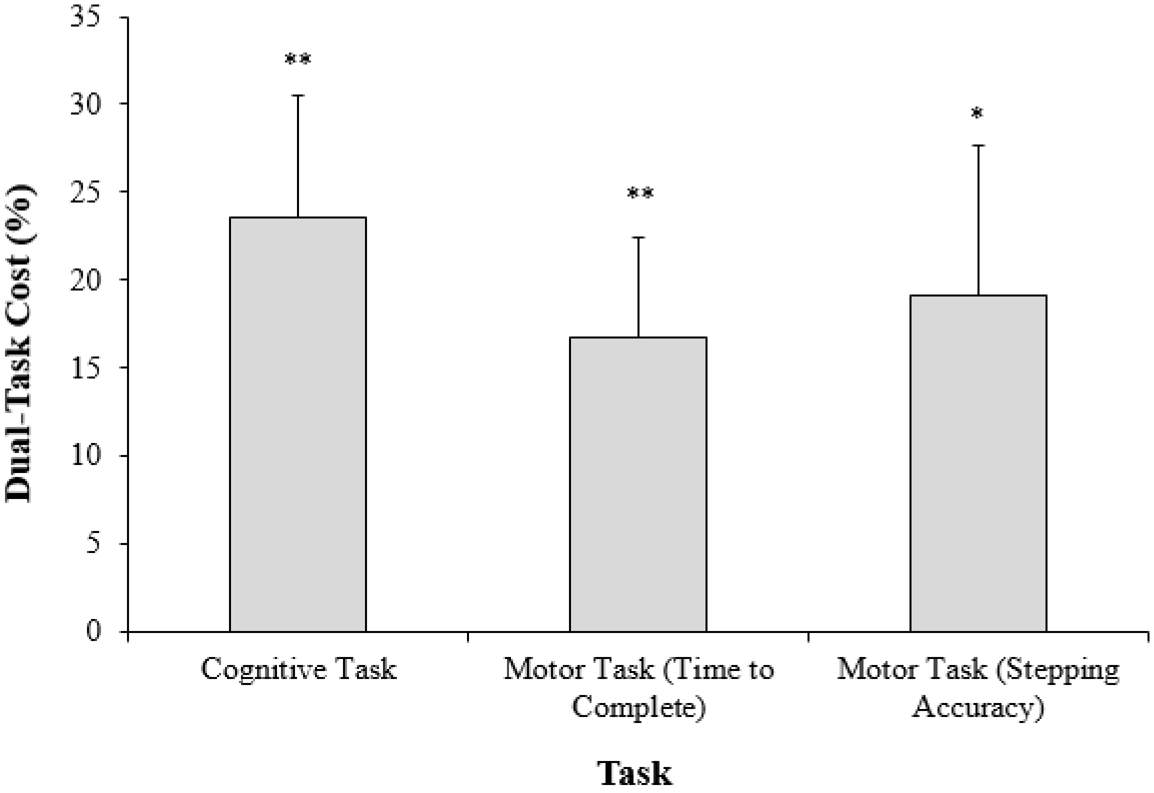

Figure 3.3. Dual-task costs (as a percentage decrease in performance compared to single-task performance) (mean ± standard error of the mean), * *p*<.05, ** *p*<.01

3.3.3 Gaze Behaviour

Task-relevant "inside" fixations. There was no significant effect of Cognitive Load on the number of task-relevant "inside" fixations, $t(10) = 1.38$, $p = .099$, $r = 0.34$. However, there was a significant effect of Cognitive Load on the duration (as a percentage of overall fixation durations) of task-relevant "inside" fixations, $Z = -2.58$, $p = .005$, $r = 0.78$. Participants spent significantly less time fixating on task-relevant "inside" areas under conditions of Cognitive Load, when compared to Baseline. These data are presented in Figure 3.4. This finding indicates that while participants did not differ in the number of task-relevant "inside" fixations made under increased cognitive load, these fixations were of a shorter duration. Trait-MSC scores were negatively correlated with duration of time spent fixating on task-relevant "inside" areas under conditions of Cognitive Load ($r= -.71$, $p = .015$), indicating that this reduction in task-relevant fixation durations was driven by high-trait-MSC individuals.

Task-irrelevant "outside" fixations. There was a significant effect of Cognitive Load on the number, $Z = -2.49$, $p = .007$, $r = 0.75$, and duration (as a percentage of overall fixation durations) of task-irrelevant "outside" fixations, $Z = -2.58$, $p = .005$, $r = 0.78$. Participants fixated "outside" the walking path more often, and for longer durations of time under conditions of Cognitive Load, when compared to Baseline. These data are presented in Figure 3.4. Trait-MSC scores were positively correlated with both the number ($r = .69$, $p = .032$) and duration of task-irrelevant "outside" fixations under Cognitive Load ($r = .71$, $p = .015$), indicating that high-trait-MSC was associated with longer and more frequent fixations on task-irrelevant "outside' areas under high cognitive load.

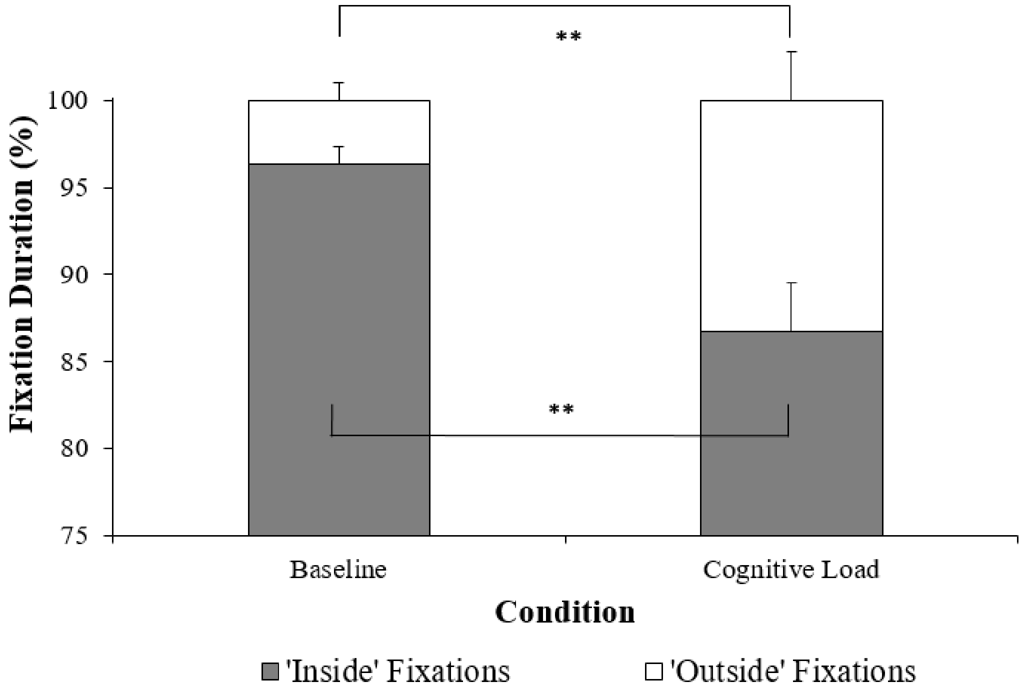

Figure 3.4. Duration (as a percentage of overall fixation durations) of task-relevant “inside” and task-irrelevant “outside” fixations under conditions of Baseline and Cognitive Load (mean ± standard error of the mean), ** *p*<.01.

3.3.4 Temporal Relationship between Cognitive Load and Visual Search

There was a significant effect of Calculation Time-Bin on the amount of time spent fixating “outside” task irrelevant areas, $F(1.86,18.58) = 6.97$, $p = = .006$, $\eta_p{}^2 = 0.41$. Bonferroni post-hoc tests revealed that individuals spent significantly more time fixating task-irrelevant areas in the 10-frames prior to verbalising both the first ($p = .041$) and second digit of an arithmetic dual-task pair ($p = .039$), when compared to 11-20-frames post second digit verbalisation (Figure 3.5).

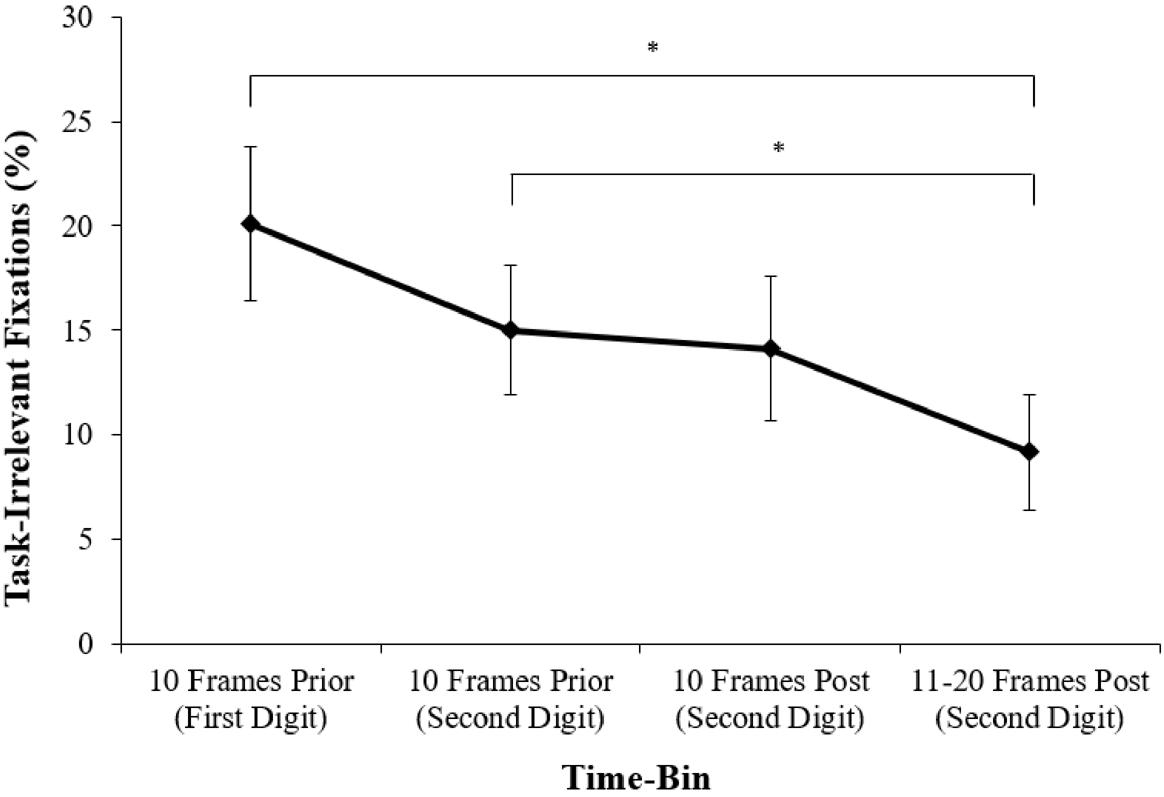

Figure 3.5. Percentage of time spent fixating task-irrelevant areas (as a %) during different time-bins (mean ± standard error of the mean), * *p*<.05

There were no significant correlations between the time spent fixating on "outside" task irrelevant areas in the 10-frames prior to verbalising the first digit and any measures of trait-reinvestment (trait-MSRS; trait-CMP; trait-MSC; *p*s > .23). However, trait-MSC was positively correlated with all three other time-bins: time spent fixating on "outside" task irrelevant areas in the 10-frames prior to verbalising the second digit of an arithmetic dual-task pair (*r* = .80, *p* = .003; Figure 3.6); time spent fixating task-irrelevant areas in the 10-frames post second digit verbalisation (*r* = .65, *p* .031), and; time spent fixating task-irrelevant areas in the 11-20-frames post second digit verbalisation (*r* = .73, *p* = .010). The lack of significant correlation between trait-MSC scores and the time spent fixating on "outside" task irrelevant areas in the 10-frames prior to verbalising the first digit in the dual-task calculation pair indicates that all participants initially prioritised the cognitive task over maintaining an effective pattern of visual search behaviours. However, in the 10-frames prior to verbalising the second digit in the dual-task calculation pair, low trait-MSC individuals had already begun to reallocate attention towards feedforward planning of how to negotiate the walking path, whereas high trait-MSC individuals continued to ‘gaze into thin-air’ at least until 20-frames following the verbalisation of the second digit in the dual-task arithmetic pair.

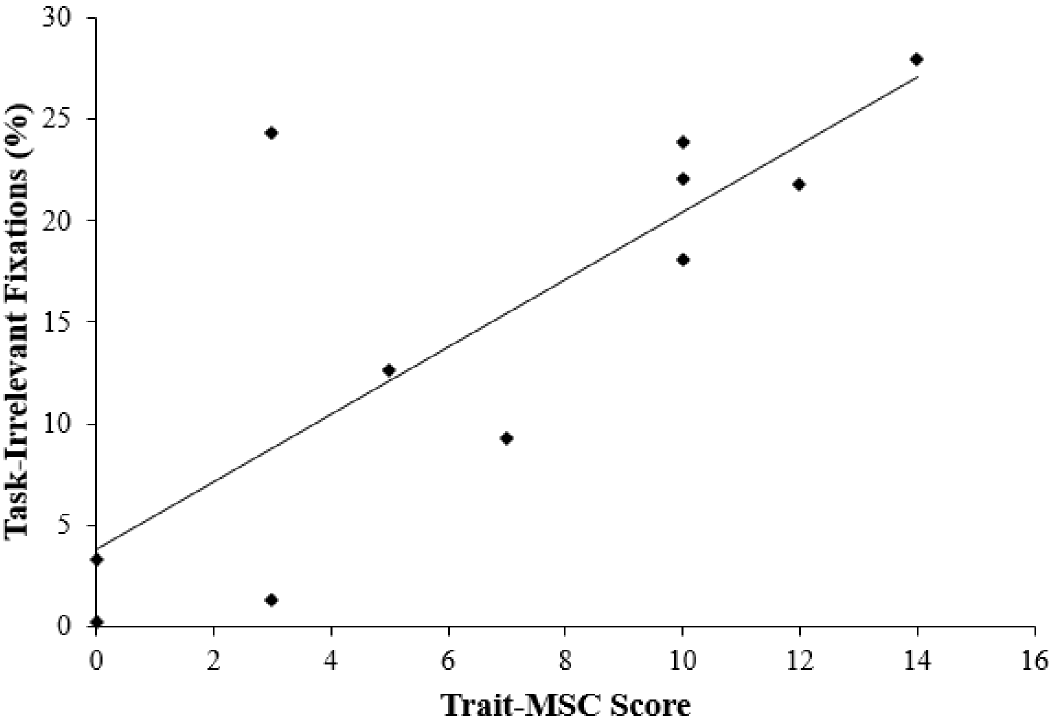

Figure 3.6. Correlation between trait-MSC and mean percentage of time spent fixating task-irrelevant areas in the 10 frames prior to verbalising the second dual-task arithmetic value.

3.4 Discussion

We examined whether increased cognitive load impacted on visual search behaviours during locomotion. Specifically, we examined whether the previously detailed less-variable patterns of visual search behaviours observed in high-risk older adults (i.e., focusing on the initial target for longer durations of time and failing to fixate on subsequent upcoming constraints) could be induced in a healthy younger adult cohort walking while simultaneously carrying out a cognitive dual-task.

Our results suggest that walking under increased cognitive load impaired individuals' ability to maintain effective visual search. However, the pattern of behaviour observed was different to that which was predicted. Instead of adopting a less-variable pattern of gaze behaviour (as described by Young et al., 2012), younger adults appeared to disengage visual attention from their walking environment altogether; a behaviour that might be termed "gazing into thin air". As illustrated in Figure 3.4, while walking under conditions of Cognitive Load participants fixated on task-irrelevant areas "outside" the walking path more often, and for longer durations of time, and fixated on task-relevant areas inside the walkway for shorter durations.

It has been suggested that the reductions in visual search observed in high-risk older adults may be caused by a form of conditioning, in which these individuals fail to effectively scan their environment as a result of being unable to retain the visual-spatial information that proactive visual search generates (Young & Williams, 2015). Therefore, it is possible that younger adults similarly disengaged from visually scanning their environment under conditions of Cognitive Load due to the reduced availability of cognitive resources necessary to store such spatial map of their surroundings in working memory. This latter suggestion is supported by research demonstrating how walking while simultaneously talking on a cell phone can cause "situational blindness", whereby younger adults fail to perceive unusual objects along their walking path, such as a unicycling clown (Hyman et al., 2009) or a tree with money attached to the leaves (Hyman et al., 2014). However, as gaze behaviour was not measured in this previous research, it is difficult to assess whether this situational blindness was in fact a consequence of individuals failing to visually scan their environment. For example, it is equally possible that participants' visual search strategies were unchanged, and that cell phone usage merely disrupted the storing of this information. This idea is supported by literature demonstrating reduced memory for objects during dual-task conditions of driving, even when the objects are directly fixated on (Strayer, Cooper, & Drews, 2004; Strayer, Drews, & Johnston, 2003). As visuo-spatial memory was not assessed in the present experiment, future research should look to investigate the relationship between cognitive load, gaze behaviour, and the retention of the visual information acquired through proactive visual search.

These changes in visual search behaviour under Cognitive Load were accompanied by significant increases in both time to complete the walking task and absolute stepping errors. Researchers have demonstrated that an absence of visual information during gait can result in both a more cautious walking pattern (i.e. slower speed, smaller steps; Terrier, Dériaz, & Reynard, 2013) and impaired stepping accuracy (Chapman & Hollands, 2006a). Therefore, it is entirely plausible that these observed reductions in motor performance under conditions of Cognitive Load may be a consequence of participants spending less time visually previewing their walking path and more time fixating on task-irrelevant areas “outside” of the walkway. This proposal is supported by research demonstrating that dual-task-related declines in gait performance are more pronounced during walking tasks requiring greater visual processing and feedforward visual planning, such as obstacle avoidance (Beurskens & Bock, 2013). However, this proposed relationship between cognitive load-induced inefficiencies in visual search and impaired gait performance needs to be explored in greater detail before a causal link can be established. Unfortunately, given the highly variable nature of the walking task used in the present research, we were unable to conduct an analysis to quantify the temporal relationship between gait and gaze behaviour and establish a causal link. For example, as task-irrelevant “outside” fixations occurred both on straight sections of the walkway and during turns, gait velocity would likely differ independent of gaze location.

Our results do, however, demonstrate a clear temporal relationship between changes in visual search and the processing of a cognitive second task. As illustrated in Figure 3.5, participants spent significantly longer time periods ‘gazing into thin air’ in the time-bins directly preceding an arithmetic calculation (verbalisation of both the first and second digit of an arithmetic calculation pair), when compared to the time-bins post-verbalisation of the second digit. These results indicate that younger adults disengaged visual attention from the walking path in order to prioritise the processing of information relevant to the cognitive secondary task. This observation suggests that acquiring and processing visual information during adaptive gait carries an attentional demand, which can be significantly disrupted under when performing a cognitively demanding simultaneous task.

From a working memory perspective (e.g., Baddeley, 1974), we might have predicted that the level of interference between the two tasks should have been minimal, because each depends on a different aspect of working memory. For example, the information obtained through visual search behaviour is likely to be processed and stored within the visuo-spatial sketchpad (a system dedicated to maintaining and manipulating visuo-spatial information), while the arithmetic dual-task is likely to be processed within the phonological loop (a short-term buffer responsible for storing and processing verbal information). However, our results suggest that the two tasks may share common central processing resources. Visual information acquired during adaptive needs to be constantly monitored and updated (Higuchi, 2013); two processes which necessitate input from the central executive component of working memory (Henry, 2011). In addition, researchers have demonstrated how loading the central executive impairs performance on a wide range of mental arithmetic tasks (de Rammelaere, Stuyven, & Vandierendonck, 1999, 2001; Seitz, & Schumann-Hengsteler, 2001), which this research also implying that the central executive plays a role in even simple arithmetic calculations. Therefore, our results suggest that a form of structural interference occurred, with both tasks competing for common central executive resources, and participants disengaging from visually scanning their environment in order to prioritise the arithmetic calculation. According to this rationale, visual search during locomotion may be disrupted by the simultaneous processing of any task requiring central executive input, which may include anxiety-related processes (Derackshan & Eysenck, 2009; Eysenck et al., 2007) and conscious movement monitoring and control (i.e., reinvestment; Masters & Maxwell, 2008).

Indeed, this study is the first to indicate a relationship between trait-reinvestment and changes in visual search strategies. As predicted, the changes in visual search behaviours under cognitive load were the most pronounced in high-trait-reinvesters. We found that trait-MSC scores (a measurement of how self-conscious an individual is about the way they look when moving) were negatively correlated with the duration of time spent fixating on task-relevant “inside” areas under Cognitive Load, and positively correlated with both the number and duration of task-irrelevant “outside” fixations under Cognitive Load. We suggest that the aforementioned significant Baseline-Cognitive Load changes in visual search were driven by the gaze behaviour of high-trait-reinvesters. Researchers have previously suggested that trait-reinvestment places greater cognitive demands upon the working memory of older adults (Young et al., 2016). Therefore, we speculate that trait-MSC-related processes (such as forming a visual representation of the way you move, or ruminating about the way you look when you move) may place demands on the central executive component of working memory. These results indicate that due to demands associated with maintaining an awareness of body movements, high-trait-MSC individuals disengaged from visually scanning the walking path in order to make the necessary cognitive resources available to perform the arithmetic task.

Our results also demonstrate that trait-reinvestment was related to temporal changes in visual search. While there was no significant correlation between trait-MSC scores and the time spent ‘gazing into thin air’ in the 10-frames prior to verbalising the first digit of an arithmetic dual-task pair, strong, significant positive correlations were observed between trait-MSC scores and the time spent ‘gazing into thin air’ in: 1) the 10-frames prior to verbalising the second digit of an arithmetic dual-task pair; 2) the 10-frames post second digit verbalisation; and 3) the 11-20-frames post second digit verbalisation. These correlations, in combination with the aforementioned temporal analysis data, suggest that, regardless of trait-reinvestment scores, younger adults in general experienced structural interference in the 10-frames prior to verbalising the first digit of an arithmetic dual-task pair, resulting in a situation where they had to prioritise between visual search and the cognitive task. Participants then disengaged from visually scanning their walking path in order to prioritise this cognitive task. However, in the 10-frames prior to verbalising the second value in the dual-task calculation pair, low-trait-MSC individuals began to reallocate attention towards the walking path. In contrast, high-trait-MSC individuals continued to ‘gaze into thin air’ up to 20-frames (660 ms) following the verbalisation of the second digit in the dual-task calculation. This finding suggests that trait-reinvestment disrupted the ability to re-engage visual attention towards the path following an incidence of ‘gazing into thin air’.

One of the roles of the central executive is to allocate attention between tasks (Henry, 2011). Therefore, it is conceivable that demands placed on the central executive by reinvestment-related processes disrupted individuals’ abilities to switch attention between processing the cognitive dual-task and carrying out effective visual search. Indeed, Young et al. (2016) found higher levels of trait-reinvestment in older adults who “stopped walking when talking”; that is to say, individuals who were unable to effectively switch attention between two tasks (walking and answering a researcher’s question). If trait-reinvestment does disrupt the allocation of attention between tasks it is, therefore, possible that the previously detailed postural stiffening observed in high-trait-MSC younger adults under conditions of anxiety (Zaback et al., 2015) may not relate to conscious movement control and the freezing of degrees of freedom associated with deliberate control of an automatic movement, as previously suggested (Young & Williams, 2015). This reinvestment-related stiffening may be a protective mechanism for stabilising posture, so as to allow disengagement of attention from postural control for purposes of anxiety-related processing.

Our results suggest that older adults with high levels of trait-reinvestment might be particularly susceptible to reductions in the efficiency of visually previewing an intended path when carrying out a concurrent task. This is particularly problematic, as reduced visual previewing is associated with increased frequency of gross stepping errors in this population (Young & Williams, 2015; Young et al., 2012). However, as we only explored changes in visual search behaviours under cognitive load in a younger adult cohort, the results presented cannot be generalized to clinical populations at a high risk of falling (i.e., high-anxious older adults). For example, as the walking task used in the present research was one of both relative simplicity and low risk, it is possible that younger adults felt able to safely disengage from visually scanning their environment while maintaining balance. Published reports suggest that the degree to which older adult fallers prioritise a postural task over a cognitive dual-task is dependent upon perceived risk (Muhaidat, Kerr, Evans, & Skelton, 2013). Consequently, it is possible that these results will not translate to older adults; particularly those deemed to be at a high risk of falling. Another limitation of this study relates to the use of low-powered correlational analyses to evaluate an association between conscious movement processing (i.e., “reinvestment”) and attentional processing inefficiencies/visual search behaviours. Future experimental chapters will thus explore how experimentally-induced conditions of heightened conscious movement processing influences both attentional processing efficiency and visual search during adaptive locomotion.

3.5 Conclusions

Our results demonstrate that cognitive load impacted the visual search efficiency of younger adults during an adaptive gait task. While walking under conditions of Cognitive Load, young adults fixated on task-irrelevant areas “outside” the walking path more often, and for longer durations of time, and fixated on task-relevant areas “inside” the walkway for shorter durations. These changes were most pronounced in high-trait-MSC individuals, presumably because reinvestment-related processes placed an additional cognitive demand upon working memory. These increased task-irrelevant “outside” fixations were accompanied by both slower walking task completion rates and greater gross stepping errors, indicating that these changes in visual search negatively impacted gait performance. The findings suggest that attention is important for the maintenance of effective gaze behaviours, supporting previous claims that aforementioned maladaptive changes in visual search observed in high-risk older adults may be a consequence of inefficiencies within attentional processing (Young & Williams, 2015). Future experimental chapters will thus seek to use experimental manipulations to explore the conditions which can impair attentional processing efficiency during (e.g., fall-related anxiety, conscious movement processing, etc.).

Chapter 4: Conscious Motor Control Impairs Attentional Processing Efficiency During Precision Stepping

Study 2 was published in *Gait and Posture*

(see Section List of Thesis Publications)

4.1 Introduction

It is widely accepted that the control of posture and gait requires some degree of cognitive input (Woollacott & Shumway-Cook, 2002). Much in the same way that anxiety can disrupt attentional processing, and subsequent performance, on other tasks requiring cognitive input (such as analogical problem solving; Beilock, Kulp, Holt, & Carr, 2004; Eysenck et al., 2007), research demonstrates that fall-related anxiety can compromise attentional processing efficiency during gait in both young (Gage et al., 2003) and older adults (Gage et al., 2003; Uemura et al., 2012). These inefficiencies can reduce the cognitive resources available for carrying out cognitively demanding concurrent processes necessary for safe locomotion – which, as Chapter 3 indicates, may include the maintenance of effective visuomotor control of locomotion.

Fall-related anxiety may impair processing efficiency by virtue of walkers allocating attention ‘internally’ towards movement-specific processes (Gage et al., 2003). A causal relationship between fall-related anxiety and increased conscious movement processing has been documented in both young adults standing at height (Huffman et al., 2009; Zaback et al., 2015, 2016) and older adults when walking (Young et al., 2016). Cross-sectional results presented in Chapter 3, as well as those published previously by Young et al. (2016), also indicate that consciously processing movement increases the attentional demands of walking, thereby reducing cognitive resources available for carrying out concurrent processes. However, a causal relationship between the adoption of an internal focus and compromised attentional processing efficiency during gait is yet to be evaluated.

In the current study we aimed to investigate whether fall-related anxiety can compromise attentional processing efficiency during gait, as a consequence of walkers allocating attention towards movement-specific processes. To achieve this aim, we sought to experimentally induce both fall-related anxiety and conscious movement processing (independent of anxiety) and answer whether an internal focus of attention can impair attentional processing efficiency during gait in a manner similar to anxiety. Young adults performed a precision stepping task during both single- and dual-task, under three conditions: Baseline; Threat, and; Internal focus of attention. We predicted that: (a) Attentional processing efficiency would be impaired during Threat (indicated by greater cognitive dual-task costs); (b) These inefficiencies would be associated with greater internal focus, with the greatest costs observed in individuals reporting the highest levels of conscious movement control, and; (c) Significant processing inefficiencies would also be observed when manipulating attentional focus during the Internal condition (independent of anxiety).

4.2 Method

4.2.1 Participants

Fifteen young adults (male/female: 8/7; mean ± SD age: 25.47 ± 2.42 years) were recruited from postgraduate courses at the lead institution. Inclusion criteria required participants to be free from any musculoskeletal, visual, auditory or speech problems. Ethical approval was obtained by the local ethics committee at the lead institution and the research protocol was carried out in accordance with the principles laid down by the Declaration of Helsinki. All participants provided written and informed consent. Based on previous research which has reported very large effect sizes for the effects of conditions of fall-related anxiety on dual-task performance (Gage et al., 2003), a power analysis conducted with G*Power (Faul et al., 2009) determined that between 5 and 12 participants would be required to obtain 80% power (Cohen, 1988).

4.2.2 Procedure

Participants walked at a self-determined pace along a 3.3 m wooden walkway and stepped into two foam targets (see Figure 4.1) comprising raised borders (border width and height = 4 cm). The inside area of the target was 19 cm x 41.5 cm (width x length). Participants were instructed to “step into the middle of the target, placing the mid-foot marker (see section 4.2.4) as close to the centre of the target as possible”. Participants were permitted to step into each target with whichever foot they wished. At the start of each trial, participants stood behind a ‘start line’ and began walking upon an auditory ‘go’ tone (played through a speaker located 0.75 m to the left of the walkway). The 3.3 m distance from the start to the end of the walkway used in the present research was comparable to distances used previously by Matthis and Fajen (2014) for similar adaptive gait tasks.

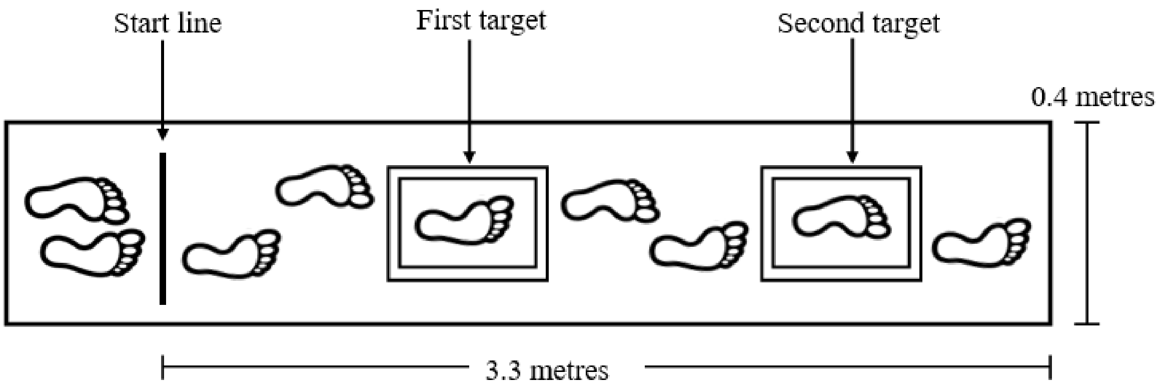

Figure 4.1. Schematic diagram of the walkway and precision stepping task. The foam targets had a border width and height of 4 cm (i.e., the foam border was 4 cm wide and raised 4 cm from the walkway). The inside area of the target was 19 cm x 41.5 cm (width and length, respectively).

Participants completed walks under three conditions: Baseline; Threat, and; Internal. Baseline involved participants completing the protocol at ground level. Threat involved participants completing the protocol while the walkway was elevated 1.1 m above ground, in the absence of a safety harness. Internal required participants to complete the protocol at ground level, while focusing their attention internally towards movement. To achieve this, participants were informed that after each trial in this condition, they would be asked a question relating to their movement. These questions were comparable to those used previously to determine “internal awareness” (Uiga, Capio et al., 2015; Young et al., 2016) and were designed to encourage the adoption of an internal focus throughout the duration of the trial. Examples included: “What foot did you step into of the first/second target with?” and “How many steps did you take to complete the trial?” Participants were ‘informed’ that any trials in which they answered incorrectly would be repeated. While this deception was used to ensure engagement with the manipulation, response accuracy was recorded. Four participants provided an incorrect answer for 1 trial, respectively.

Participants completed 10 trials per condition, split across two 5-trial blocks. The presentation order of conditions was randomised, however participants only ever completed 5 trials in one condition, before being presented with a different condition. Target locations were rearranged after every block to prevent familiarisation. Targets could appear in two randomised locations (first target: either 100 cm or 110 cm from the start line; second target: either 190 cm or 200 cm from the start line).

Trials were completed under both Single-task and Dual-task conditions. Dual-task consisted of walking while concurrently subtracting in 7s from a randomised number between 70 and 90. Participants were presented with the starting number directly prior to the ‘go’ tone, following which they began to walk and subtract out loud. Participants were instructed to allocate equal attention towards both the walking and arithmetic task (as per Chapter 3). For each condition, participants completed five Single-task and five Dual-task trials, the order of which was randomised across each condition (i.e., each 5-trial block contained a randomised combination of Single- and Dual-task trials).

4.2.3 Self-Reported State Psychological Measures

Participants rated their fear of falling and state movement-specific reinvestment (to measure conscious movement processing) after each block of 5-trials. To assess fear of falling, participants were asked: “Using the following scale, please rate how fearful of falling you felt during the past five trials” (Zaback et al., 2015). This scale ranged from 0% (not at all fearful) to 100% (completely fearful). State movement-specific reinvestment was measured using a shortened version of the Movement Specific Reinvestment Scale (MSRS; Masters et al., 2005). This 4-item questionnaire consisted of two 2-item subscales: conscious motor processing, i.e., ‘movement control’ (state-CMP; e.g., “I am always trying to think about my movements when I am doing this task”) and movement self-consciousness, i.e., ‘movement monitoring’ (state-MSC; e.g., “I am concerned about my style of moving when I am doing this task”). Items were rated on a 6-point Likert scale (1 = *strongly disagree*; 6 = *strongly agree*). A shortened 4-item version of the MSRS has been used previously by Young et al. (2016).

4.2.4 Attentional Processing (Dual-Task Assessments)

To quantify the extent to which these experimental conditions influenced an individual’s ability to execute two tasks concurrently, we calculated dual-task costs (DTCs) using the identical formula to that used previously in Chapter 3. Thus, higher DTCs reflect decreased performance under dual-task. Raw performance values are presented in Table 4.1.

Cognitive DTCs. Cognitive performance was defined as the number of correct arithmetic calculations verbalised. Dual-task scores were calculated during trials where participants performed the cognitive task while walking (‘Dual-task’). Single-task scores were calculated while participants performed the cognitive task from a seated position (‘Single-task’). During Single-task, participants were given 30 seconds to subtract as many times as possible in 7s from a randomised number. The number of correct calculations verbalised during Dual-task trials (until participants reached the end of the walkway) were then compared to those verbalised during a proportional period of time during Single-task. Separate single- and dual-task scores (and subsequent DTCs) were calculated for Baseline, Threat and Internal.

Motor DTCs. Two separate motor variables were calculated: (1) Stepping accuracy (mm) in the first target, for both anterior-posterior (AP) and medial-lateral (ML) directions, and (2) Gait speed (m/s). Stepping accuracy was calculated using reflective markers placed on the heel, toe (second metatarsal) and mid-foot (mid-point between the heel and second metatarsal) of both feet. The motor task featured two targets, rather than one, as previous research suggests that anxiety may only influence stepping accuracy (into the first target) when two or more stepping constraints are present (Young et al., 2012). Stepping accuracy was evaluated for the first target only to allow us to place our results within the context of previous research (Chapman & Hollands, 2007; Curzon-Jones & Hollands, 2018; Vitório, Gobbi, Lirani-Silva, Moraes, & Almeida, 2016; Young et al., 2012). Kinematic data were collected at 100Hz using a Vicon motion capture system (Oxford Metrics, England). Kinematic data were passed through a low-pass butterworth filter with a cut-off frequency of 5 Hz and analysed using custom algorithms in MATLAB 7.11 (MathWorks, Natick, MA). Stepping accuracy was calculated by subtracting the AP and ML co-ordinate of the mid-foot marker from that of the centre of the target (Young & Hollands, 2012b); with higher values representing greater stepping error. Gait speed was calculated until heel contact (calculated as the maximum vertical acceleration of the heel marker; Young & Hollands, 2012b) into the first target. Single-task performance was calculated during trials of Single-task walking (no cognitive dual-task), while dual-task scores were calculated during trials where participants performed the cognitive task while walking (‘Dual-task’). Separate single- and dual-task scores (and subsequent DTCs) were calculated for Baseline, Threat and Internal.

4.2.5 Statistical Analysis

Separate repeated-measures ANOVAs (effect size reported as partial eta squared; Bonferroni post-hoc tests used to follow up statistically significant results) were used to investigate the effect of Condition on self-reported state psychological measures (fear of falling, state-CMP and state-MSC) and cognitive DTCs. Separate paired-samples *t*-tests were then used for each condition to determine whether any cognitive DTCs were significant, when compared to zero (i.e., to determine whether performance significantly declined during Dual-task conditions) (as per Chapter 3). Effect size is reported as Cohen's *d.*

Separate Friedman tests were used to investigate the effect of Condition on motor DTCs (AP and ML stepping accuracy, and gait speed). The use of a non-parametric test was deemed necessary as data were non-normally distributed. Any significant main effects were followed up by separate Wilcoxon tests (Bonferroni corrected to 0.017). Due to difficulties associated with calculating effect size for Friedman tests, effect sizes are calculated (as $r=Z/\sqrt{N}$) instead for any Wilcoxon test follow-ups (Field, 2013). Separate Wilcoxon tests/paired-samples *t*-tests were then used for each variable to determine whether any motor DTCs were significant, when compared to zero (effect sizes calculated as either Cohen's *d* or $r=Z/\sqrt{N}$) (as per Chapter 3).

Separate bivariate correlations were used to explore possible relationships between each self-reported state psychological measure (fear of falling, state-CMP and state-MSC) during Threat and both cognitive and motor DTCs during this condition. To investigate the potential confounding influence of between-condition differences in gait speed, motor DTCs for gait speed were also correlated with cognitive and stepping accuracy DTCs for each respective Condition. Only significant correlations are reported (alpha set *a priori* at 0.05).

4.3 Results

4.3.1 Self-Reported State Psychological Measures

There was a significant effect of Condition on fear of falling ($F(1.04,14.49) = 19.49$, $p < .001$, $\eta p^2 = 0.58$). Participants reported significantly greater fear of falling during Threat ($M = 34.33\%$, $SD = 28.84$), compared to both Baseline ($M = 5.33\%$, $SD = 5.50$, $p = .002$) and Internal ($M = 7.67\%$, $SD = 7.99$, $p = .002$).

There was also a significant effect of Condition on state-CMP ($F(2,28) = 6.31$, $p = .005$, $\eta p^2 = 0.31$). Compared to Baseline ($M = 7.40$, $SD = 2.58$), participants reported significantly greater state-CMP during both Threat ($M = 9.03$, $SD = 2.77$, $p = .031$) and Internal ($M = 9.60$, $SD = 1.39$, $p = .021$). There was no significant effect of Condition on state-MSC (*Baseline* $M = 6.13$, $SD = 2.17$; *Threat* $M = 6.57$, $SD = 2.85$; *Internal* $M = 6.93$, $SD = 2.57$, $F(2,28) = 0.84$, $p = .44$, $\eta p^2 = 0.06$).

4.3.2 Attentional Processing (Dual-Task Assessments)

There was a significant effect of Condition on cognitive DTCs ($F(1.04,14.49) = 7.76$, $p = .002$, $\eta p^2 = .36$). Post-hoc tests revealed significantly greater cognitive DTCs during both Threat ($p = .028$) and Internal ($p = .011$), compared to Baseline (Figure 4.2). While significantly greater DTCs were observed for these two conditions, significant cognitive DTCs (significant decrease in performance during Dual- compared to Single-task) were observed for all 3 conditions: Baseline ($t(14) = 6.19$, $p < .001$, $d = 2.26$), Threat ($t(14) = 13.07$, $p < .001$, $d = 4.77$) and Internal ($t(14) = 8.14$, $p < .001$, $d = 2.97$) (Figure 4.2).

There was no significant effect of Condition on motor DTCs for either AP ($\chi^2(2) = 0.13$, $p = .94$) or ML stepping accuracy ($\chi^2(2) = 1.20$, $p = .55$), or gait speed ($\chi^2(2) = 1.20$, $p = .55$) (Figure 4.2). Despite the lack of any significant effect of Condition of motor DTCs, significant motor DTCs for ML stepping accuracy (i.e., significantly greater stepping errors during Dual- compared to Single-task) were observed during both Threat ($Z = -1.93$, $p = .027$, *r* = 0.50) and Internal (*Z* = -2.16, *p* = .016, *r* = 0.56) (Figure 4.2). Significant motor DTCs for gait speed (i.e., significantly slower gait during Dual-task) were also were also observed for: Baseline (*t*(14) = -3.20, *p* = .003, *d* = 1.17), Threat (*Z* = -2.57, *p* = .006, *r* = 0.66) and Internal (*t*(14) = -3.78, *p* = .001, *d* = 1.38) (Figure 4.2).

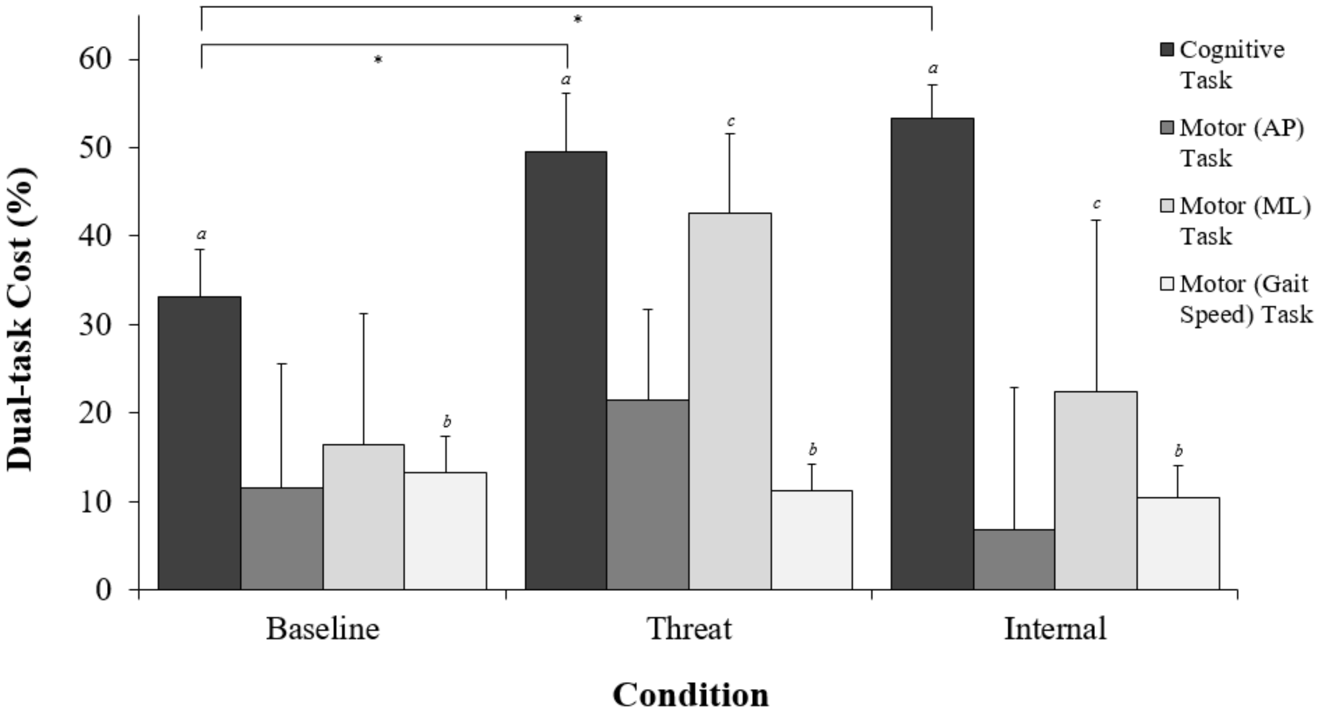

Figure 4.2. Dual-task costs (as a percentage decrease in performance during Dual- compared to Single-task) (mean ± standard error of the mean), * $p < .05$; ^{a} dual-task cost significant to $p < .001$ (i.e., a significant decrease in performance during Dual- compared to Single-task), ^{b} dual-task cost significant to $p < .01$, ^{c} dual-task cost significant to $p < .05$

Table 4.1. Raw mean ± SD single- and dual-task values.

	Single-task Performance			**Dual-task Performance**		
	Baseline	**Threat**	**Internal**	**Baseline**	**Threat**	**Internal**
Cognitive Task (no. correct)*	2.29 ± 0.99	3.00 ± 1.11	2.91 ± 1.41	1.45 ± 0.51	1.45 ± 0.49	1.32 ± 0.75
AP Stepping Accuracy (mm)	30.62 ± 15.46	27.93 ± 15.79	27.43 ± 11.70	30.80 ± 16.18	30.68 ± 16.81	27.36 ± 12.84
ML Stepping Accuracy (mm)	16.04 ± 7.27	15.25 ± 9.60	17.45 ± 7.11	17.82 ± 10.09	18.79 ± 12.19	20.09 ± 7.34
Gait Speed (m/s)	0.69 ± 0.18	0.65 ± 0.19	0.63 ± 0.17	0.59 ± 0.19	0.58 ± 0.18	0.56 ± 0.17

*Note, that while single-task performance on the Cognitive Task was calculated during a 30-s period of arithmetic calculation (completed while seated), single-task values were extracted for a time-period proportional to the participants' mean Dual-task trial length for that condition (i.e., if a participant completed Dual-task Threat trials in 9-seconds, then single-task performance was calculated for the first 9-seconds while seated). Consequently, the time period during which participants performed the arithmetic task was proportionate within (i.e., proportionate for single- and dual-task within that condition), but not between, experimental conditions. As such, between-condition comparisons are performed on DTCs, rather than raw values.

4.3.3 Correlational Analyses

During Threat, state-CMP was significantly positively correlated with cognitive DTCs (r = .47, p = .04) (Figure 4.3), while fear of falling was significantly negatively correlated with motor DTCs for ML stepping accuracy (r = -.66, p = .008). There was a lack of any other significant correlations (p's > .18). Additionally, gait speed DTCs were not significantly correlated with any other DTC variables (p's > .11).

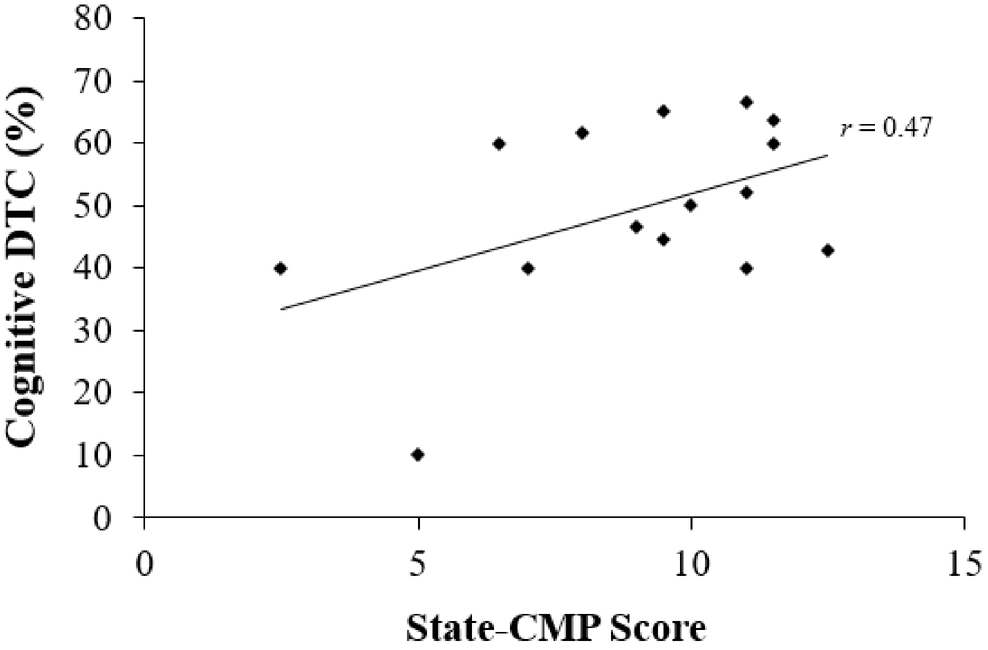

Figure 4.3. Correlation between cognitive DTCs (%) and State-CMP scores during Threat.

4.4 Discussion

As predicted, significantly greater cognitive DTCs were observed during Threat, compared to Baseline (Figure 4.2). Moreover, state-CMP was significantly correlated with cognitive DTCs during Threat, indicating that the greatest cognitive DTCs were observed in the individuals directing the most attention towards conscious motor control.

We also observed significantly greater cognitive DTCs for Internal (during which participants reported significantly greater conscious movement control), compared to

Baseline. This finding demonstrates evidence of a causal link between conscious movement control and impaired attentional processing efficiency during gait. These results extend the cross-sectional data presented in Chapter 3, confirming the assumption that consciously attending to movement processes is attention demanding and reduces resources available for carrying out secondary tasks during gait. They also support other research which has reported similar patterns of results in other tasks, such as sporting movements (Masters & Maxwell, 2008), complex decisions (Kinrade, Jackson, & Ashford, 2015) and mental arithmetic (Kinrade, Jackson, & Ashford, 2010).

Attentional processing inefficiencies have been previously reported in individuals when walking at height (Gage et al., 2003; Uemura et al., 2012). Gage et al. (2003) speculated that fall-related anxiety may impact attentional processing as a consequence of increased cognitive resources being directed towards the control of gait. Results from the present study provide empirical evidence for this relationship; implicating conscious movement control as the mediating variable in the relationship between fall-related anxiety and attentional processing inefficiencies. One population for whom fall-related anxiety is a prevalent problem is older adults (Hadjistavropoulos et al., 2011; Young & Williams, 2015). Attentional processing inefficiencies have also been reported in older adults anxious about falling (Gage et al., 2003; Uemura et al., 2012), with these inefficiencies associated with poorer stepping performance (Uemura et al., 2012). Future research should, therefore, assess the degree to which these inefficiencies observed in anxious older adults are a consequence of increased conscious movement processing.

Despite the comparable increases in both conscious movement control and cognitive DTCs during Threat and Internal (and the significant correlation observed between state-CMP and cognitive DTCs during Threat), we cannot be certain that these processing inefficiencies are underpinned by the same mechanism (i.e., conscious movement control).

For example, research demonstrates attentional processing inefficiencies in anxious individuals irrespective of any change in conscious movement processing (Beilock et al., 2004; Eysenck et al., 2007); through the likely mechanism of ruminative thoughts/worries (Eysenck et al., 2007). Therefore, one cannot dismiss the potential influence of other anxiety-related mechanisms during Threat. The following experimental chapters will, thus, seek to provide a more detailed account of the changes in attention that occur when anxious about falling and which may also influence attentional processing efficiency (e.g., worrisome thoughts related to falling or self-regulatory strategies to overcome anxiety).

The increased cognitive DTCs observed during both Threat and Internal were accompanied by significant motor DTCs for ML stepping accuracy, highlighting poorer stepping accuracy during Dual, compared to Single-task, trials in both Threat and Internal (Figure 4.2). No such Dual-task related declines in stepping accuracy were observed during Baseline. This result was unexpected, as we predicted that directing attention towards movement during Threat and Internal would have resulted in participants adopting a “posture-first” strategy; whereby the motor task would have been prioritised above the cognitive task, thus resulting in maintained motor performance. While participants did direct attention towards consciously controlling movement during both Threat and Internal, significant motor DTCs (i.e., significantly poorer stepping accuracy compared to Single-task) were also observed during these conditions.

Stepping is a visually guided action, requiring both on-line and feedforward visual control (Hollands & Marple-Horvat, 1996; Hollands et al., 1995). The results presented in Chapter 3 also demonstrate that effective visual search during adaptive gait requires cognitive resources. Consequently, we propose that attempting to consciously control one’s movement while simultaneously performing a secondary cognitive task limited the attentional resources available for carrying out the processes necessary for effective performance on the motor task

– such as effective visual search/visuomotor control. Indeed, Uiga, Cheng et al. (2015) propose that adopting an internal focus during gait may increase fall-risk by reducing the likelihood of perceiving external information necessary for successful locomotion. The following experimental chapter will seek to explore this proposal further.

One limitation of the present research relates to the aggregating of the state psychological measures across each experimental block (which contained both Single- and Dual-task walks), rather than measuring these on a trial-by-trial basis. It is possible that the arithmetic dual-task may have acted as a ‘distracter’, with individuals less able to focus on consciously processing their movement during Dual-task; and that the higher state-CMP scores observed during Threat and Internal represent greater conscious motor processing during Single-task only. However, measuring the impact of a secondary task during motor performance is a common method to assess movement automaticity (Kal, Van Der Kamp, & Houdijk, 2013), under the assumption that conscious movement control places greater demands on cognitive resources. As Kal et al. (2013) note, “the execution of a secondary task is expected to interfere with performance on a consciously controlled motor task […] but should not – or to a lesser extent – affect performance on an automatized task” (p. 528). Therefore, if participants only consciously controlled their movement during Single-task, we would not expect to observe increased DTCs during Threat or Internal (as this line of argument would propose that conscious control would have ‘returned’ to Baseline levels during Dual-task trials in these two conditions). Furthermore, as these measures were used to assess the relationship between state psychological functioning and DTCs (which, themselves, are a composite score of Single- and Dual-task performance), we determined it necessary to aggregate these measures across trials of both Single- and Dual-task.

4.5 Conclusions

These results demonstrate evidence of a causal link between conscious movement processing and impaired attentional processing efficiency during gait. They also implicate conscious movement control as a potential mediator between fall-related anxiety and impaired attention processing, supporting speculations made previously by Gage et al. (2003). These findings suggest that such conscious mode of motor control may thus reduce the cognitive resources available for carrying out other concurrent process; which, during adaptive locomotion, may include proactive visual search (Young & Williams, 2015). The next stages in this programme of research will thus explore the influence of conscious movement processing (and fall-related anxiety) on visual search behaviours during adaptive locomotion; and examine whether visual search is influenced during these conditions as a result of impaired processing efficiency.

Chapter 5: The Influence of Anxiety and Attentional Focus on Visual Search During Adaptive Gait

Study 3 was published in *Journal of Experimental Psychology: Human Perception and Performance*

(see Section List of Thesis Publications)

5.1 Introduction

Research demonstrates the varied and largely detrimental effects that anxiety can have on perceptual-motor performance (e.g., taking a penalty kick during a world-championship final [Hardy, 1996; Nieuwenhuys & Oudejans, 2012]). Research from the domain of sport psychology highlights how anxiety can jeopardise both motor coordination and the extent to which performers visually scan their environments prior to, and during, movement execution (for reviews, see Janelle, 2002; Nieuwenhuys & Oudejans, 2012; Vickers, 2007). Typically, anxious performers display less efficient visual scanning behaviours (Janelle, 2002). They are more easily distracted by task-irrelevant information (Nieuwenhuys & Oudejans, 2012; Williams & Elliott, 1999) and they focus on task-relevant information for shorter durations (Nibbeling et al., 2012; Wilson, Vine et al., 2009). Such behaviours are strongly correlated with poorer execution of subsequent movements (Nibbeling et al., 2012; Vickers, 2007; Wilson et al., 2009).

Locomotion, particularly in complex environments, is predominantly a visually guided action (Chapman & Hollands, 2006a; Matthis et al., 2015, 2017; Matthis & Fajen, 2013; Patla, 1991, 1998; Patla & Vickers, 2003). Therefore, the visual-perceptual processes necessary for effective control of this movement (e.g., visually scanning one’s environment to acquire information necessary to avoid a trip-hazard) may be susceptible to similar anxiety-related disruptions as those observed during visually guided sporting motor tasks. Indeed, researchers have suggested that fall-related anxiety may impair visual search behaviours during locomotion (Staab, 2014; Young & Williams, 2015). Despite this, the majority of research within the field of gait and posture focuses on how fall-related anxiety impacts cognitive processing and motor output during locomotion (e.g., Gage et al., 2003; Uemura et al., 2012; Young et al., 2016), rather than considering how processes related to the acquisition of sensory information (e.g., altered eye movements) may also contribute to these changes.

Research highlights that older adults at a high-risk of falling display altered patterns of visual search during adaptive gait (Chapman & Hollands, 2006b), including behaviours causally linked to increased stepping errors and reduced safety (Young & Hollands, 2010). As a result, the identification of underlying causal factors contributing to these altered patterns of visual search will allow for the development of strategies to target these potentially dangerous behaviours.

5.1.1 Visual Control of Locomotion

Research demonstrates a robust spatiotemporal coupling between eye and foot movements during adaptive locomotion (Hollands & Marple-Horvat, 2001; Hollands, Marple-Horvat, Henkes, & Rowan, 1995; Patla & Vickers, 2003), indicating that visual information is sampled during specific phases of the stepping cycle. Typically, individuals will transfer their gaze towards a target at the start of the stance phase prior to initiating the step towards this stepping constraint, maintaining this fixation until shortly before the step is completed (i.e., *on-line* visual control; using vision to guide the ongoing action). However, rather than relying solely on on-line visual information to guide stepping trajectory, safe and energetically efficient locomotion also requires visual information to be used to plan movement in a *feedforward* manner. For example, while visual information can be used to make rapid, on-line adjustments once a step has been initiated (Reynolds & Day, 2005), locomotion is likely to be more stable if movements are guided through feedforward control rather than having to rely on making unexpected changes to foot trajectory mid-step (Matthis & Fajen, 2014). Similarly, precision steps are likely to be more accurate when controlled in a feedforward, rather than purely on-line, manner (Chapman & Hollands, 2006a).

As we walk through our cluttered world, we build a visual-spatial map of our environment (Zettel et al., 2007). Feedforward visual sampling allows not only for the identification of potential threats to balance, but also for the subsequent planning and execution of stepping behaviours necessary to avoid tripping. Recent research by Matthis and colleagues describes a “critical phase” for visual control of human locomotion (Matthis et al., 2015, 2017; Matthis & Fajen, 2014). These findings suggest that while walkers *can* use on-line vision to control precision stepping, visual information from at least two step-lengths ahead is needed to *effectively* navigate a stepping constraint. Matthis and colleagues (Matthis et al., 2015, 2017; Matthis & Fajen, 2014) describe that such feedforward planning allows for the mechanical state of the body to be adjusted to optimise the trajectory of both the centre of mass and stepping leg, prior to the initiation of the precision step itself. This allows the walker to maximise stability and reduce the likelihood of having to produce a potentially destabilising mid-step adjustment. Consequently, failing to acquire visual information relating to a stepping constraint prior to this critical phase will likely reduce safety during locomotion by virtue of the walker having reduced ability to avoid an obstacle or step accurately onto a target.

5.1.2 Disrupted Visual Search when Anxious About Falling

It has been suggested that fall-related anxiety may disrupt visual search during gait and potentially compromise the important processes necessary for ensuring safety during locomotion (Staab, 2014; Young & Williams, 2015). For example, when standing on an elevated balcony (raised 20 metres above ground), individuals fearful of heights will restrict both their head movements and visual exploration of their environment, instead “freezing” their gaze on the horizon (Kugler, Huppert, Schneider, & Brandt, 2013). Similar patterns of results were also presented when fearful individuals traversed this elevated balcony (Kugler, Huppert, Eckl, Schneider, & Brandt, 2014), with gaze fixated predominantly on the “ground nearby in the heading direction” (Kugler et al., 2014, p. 8). As optimal feedforward movement planning requires two step lengths worth of visual information (Matthis & Fajen, 2014), the authors suggest that this limited visual search behaviour will likely reduce safety during adaptive locomotion (Brandt, Kugler, Schniepp, Wuehr, & Huppert, 2015). However, as the task employed by Kugler and Colleagues (2014) did not involve the navigation of stepping constraints, but rather walking on an even flat surface, there would have been little negative consequence of reduced feedforward movement planning.

Similar reductions in visual exploration have, however, been observed in anxious older adults when approaching a target followed by a series of obstacles (Young et al., 2012). Here, older adults deemed to be at a low risk of falling displayed a “proactive” pattern of visual exploration, fixating, and transferring their gaze between, subsequent stepping constraints. In contrast, high-risk older adults directed their gaze predominantly towards the proximal stepping target and displayed reduced visual previewing of future stepping constraints. These high-risk older adults subsequently transferred their gaze away from this initial stepping target significantly earlier (i.e., before the step into the target had been completed), in order to fixate the following constraints; presumably because they had failed to acquire this visual information during the approach to the initial stepping constraint. The magnitude of this premature gaze transfer was associated with increased stepping errors into this target, thus indicating reduced safety. As the high-risk older adults also reported significantly greater levels of state anxiety, the authors speculated that observed reductions in visual previewing and associated stepping errors were a consequence of heightened fear of falling. However, as these authors did not specifically manipulate anxiety, but rather task complexity which resulted in heightened fear of falling, one must be cautious when attributing these changes directly to fall-related anxiety and not, for example, group differences in ability to navigate the more challenging stepping task.

5.1.3 Theoretical Accounts of Altered Visual Search

As described in Section 2.5, two main dichotomising theoretical explanations have been proposed to account for anxiety-related alterations in visual search during gait (Young & Williams, 2015). *Distraction* theories postulate that anxiety disrupts performance by directing attention towards threatening, task-irrelevant cues, thus reducing the attentional resources available for processing task-relevant information (Wine, 1971). These task-irrelevant cues can be either *internal* (i.e., worries or disturbing thoughts relating to the consequences of failure) or *external* (i.e., threatening task-irrelevant distracters, such as the crowd behind a goal when taking a penalty kick). In contrast, *self-focus* – or, *explicit-monitoring* (Beilock & Carr, 2001) – theories hold that anxiety leads the performer to direct conscious attention towards monitoring or controlling movements governed by largely "automatic" processes (Baumeister, 1984). In broad terms, distraction theories suggest that anxiety leads to performance break-down as a result of directing *too little* on-line attention towards movement execution, while self-focus theories postulate that performance decrements are a consequence of directing *too much* on-line attention towards movement.

Distraction perspectives. Providing support for distraction theories, Young and Williams (2015) suggest that anxiety-related reductions in visual exploration may reflect an inability to plan future actions as a result of preferentially processing internal worries. Indeed, a recent case study describes the dramatic changes in visual search behaviours (and subsequent stepping accuracy) in an older adult 2-3 weeks following their first fall; despite no recorded changes in cognitive or physical functioning, with the single exception of increased concerns/worries about falling (Young & Hollands, 2012b). Staab (2014) similarly highlights distraction theories as a potential explanation for anxiety-related changes in visual search during gait. However, rather than implicating internal distracters (such as worries) as an underlying cause of this behaviour, Staab (2014) interprets the aforementioned altered patterns of visual search in anxious older adults to be representative of an attentional bias for external threat-related stimuli – with preferential allocation directed towards upcoming threats to balance.

Self-focus perspectives. In contrast, researchers have also used self-focus theories to explain how fall-related anxiety may alter visual search during gait (Uiga, Cheng et al., 2015; Young & Williams, 2015). Chapter 4 described evidence of a causal link between fall-related anxiety and heightened conscious movement processing when walking; results also supported by research conducted by Young et al. (2016). As this form of movement execution is characterised by increased on-line movement processing (Jackson et al., 2006), it is possible that the reduced visual exploration observed in anxious individuals – whereby gaze is fixated predominantly on the “ground nearby in the heading direction” (Kugler et al., 2014, p. 8) – is a consequence of the prioritisation of the on-line visual information needed to consciously control/monitor individual stepping movements. Indeed, Beilock and Carr’s (2001) theory of explicit monitoring suggests that anxiety “increases the attention paid to skill processes and their *step-by-step* control [emphasis added]” (p. 701). The question remains if adopting “step-by-step control” during locomotion occurs at the expense of visually exploring one’s environment and planning future stepping actions.

Integrated perspectives. While research has traditionally focused on the dichotomy between the influence of distraction and self-focus (e.g., Baumeister & Showers, 1986; Beilock & Carr, 2001), recent theoretical developments have led researchers to consider the interplay between these factors. For example, Attentional Control Theory (ACT; Eysenck et al., 2007) – and the subsequent update and application of this theory to perceptual-motor tasks, Attentional Control Theory: Sport (ACTS; Eysenck & Wilson, 2016) – posits that anxiety disrupts the balance between the goal-directed ("active" top-down attention influenced by prior experience and knowledge) and stimulus-driven attentional systems ("passive" bottom-up attention driven by salient and threatening stimuli) (Corbetta & Shulman, 2002). As such, anxious individuals are less able to inhibit the diversion of attention away from task-relevant cues towards internal or external task-irrelevant threat-related distractions (as per distraction accounts). Consequently, attention is biased towards "detecting the source of the threat and deciding how to respond" (Wilson, 2008, p. 195); with ACTS proposing that anxious individuals may be less able to inhibit such responses from being initiated and/or controlled via potentially disruptive conscious, on-line mechanisms (as per self-focus accounts).[4]

Similarly, in *the Integrated Model of Anxiety and Perceptual-Motor Performance*, Nieuwenhuys and Oudejans (2012) propose that anxious performers will direct preferential attention towards task-irrelevant distractions. However, this model argues that during perceptual-motor tasks typically governed by "automatic", lower-level processes (such as locomotion), such task-irrelevant distractions may also include the direction of attention towards movement execution – given that consciously processing such information is not typically required for successful performance. This assumption is supported by research demonstrating that consciously processing movement during gait can "distract" attention away from other task-relevant processes, such as extracting relevant visual information from one's walking environment (Uiga, Cheng et al., 2015).

Despite these contrasting theoretical accounts, little attempt has been made to explore specific psychological factors underpinning previously observed anxiety-related

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[4] While ACT is often classified as a distraction model (e.g., Christensen, Sutton, & McIlwain, 2015; Nieuwenhuys & Oudejans, 2012), given the recent theoretical developments associated with ACTS which allow for both distraction and self-focus factors to be contextualised within this model, we thus view this theory as an integrated model.

changes in visual search during locomotion. Instead, researchers typically apply psychological theory to existing findings in a retrospective manner (i.e., Young & Williams, 2015). Understanding mechanisms that underpin these changes is the necessary first step in designing interventions aimed at minimising the negative impact of fall-related anxiety.

5.1.4 The Present Experiments

The emerging body of literature documenting anxiety-related changes in visual search behaviours during adaptive gait (e.g., Kugler et al., 2014; Young & Hollands, 2012b; Young et al., 2012) are described above. However, to date, this previous research has only studied clinical populations suffering from co-morbidities likely to confound observations, such as individuals with visual intolerances to height (Kugler et al., 2014) or age-related deficits in visuomotor processing (Young et al., 2012). Furthermore, as noted previously, the conclusions drawn from this research are limited, on the basis of either featuring simple locomotive tasks requiring limited feedforward planning (Kugler et al., 2014) or failing to directly manipulate fall-related anxiety (Young et al., 2012). Additionally, while this research offers a preliminary account of *possible* anxiety-related changes in behaviour, these studies were not designed to provide a mechanistic description of the potential psychological/attentional factors underpinning these alterations. As such, the methodologies used, the variables assessed, and the conclusions drawn from this previous work are insufficient to conceptualise these behaviours within the context of distraction, self-focus/explicit monitoring, or integrated perspectives.

Experiment 1 aimed to evaluate a possible causal link between fall-related anxiety and altered patterns of visual search during a precision stepping task in a healthy young adult ‘model’ unaffected by countless confounding factors related to either age or clinical disorders. Importantly, the stepping task was designed to require feedforward movement planning, with gaze behaviour variables designed to test predictions presented by different theoretical perspectives. In addition, owing to the difficulties associated with attempting to theoretically interpret alterations in gaze behaviour, a verbal reports protocol was employed to further explore how anxiety-related changes in attentional processing may be associated with altered visual search. For example, while we may observe participants fixating a particular area of the walkway for longer durations when anxious about falling, it is difficult to assign theoretical meaning to such change alone. However, if participants are observed fixating stepping constraints for significantly longer durations as a result of an anxiety-related bias for external threat-related stimuli, we would thus expect verbal reports to indicate that these constraints were indeed interpreted as threats to balance. Experiment 2 then sought to further evaluate possible attentional factors underpinning changes in visual search observed in Experiment 1. Here, participants completed the same task under conditions of both: (a) an internal focus of attention (i.e., conditions designed to increase conscious movement processing); and (b) reduced cognitive resources available for movement planning.

The relationship between fear of falling and increased fall-risk is well documented (Friedman et al., 2002; Hadjistavropoulos et al., 2011; Young & Williams, 2015). In both experiments, therefore, we sought to advance our understanding of how fall-related anxiety can influence movement planning and jeopardise balance safety during locomotion.

5.2 Experiment 1

Experiment 1 compared patterns of visual search, as well as changes in attentional focus (through a verbal report protocol), during a precision stepping task varying in the degree of postural threat. We predicted that under conditions of postural threat, participants would display patterns of visual search supportive of distraction theories, rather than either self-focus or integrated perspectives. Specifically, we predicted preferential allocation of attention towards immediate external threats at the expense of planning future stepping actions (thus indicating increased sensitivity for the stimulus-driven, rather than goal-directed, system). Namely, we predicted that participants would display hypervigilance (i.e., rapid visual fixations) towards the immediate threat to their balance (first stepping constraint). We predicted that participants would then have difficulties disengaging attention away from this immediate external threat, with this reflected in: (a) longer fixation durations on the initial stepping constraint, at the expense of previewing future stepping constraints; (b) reduced fixations made towards subsequent stepping constraints; and (c) reduced gaze transfers between different areas of the walkway (i.e., participants 'freezing' their gaze towards this immediate stepping constraint/threat to balance). We predicted that these changes in visual search would be accompanied by individuals reporting greater attention directed towards both internal (i.e., worries) and external threats (i.e., the stepping constraints), as measured by a verbal report protocol.

While we also predicted that participants would report directing greater attention towards processing movement, we did not expect to observe any patterns of visual search supportive of a self-focus/explicit monitoring account.[5] As such, rather than prioritising the areas of the walkway needed for on-line control of stepping (i.e., freezing gaze towards the immediate walkway one step ahead), we predicted that participants would instead visually prioritise the immediate external threat (the initial stepping constraint). Such behaviour would provide support for distraction rather than either self-focus or integrated perspectives, as support for these models would necessitate that participants display increased on-line visual control as either the sole anxiety-related change (self-focus) or in conjunction with directing increased attention towards external threats (integrated perspectives).

As this hypothesised visual search strategy will limit the amount of visual information acquired about subsequent stepping constraints, we predicted that participants

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[5] As such, while it is possible to place the hypothesised overall attentional response to threat within an integrated perspective that unifies distraction and self-focus factors (such as ACT/ACTS), we predict to observe a lack of influence of self-focus factors on gaze behaviour.

would demonstrate earlier transfers of gaze away from this initial stepping constraint (i.e., transferring gaze away from the target before the step has been completed) in order to fixate the upcoming stepping constraint. These early transfers of gaze were predicted to correlate with the degree of stepping error (e.g., Young & Hollands, 2010). We propose that any observation of early gaze transfers would provide further support for distraction theories, as one would expect self-focused individuals prioritising on-line vision to guide stepping actions to continue fixating a constraint *until* the step towards it has been completed.

5.3 Method

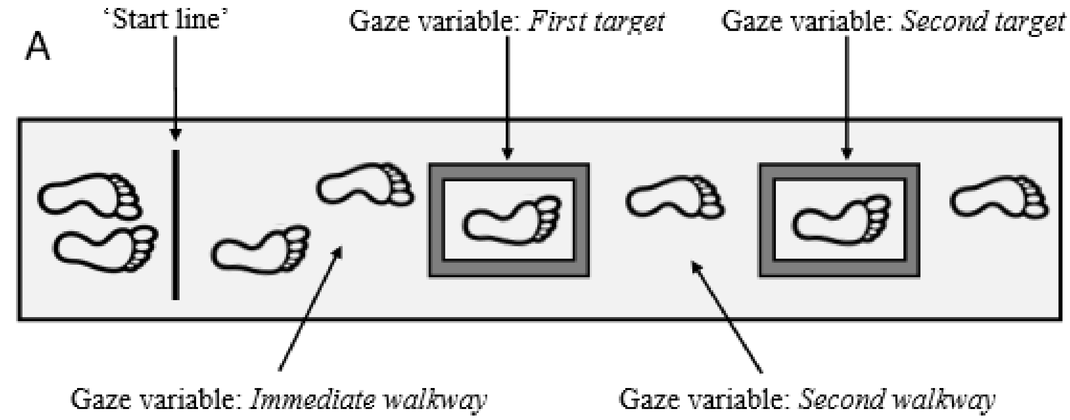
5.3.1 Participants

Fourteen young adults (female/male: 8/6; mean ± SD age: 25.86 ± 3.03 years) were recruited from postgraduate courses. Participants were free from any musculoskeletal or neurological impairment. Ethical approval was obtained by the local ethics committee at Brunel University London and the research protocol was carried out in accordance with the principals laid down by the Declaration of Helsinki. All participants provided written and informed consent. Previous research investigating the influence of state anxiety on gaze behaviour during locomotion has reported effect sizes (partial eta squared) between 0.75 and 0.99 for key, comparable variables (Young et al., 2012). Consequently, a power analysis conducted with G*Power (Faul et al., 2009) determined that between 8 and 13 participants would be required to obtain 80% power (Cohen, 1988).

5.3.2 Procedure

On arrival, participants were fitted with reflective markers placed on the heel and mid-foot of both feet (see Young & Hollands, 2012b), and then with a Mobile Eye-XG portable eye-tracking system (as described previously in Chapter 3). As per Chapter 4, the experimental task involved walking at a comfortable, self-determined pace along a wooden walkway (width of 40 cm and length of 3.3 m) and stepping into two foam rectangular targets. While participants were instructed to walk normally (i.e., steady gait rather than multiple discreet steps), we did not impose strict guidelines on walking speed as we wished to observe changes in visual search without unnatural constraints on their walking behaviour. The foam targets had raised borders (foam border width and height = 4 cm), and the inside area of the target was 19 cm x 41.5 cm (width and length, respectively; see Figure 5.1a). The raised edges were designed to encourage participants to make accurate steps into the target centre by imposing a degree of postural threat, as there would be the chance of a trip occurring if a participant failed to step into the target accurately and caught their foot on a raised edge. Participants were instructed to "step into the middle of the target with the middle of the foot, placing the mid-foot marker as close to the centre of the target as possible." Participants were permitted to step into each target with whichever foot they wished. Prior to the start of each trial, participants stood at the 'start line' (see Figure 5.1a) with their eyes closed, to prevent them from visually previewing the walkway. When they heard an auditory 'go' tone, participants opened their eyes and commenced the walking task. Prior to commencing data collection, participants completed five familiarisation trials.

Participants completed the protocol under two conditions: (a) Baseline, and (b) Threat. Baseline involved participants completing the protocol at ground level. Threat involved participants completing the protocol while the walkway was elevated 1.1 m above the laboratory floor (see Figure 5.1b). All trials were completed in the absence of a safety harness. Following the completion of the trial, participants stepped either directly away from the walkway (Baseline) or climbed down steps at the end of the walkway (Threat) before walking back to the walkway 'start line' to await the next trial. Participants completed one 5-trial block of walks for each condition, with this number of trials selected to avoid participants becoming desensitised to the height manipulation. The presentation order of these conditions was counterbalanced across participants. Target locations were rearranged after each block to reduce familiarisation. Targets could appear in two possible locations (first target: either 1 m or 1.1 m from the start line of the walkway; second target: either 1.9 m or 2 m from the start line of the walkway). Target locations were randomised across participants.



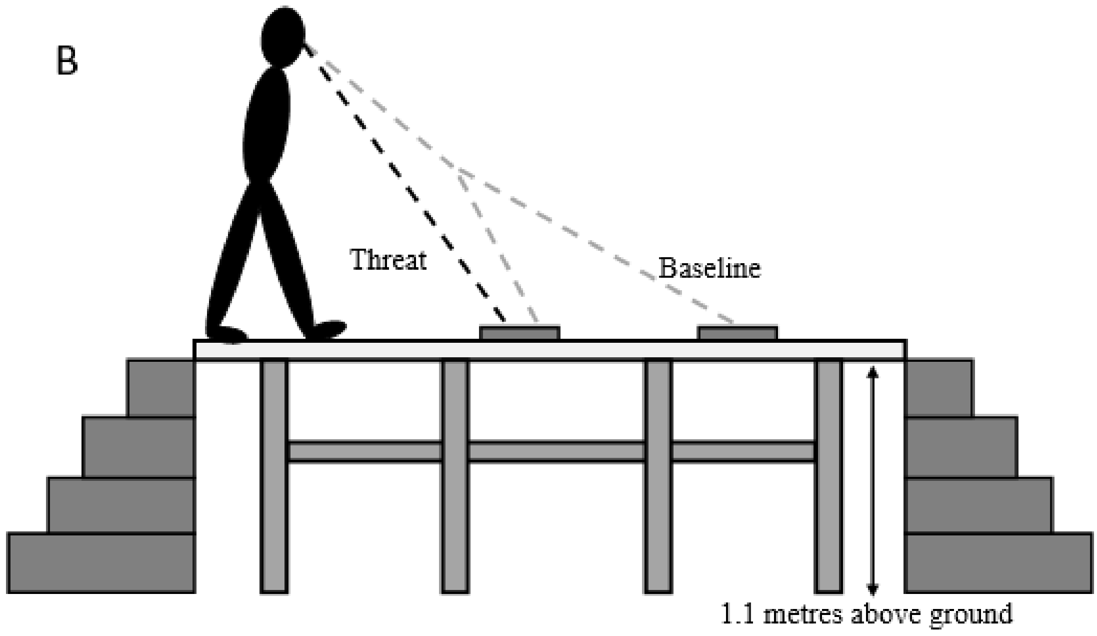


Figure 5.1a. Schematic diagram of the precision stepping task. The arrows denote the different areas of interest for which the walkway was separated into for the gaze analysis. *Figure 5.1b.* Schematic diagram of the raised walkway during Threat. The black dashed lines represent the 'restricted' visual exploration predicted during Threat, whereby participants prioritise the immediate stepping constraint at the expense of previewing future stepping actions, while the grey dashed lines represent the 'proactive' visual search predicted during Baseline at ground level.

5.3.3 Self-Reported Measures

Directly after each block, participants rated their state fear of falling (as a measure of state-anxiety), reported on a scale ranging from 0% (not at all fearful) to 100% (completely fearful) (as per Chapter 4). After each block, a verbal report protocol was also used to investigate anxiety-related changes in attentional focus (Oudejans, Kuijpers, Kooijman, & Bakker, 2011; Zaback et al., 2016). Participants were asked to report both: what they were thinking about while completing the walking task, and; what they were directing their attention towards while completing the walking task. These questions were derived from those used previously by Oudejans et al. (2011) and Zaback et al. (2016). As both questions served the same purpose (to explore how, and where, participants allocated their attention), answers to each were analysed together (Oudejans et al., 2011).

Statements were coded into one of the following five categories: *Movement processes* (thoughts relating to controlling or monitoring movement, e.g., “I focused on walking slowly”); *Threats to balance* (thoughts about environmental threats to balance, e.g., raised edges of the stepping targets or the walkway edge); *Worries or disturbing thoughts* (e.g., thoughts relating to falling and the potential negative consequences of this); *Self-regulatory strategies* (positive self-talk statements, as well as thoughts/processes adopted to enhance concentration, e.g., “I concentrate on making my breathing more controlled”); and *Task-irrelevant information* (statements unrelated to walking or maintaining balance, e.g., thinking about what one is having for dinner or letting one’s mind wander). These categories were selected on the basis of previous research (Oudejans et al., 2011; Zaback et al., 2016). Examples of categorised verbal report statements are presented in Table 5.1. Statements were categorised by two independent researchers (authors TJE and WRY), who were blinded to experimental conditions, resulting in 94.1% inter-observer reliability. Any disagreements were discussed until an agreement was met.

Table 5.1. Example items for each category.

Attentional categories	**Examples**
Movement processes	Participant 1: *"I kept all movement as controlled as possible."* Participant 10: *"Attention was on keeping steps to the same length each time."*
Threats to balance	Participant 6: *"I directed my attention towards the edges of the walkway."* Participant 10: *"[I directed my attention towards] The edges of the foam target."*
Worries or disturbing thoughts	Participant 4: *"I was worried about falling down."* Participant 11: *"Worried I might lose my balance and fall."*
Self-regulatory strategies	Participant 3: *"[...] Reminding myself that [walking on the raised platform during Threat] was the same as walking at ground level."* Participant 12: *"Thinking about getting to the end so I could come down to ground height."*
Task-irrelevant information	Participant 12: *"My mind was wandering about other things [aside from the walking task]."* Participant 13: *"I was feeling a little bit thirsty."*

5.3.4 Motor Performance

The following motor performance variables were calculated: (1) Time to complete the walking trial (s), and; (2) stepping error (mm) in both the anterior-posterior (AP) and medio-lateral (ML) planes for the first target. Time to complete the walking trial was calculated from the eye-tracking video acquired from the gaze tracker (sampling at 30Hz), by subtracting the frame in which the 'go' tone occurred from the frame in which the participant stepped off the end of the walkway. As participants' heads were pitched down at an angle that also captured their feet during the step off the walkway, this allowed for a reliable visual inspection of the frame in which the foot contacted either the laboratory floor (Baseline) or the steps (Threat) after the walkway (see Figure 5.1b). As per Chapter 4, kinematic data were collected at 100Hz using a Vicon motion capture system (Oxford Metrics, England) and passed through a low-pass butterworth filter with a cut-off frequency of 5 Hz. Stepping error was calculated through the same custom MATLAB algorithms described in Chapter 4. Variables were averaged across each condition. Kinematic data were assigned a randomised code, to allow for blinded analysis.

5.3.5 Gaze Behaviour

Fixation locations were classified as one of four areas of interest (see Figure 5.1a): (1) immediate walkway (the walkway area proximal to the first target); (2) the first target; (3) second walkway area (the walkway between the first and second target), and; (4) the second target. These areas of interest were used to determine the duration spent fixating each location during the approach to the first target. Fixation duration data were normalised to individual trial length by presenting data as the percentage of time spent fixating each area of interest from the point when participants opened their eyes following the ‘go’ tone and made their first fixation, until the time when they stepped into the first target (time of heel contact into the first target, calculated as the maximum vertical acceleration of the heel marker, identified by zero crossing in the jerk profile). The eye-tracker was synchronised with the motion-capture system through the identification of the frame number in which this ‘go’ tone occurred (as this tone occurred during the first recorded frame of the motion-capture system). As a further measure of visual previewing, the number of fixations made towards the second target (until heel contact into the first target) were also calculated.

Other gaze variables analysed were: Number of gaze transfers between the four areas of interest listed above (calculated as the average number of gaze transfers per second, prior to heel contact in the first target); Time of gaze transfer away from the first target relative to the time of heel contact in that target (ms), with a negative value denoting an early transfer of gaze; Timing (ms) of the first fixation (i.e., delay between the start of the trial and the first fixation onset), and; Location of the first fixation. The number of gaze transfers between the four areas of interest were included to determine any changes in visual exploration (Kugler et al., 2014; Young et al., 2012). The timing and location of the first fixation were included to assess whether fall-related anxiety may induce a hypervigilant visual response (i.e., rapid visual fixations) towards immediate threats; similar to hypervigilant responses observed in clinical anxiety disorders (Staab, 2014). To determine the location of the first fixation, each area of interest was allocated a number from 1–4 (immediate walkway = 1; first target = 2; second walkway area = 3; second target = 4), with lower numbers indicating that the first fixation occurred in an area of interest closer to the walker's feet.

Variables were averaged across the analysed trials for each condition. Trials in which the point of gaze crosshair disappeared for the duration of four frames or more were discarded (see Chapter 3). Participants with a trial-discard rate higher than 40% for either condition were excluded from all analyses (i.e., participants were only included in analyses if they presented three-or-more usable eye-tracking trials per-condition). This procedure resulted in 1 participant's data being excluded. A total of 50 trials were analysed for Baseline (*M* = 3.85 trials per participant) and 53 trials analysed for Threat (*M* = 4.08 trials per participant). While attempts were made to blind the assessor to experimental conditions, this was not possible given the between-condition differences in the environmental scene present in the eye-tracking videos.

5.3.6 Statistical Analysis

Self-reported measures. A Wilcoxon test was used to determine whether participants experienced significant changes in state fear of falling during the Threat condition, compared to Baseline. Separate Wilcoxon tests were used to determine the Baseline-Threat change in the number of attentional verbal reports coded for each of the five attentional categories (Zaback et al., 2016). The use of a non-parametric test was deemed necessary here as data were non-normally distributed. For all statistical comparisons, effect sizes are reported as Cohen's *d*, unless the assumption of normality is violated, where effect sizes are reported as $r=Z/\sqrt{N}$ (Fritz et al., 2012).

Motor performance. Separate paired-samples *t*-tests were used to determine the Baseline-Threat change in: Time to complete the walking trial and stepping error in both the AP and ML planes for the first target.

Gaze behaviour. Separate paired-samples *t*-tests were used to determine any Baseline-Threat change in: the number of gaze transfers between the areas of interest; the time and location of the first fixation, and; the duration (presented as a percentage) spent fixating the second walkway area. Separate Wilcoxon tests were used to determine whether there was a significant change during Threat for: percentage of time spent fixating the immediate walkway; percentage of time spent fixating the first target; time of gaze transfer away from the first target relative to heel contact in the target; percentage of time spent fixating the second target, and; visual previewing of future stepping constraints (number of fixations made towards the second target). The use of non-parametric tests were deemed necessary here as data were non-normally distributed. Separate Spearman's correlations were used to analyse data from the Threat condition and evaluate a possible relationship with the time of gaze transfer away from the first target and AP/ML stepping error (Young et al., 2012).

5.4 Results

5.4.1 Self-Reported Measures

Fear of falling. Participants reported significantly greater state fear of falling during Threat (M = 35.77%, SD = 29.22), compared to Baseline (M = 3.85%, SD = 6.50), Z = -3.06, p = .001, r = 0.89.

Attentional focus verbal reports. Under conditions of Threat, participants directed significantly greater attention towards both movement processes (Z = -2.11, p = .035, r =

0.59) and threats to balance (*Z* = -2.17, *p* = .030, *r* = 0.60). They also directed significantly less attention towards task-irrelevant information (*Z* = -2.07, *p* = .038, *r* = 0.57). According to this measure, there was no change in the amount of attention directed towards either worries or disturbing thoughts (*Z* = -1.63, *p* = .10, *r* = 0.45), or self-regulatory strategies (*Z* = -1.34, *p* = .18, *r* = 0.37). These data are presented in Table 5.2.

Table 5.2. Number of statements in each attentional category obtained from the verbal reports for both Baseline and Threat.

Attentional category	Baseline	Threat
Movement processes	22	33*
Threats to balance	7	15*
Worries or disturbing thoughts	0	5
Self-regulatory strategies	0	3
Task-irrelevant information	8	0*
Total	37	56

**p* < .05

5.4.2 Motor Performance

Compared to Baseline (*M* = 3.80 s, *SD* = 0.61), participants took significantly longer to complete the walking task during Threat (*M* = 4.47 s, *SD* = 0.93), *t*(12) = -2.97, *p* = .006, *d* = 0.85. There was no significant Baseline-Threat change in stepping error in either the AP (*Baseline M* = 29.10 mm, *SD* = 14.96; *Threat M* = 28.97 mm, *SD* = 15.69, *t*(12) = 0.48, *p* = .96, *d* = 0.01) or ML direction (*Baseline M* = 17.58 mm, *SD* = 8.15; *Threat M* = 16.62 mm, *SD* = 8.08, *t*(12) = 0.28, *p* = .79, *d* = 0.12).

5.4.3 Gaze Behaviour

First fixation (timing and location). Onset times to initial fixations were significantly shorter during Threat (*M* = 687.27 ms, *SD* = 232.71) compared to Baseline (*M* = 797.14 ms, *SD* = 308.88), *t*(12) = 1.87, *p* = .043, *d* = 0.40. Participants' first fixations were located significantly closer to the start of the walkway during Threat (*M* = 1.67, *SD* = 0.46) compared to Baseline (*M* = 2.25, *SD* = 0.46), *t*(12) = 4.05, *p* = .001, *d* = 1.25.

Duration of fixation(s) on the immediate walkway. Participants spent a significantly greater percentage of time fixating the walkway before the first target during Threat (*M* = 15.69%, *SD* = 16.24) compared to Baseline (*M* = 2.82%, *SD* = 5.46), *Z* = -2.50, *p* = .013, *r* = 0.69 (see Figure 5.2).

Duration of fixation(s) on the first target. There was no difference in the percentage of time that participants spent fixating the first target between Baseline (*M* = 61.17%, *SD* = 17.58) and Threat (*M* = 58.44, *SD* = 20.75), *Z* = -0.80, *p* = .42, *r* = 0.22 (see Figure 5.2).

Duration of fixation(s) on the second walkway area. There was no difference in the percentage of time that participants spent fixating the second walkway area (located between the first and second target), between Baseline (*M* = 18.55%, *SD* = 12.47) and Threat (*M* = 21.86%, *SD* = 18.88), *t*(12) = -0.57, *p* = .58, *d* = 0.21 (see Figure 5.2).

Duration of fixation(s) on the second target. Participants spent a significantly smaller percentage of time fixating the second target during Threat (*M* = 4.01%, *SD* = 7.27) compared to Baseline (*M* = 17.46%, *SD* = 17.97), *Z* = -2.59, *p* = .01, *r* = 0.72 (see Figure 5.2).

Visual previewing of future stepping constraints. Participants made significantly fewer fixations towards the second target during Threat (*M* = 0.20 fixations per trial, *SD* = 0.29) compared to Baseline (*M* = 0.69 fixations per trial, *SD* = 0.46), *Z* = -2.99, *p* = .02, *r* = 0.80. As Figure 5.3 illustrates, eight participants failed to make a single fixation towards the second target during the approach to the first target under conditions of Threat.

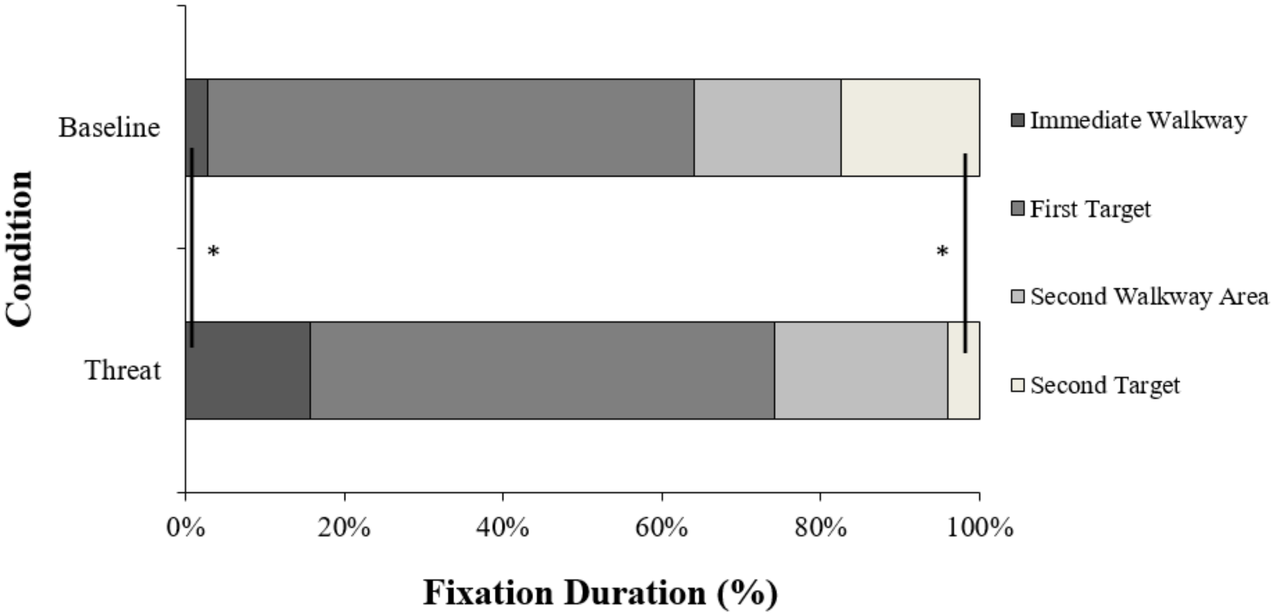


Figure 5.2. Duration (mean duration as a percentage) of time spent fixating the different areas of the walkway under conditions of Baseline and Threat, **p*<.05.

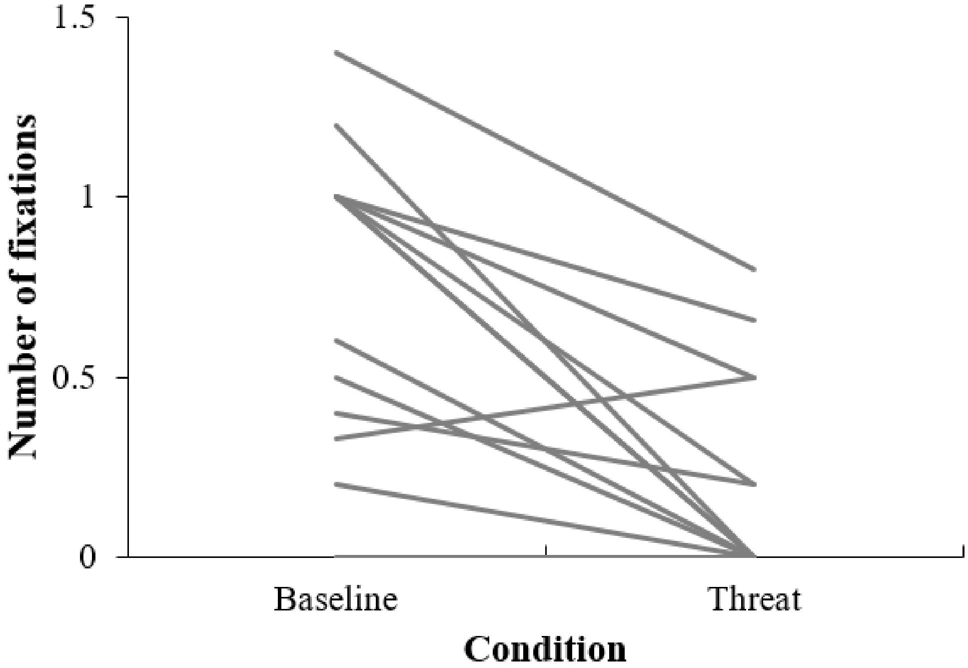


Figure 5.3. Average number of fixations (per trial) made towards the second target during the approach to the first target, for individual participants. Note, that two separate participants fixated the second target once during Baseline and zero times during Threat, while two other participants fixated the second target zero times during both Baseline and Threat.

Number of gaze transfers between areas of interest. Participants made significantly fewer transfers of gaze between areas of interest during Threat (*M* = 0.51 transfers/second, *SD* = 0.25), compared to Baseline (*M* = 0.97 transfers/second, *SD* = 0.41), *t*(12) = 6.02, *p* < .001, *d* = 1.38 (see Figure 5.4a).

Early transfer of gaze from the first target. Participants transferred their gaze away from the first stepping target significantly earlier during Threat (*M* = 349.50 ms prior to heel contact, *SD* = 325.84) compared to Baseline (*M* = 167.34 ms prior to heel contact, *SD* = 280.99), *Z* = -2.06, *p* = .019, *r* = 0.57. These data are presented in Figure 5.4b. During Threat, early gaze transfer was not significantly correlated with stepping error in either the AP (*r* = 0.05, *p* = .43) or ML direction (*r* = -0.05, *p* = .43).

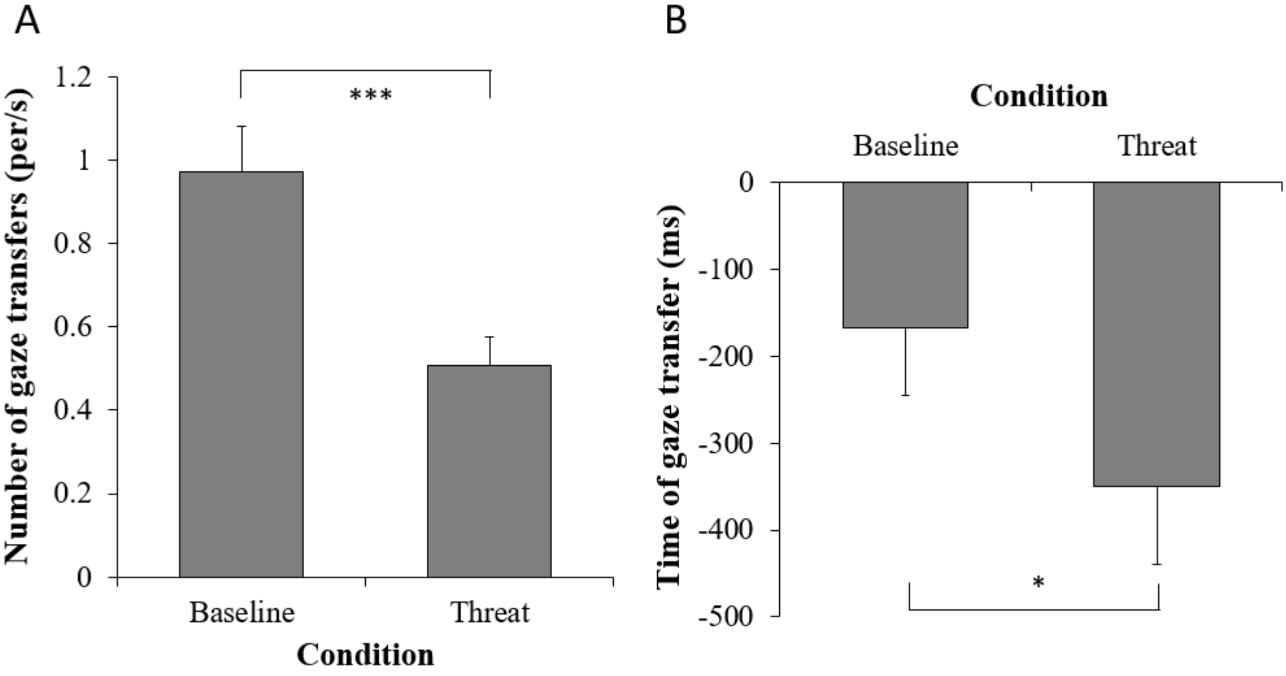


Figure 5.4a. Number of gaze transfers (per second) between different areas of the walking environment, under conditions of Baseline and Threat (mean ± standard error of the mean), ****p*<.001
Figure 5.4b. Time of gaze transfer away from the first target (ms), relative to heel contact into the target, under conditions of Baseline and Threat (mean ± standard error of the mean), **p*<.05. Note, a negative value denotes premature gaze away from the target before heel contact.

5.5 Discussion

The results from Experiment 1 demonstrate marked differences in how individuals visually scan their walking path when fearful of falling. Here, participants made more rapid initial fixations towards more proximal areas of the walkway; indicating hypervigilance towards immediate stepping constraints/threats to balance. Participants also displayed significant reductions in visual exploration (reductions in the number of gaze transfers between different areas of the walkway). As predicted, these altered patterns of visual search were accompanied by participants reporting significantly greater attention directed towards external threat-related stimuli (such as the raised edges of the stepping target). There was, however, a lack of significant anxiety-related change in attention directed towards worries or disturbing thoughts, indicating that young adults anxious about falling will preferentially allocate attention towards external, rather than internal, threat-related stimuli.

While participants did preview the second target less during Threat (with 8 participants failing to fixate this constraint at all during the approach to the first target), this was not a consequence of increased time spent fixating the first target, as predicted. Rather, participants spent significantly longer fixating the walkway prior to this first target. We had predicted that participants would display a visual bias for the first target; given that this represented the immediate stepping constraint/threat to balance. However, it is possible that participants walking at height perceived the walkway before the first target (and the walkway in general) to be a threatening stimulus, as any misplaced steps on the walkway may have resulted in a fall. This interpretation is in line with the predictions presented in ACT/ACTS (Eysenck et al., 2007; Eysenck & Wilson, 2016), suggesting that anxiety increases the influence of the stimulus-driven system (i.e., immediate threats) at the expense of the goal-directed system (i.e., scanning one’s whole environment and planning future stepping actions).

It is, however, of note that only one verbal report directly referred to perceiving the walkway before the first target as a threat to balance; with these threat-relevant statements instead more commonly referring to the targets themselves (e.g., "[I was directing attention towards…] The edges of the foam targets"). In contrast, a large quantity of statements referred to consciously controlling/monitoring each individual step (e.g., "Focusing on making sure my feet were always in the middle of the wooden plank" and "Attention was on keeping steps to the same length each time"). As such, we suggest that the increased time spent fixating the immediate walkway instead represents a prioritisation of the visual information needed to consciously control/monitor each individual step. We hypothesise that such conscious movement processing manifested as both increased short-term planning (e.g., planning individual steps rather than planning future stepping movements) and on-line control (e.g., guiding the trajectory of the step itself). This interpretation is supported by research indicating that anxious walkers rely on on-line vision to a greater extent to control locomotion (Brown, Doan, McKenzie, & Cooper, 2006).

Taken together, these results suggest that when anxious about falling, participants displayed an initial hypervigilance towards immediate threats to balance. Motivated to avoid falling, they subsequently attempted to consciously control/monitor each individual step; thus resulting in an increase in both short-term planning an on-line visual control of individual steps. This manifested as participants "freezing" gaze to the ground one step ahead; at the expense of transferring gaze between the first and second targets, three-to-five steps ahead. As such, at the time when stepping into the first target, there would have been an urgent need to acquire visual information regarding subsequent constraints. It seems intuitive that this is why participants transferred their gaze from the first target significantly earlier (prior to heel contact) during Threat trials (see Figure 5.4b). However, it is also possible that this behaviour is a further reflection of the increased influence of the stimulus-driven system (at the expense of goal-directed attention, as predicted by ACT/ACTS [Eysenck et al., 2007; Eysenck & Wilson, 2016]), with participants directing preferential attention towards upcoming constraints at the expense of fixating the first target until the precision step has been completed (i.e., the current goal).

Our interpretations of observed behaviours propose an interplay between distraction and self-focus/explicit monitoring factors – thus providing support for integrated perspectives, specifically ACT/ACTS (Eysenck et al., 2007; Eysenck & Wilson, 2016). However, as these interpretations are drawn largely from self-reported data, we are unable to draw any conclusions regarding causality between these factors. For example, it is possible that the increased self-focus/explicit monitoring reported is unrelated to any alterations in visual search behaviours; with these changes occurring simultaneously, yet unrelated, to one another. As such, there is a need to conduct further theoretically-driven experimental manipulations to evaluate possible causal relationships underpinning altered gaze behaviour during adaptive gait.

5.6 Experiment 2

Experiment 1 implicates possible psychological factors that may contribute to anxiety-related changes in visual search. However, given the aforementioned difficulties in interpreting data pertaining to gaze behaviour, it is necessary to experimentally test these interpretations, through the isolation of independent factors implicated during Experiment 1. For example, while we interpret the increased time spent fixating the immediate walkway areas to indicate increased reliance on both short-term planning and on-line vision to consciously control discrete stepping movements, it is possible that this behaviour may instead reflects a gaze bias for external threats, and a subsequent inability to shift attention back towards planning future stepping actions. Similarly, while we interpret the premature gaze transfers observed during Threat to be a consequence of the reduced time spent fixating subsequent stepping targets, it is possible that this behaviour may alternatively reflect impaired attentional control (e.g., increased dominance of the stimulus-driven attentional system; Eysenck et al., 2007; Eysenck & Wilson, 2016). Therefore, Experiment 2 sought to determine whether similar patterns of visual search described in Experiment 1 during conditions of Threat can be induced during experimental conditions of heightened conscious movement processing, independent of fall-related anxiety.

As with the Threat condition in Experiment 1, we predicted to similarly observe a visual prioritisation of the walkway areas needed for the conscious monitoring/control of individual steps during experimentally induced conditions of heightened conscious movement processing. We predicted that this would similarly manifest as an increase in both short-term planning and on-line control of individual steps (i.e., participants ‘freezing’ their gaze to the ground one step ahead), at the expense of previewing the second target, approximately four-to-five steps ahead. Consequently, as participants will have obtained limited information regarding the second target at the time they step towards the first target, we expected to also observe earlier transfers of gaze away from the first target (i.e., prior to heel contact). However, as we interpret the rapid initial fixations towards more immediate areas of the walkway during Experiment 1 to indicate a hypervigilant gaze bias for immediate threats, we did not expect to observe comparable behaviours during Experiment 2.

A second aim of Experiment 2 was to explore the possible mechanisms through which consciously processing movement may alter visual search during locomotion. Chapter 4 described that consciously attending to movement during locomotion can reduce processing efficiency, thus limiting the resources available for processing concurrent tasks – which may include the maintenance of effective visual search behaviours (e.g., Chapter 3). Indeed, Uiga, Cheng et al. (2015) suggest that consciously controlling movement may reduce an individual’s ability to extract relevant visual information from their walking environment

(Uiga, Cheng et al., 2015). More specifically, Clark (2015) suggests that if the cognitive resources needed for locomotion in complex environments are "...encumbered by the [conscious] control of the basic walking pattern, there is a heightened risk that hazards may be overlooked or ignored" (p. 2). Therefore, it is possible that consciously controlling/monitoring locomotion may influence changes in visual search by virtue of reduced processing efficiency; potentially due to an inability to retain previewed environmental information about distal path constraints (Young & Williams, 2015).

While we attribute the majority of changes observed in Experiment 1 to altered prioritisation resulting from attempts to consciously process movement – rather than associated reductions in processing resources – we nonetheless deemed it necessary to also consider (and discount) the influence of reduced attentional resources available for movement planning on visual search during gait. Given that consciously processing walking movements is associated with verbal processes (Young et al., 2016), this was achieved through the manipulation of a verbal dual-task. However, we predicted to observe significantly different visual behaviours during this condition compared to conditions of heightened conscious movement processing (and a lack of any behaviours comparable to Threat in Experiment 1). Specifically, we predicted to observe a general "disengagement" from proactive visual search during Dual-task (as per the "gazing into thin air" observed in Chapter 3), which we hypothesise will manifest itself as reduced time spent fixating the walkway in general (particularly the stepping constraints), and increased time spent fixating task-irrelevant areas outside the walking path.

5.7 Method

5.7.1 Participants

The same 14 participants from Experiment 1 participated in Experiment 2. As we wished to explore the potential factors underpinning the specific anxiety-related changes observed in Experiment 1, we deemed it most appropriate to use the same sample previously studied, rather than recruiting a new sample who may differ on trait variables likely to influence visual search during gait (such as an individual's trait propensity to consciously process their movements; Chapter 3). To ensure an absence of a practice effect occurring during the testing session, separate paired-samples *t*-tests/Wilcoxon tests (dependent on whether the data were normally distributed) were used to compare Baseline variables between the two experiments. Aside from a significant difference between the duration of fixation(s) on the first target ($Z = -1.99$, $p = .046$, $r = 0.55$), there were no other significant differences observed between experiments for any other Baseline variables (all *p*'s > 0.28). However, as the overall mean duration of fixations on the first target for Experiment 1 ($M = 61.17\%$, $SD = 4.88$) and Experiment 2 ($M = 55.96\%$, $SD = 5.87$) differed by only 5.21%, and all other variables were statistically comparable between experiments, we reason that this indicates an absence of a true practice effect between Experiment 1 and 2.

5.7.2 Procedure

Experiment 2 used an identical experimental task as Experiment 1. Following the completion of Experiment 1, participants received a 15-minute break. Once the calibration of the eye-tracking system was re-verified for accuracy, participants walked again at a comfortable, self-determined pace across the same walkway used in Experiment 1 and stepped into the same two foam targets. Participants completed one five-trial block of walks under each of the three randomised conditions: (a) Baseline; (b) Internal, and; (c) Cognitive Load. All three conditions involved participants completing the protocol at ground level.

Baseline. As with Experiment 1, Baseline involved participants completing the protocol with no other instructions other than to "step into the middle of the target with the middle of your foot".

Internal. During this condition, participants were informed that they needed to consciously process their movements throughout the trial, as after each trial in this condition, they would be asked a question relating to their movement. This manipulation was identical to that used previously in Chapter 4; whereby the experimental manipulation successfully induced levels of conscious movement processing during adaptive gait comparable to those observed under conditions of fall-related anxiety. As with Chapter 4, participants were 'informed' that they would have to repeat any trials in which they provided an incorrect answer. While this deception was used to ensure engagement with the manipulation, participants' response accuracy was recorded as an additional manipulation check. Two participants provided an incorrect answer for one trial, respectively.

Cognitive Load. This condition consisted of performing the protocol while concurrently subtracting out loud in 7s from a randomised number between 70 and 90 (as per Chapter 3 and 4). Participants were presented with this randomised number directly prior to the onset of the 'go' tone, to ensure that they had not already begun subtracting prior to the start of each trial. Once they heard the 'go' tone, participants began to walk and subtract out loud. Participants' first verbalised response was the subtracted target value of the randomised number (i.e., first verbalisation of 83 if the randomised number presented was 90). Participants were instructed to allocate an equal amount of attention towards both the walking and arithmetic task (as per Chapters 3 and 4). Mean dual-task costs were comparable to those reported in the previous two chapters (*M* = 30.23%, *SD* = 18.13).

5.7.3 Measures

The motor performance variables collected in Experiment 2 were identical to those investigated previously in Experiment 1. These were defined and calculated using an identical method as described in Experiment 1. Identical gaze behaviour variables were also calculated, with the exception of an additional fifth walkway area: 'outside areas' (any area of the surrounding environment that was not along the walking path). Based on the results presented in Chapter 3, this additional area was added to assess the degree to which participants ‘disengaged’ from visual search during Cognitive Load. As with Experiment 1, trials in which the point of gaze crosshair disappeared for the duration of four frames or more were discarded. However, as all 14 participants had at least three usable trials for each condition, no participants were excluded from analyses. A total of 57 trials were analysed for Baseline (*M* = 4.07 trials per participant), 61 trials analysed for Cognitive Load (*M* = 4.36 trials per participant) and 56 trials analysed for Internal (*M* = 4.00 trials per participant). As with Experiment 1, kinematic data were assigned a randomised code, to allow for blinded analysis. As there were no between-condition differences in the environmental scene present in the eye-tracking videos (unlike Experiment 1), gaze data analysis was also blinded.

5.7.4 Statistical Analysis

Motor performance. Separate repeated-measures ANOVAs (effect size reported as partial eta squared; Bonferroni post-hoc tests used to follow up any statistically significant results) were used to explore the effect of experimental condition on: Time to complete the walking trial and stepping error in both the AP and ML planes for the first target.

Gaze behaviour. Separate Friedman tests were used to determine the effect of Condition on: the time of the first fixation; the location of the first fixation; percentage of time spent fixating the immediate walkway; percentage of time spent fixating the first target; time of gaze transfer away from the first target relative to heel contact; visual previewing of future stepping constraints; percentage of time spent fixating the second target, and; percentage of time fixating outside areas. The use of a non-parametric test was deemed necessary as data were non-normally distributed. Any significant effects were followed up by separate Wilcoxon tests comparing each of the three conditions: Baseline, Internal and Cognitive Load (Bonferroni corrected to 0.017). Due to the difficulties associated with calculating effect size for Friedman tests, effect sizes are calculated (and reported as $r=Z/\sqrt{N}$) instead for any Wilcoxon test follow-ups (as recommended by Field, 2009). Separate repeated-measures ANOVAs (effect size reported as partial eta squared; Bonferroni post-hoc tests used to follow up any statistically significant results) were used to determine the effect of Condition on: the number of gaze transfers between the areas of interest, and; the duration (presented as a percentage) spent fixating the second walkway area. Two participants were excluded from the early gaze transfer analysis, as one participant did not fixate the first target in any trials during two of the three conditions; while the second participant only fixated the first target in one out of five trials for two of these conditions, with the time that they transferred their gaze away from the first target during these two trials falling > 2.5-3 SD above the overall group mean. Therefore, it was not possible to reliably determine the difference between when these participants looked away from, and stepped into, the first target.

5.8 Results

5.8.1 Motor Performance

There was a significant effect of Condition on the time taken to complete the walking trial ($F(2,26) = 11.84$, $p < .001$, $\eta p^2 = 0.48$). Compared to Baseline ($M = 3.74$ s, $SD = 0.59$), participants took significantly longer to complete the walking task during both Cognitive Load ($M = 4.39$ s, $SD = 0.72$, $p < .001$) and Internal ($M = 4.15$ s, $SD = 0.85$, $p = .022$). There was a lack of significant difference in times to complete the walking task observed between Cognitive Load and Internal ($p = .48$). There was no significant effect of Condition on stepping error in either the AP ($F(2,26) = 1.81$, $p = .18$, $\eta p^2 = 0.12$) or ML direction ($F(2,26) = 0.61$, $p = .55$, $\eta p^2 = 0.05$).

5.8.2 Gaze behaviour

First fixation (timing and location). There was a significant effect of Condition on the time to the first fixation ($\chi^2(2) = 9.33$, $p = .009$). Post-hoc tests revealed that compared to Baseline (*M* = 817.86 ms, *SD* = 313.56), onset times to initial fixations were significantly longer during both Cognitive Load (*M* = 982.54 ms, *SD* = 391.60, $p = .013$, $r = 0.60$) and Internal (*M* = 907.46, *SD* = 286.80, $p = .009$, $r = 0.64$). There was a lack of significant difference observed between Cognitive Load and Internal ($p = .41$, $r = 0.06$).

There was also a significant effect of Condition on the location of the first fixation ($\chi^2(2) = 10.47$, $p = .005$). Post-hoc tests revealed that participants' first fixations occurred significantly nearer the start of the walkway during Internal (*M* = 1.66, *SD* = 0.67), compared to Baseline (*M* = 2.10, *SD* = 0.69, $p = .002$, $r = 0.76$). There was a lack of significant difference observed between Cognitive Load (*M* = 1.89, *SD* = 0.56) and either Baseline ($p = .058$, $r = 0.51$) or Internal ($p = .17$, $r = 0.36$).

Duration of fixation(s) on the immediate walkway. There was a significant effect of Condition on the duration spent fixating the immediate walkway, during the approach to the first target ($\chi^2(2) = 12.72$, $p = .002$). Post-hoc tests revealed that participants spent a significantly greater percentage of time fixating the walkway before the first target during Internal (*M* = 17.94%, *SD* = 18.50), compared to Baseline (*M* = 6.50%, *SD* = 14.39, $p = .003$, $r = 0.71$). There was also a trend towards significance, for a greater percentage of time spent fixating this walkway area during Internal, compared to Cognitive Load (*M* = 9.04%, *SD* = 12.21, $p = .024$, $r = 0.53$). There was a lack of significant difference observed between Baseline and Cognitive Load ($p = .16$, $r = 0.27$) (see Figure 5.5).

Duration of fixation(s) on the first target. There was a significant effect of Condition on the duration spent fixating the first target ($\chi^2(2) = 7.54$, $p = .023$). Post-hoc tests revealed that participants spent significantly less time fixating the first target during

Cognitive Load (M = 36.69%, SD = 22.68), compared to both Baseline (M = 54.43%, SD = 21.15, p = .008, r = 0.64) and Internal (M = 54.21%, SD = 19.76, p = .017, r = 0.57). There was a lack of significant difference observed between Baseline and Internal (p = .41, r = 0.07) (see Figure 5.5).

Duration of fixation(s) on the second walkway area. There was a significant effect of Condition on the duration spent fixating the second walkway area during the approach to the first target (F(1.28,16.58) = 6.17, p = .018, ηp^2 = 0.32). While post-hoc tests revealed greater times spent fixating the walkway between the first and second target during Cognitive Load (M = 34.14%, SD = 21.69), compared to both Baseline (M = 20.58%, SD = 13.12, p = .084) and Internal (M = 18.13%, SD = 11.17, p = .058), these did not reach significance. There was also a lack of significant difference observed between Baseline and Internal (p = 1.00) (see Figure 5.5).

***Duration of fixation(s) on the second target*.** There was a significant effect of Condition on the duration spent fixating the second target, during the approach to the first target (χ^2(2) = 13.88, p = .001). Post-hoc tests revealed that participants spent significantly less time fixating the second target during both Cognitive Load (M = 8.27%, SD = 13.93, p = .004, r = 0.72) and Internal (M = 8.90%, SD = 21.44, p = .005, r = 0.69), compared to Baseline (M = 18.49%, SD = 22.11). There was a lack of significant difference observed between Cognitive Load and Internal (p = .29, r = 0.15) (see Figure 5.5).

***Duration of fixation(s) on outside areas*.** There was a significant effect of Condition on the duration spent fixating areas outside the walking path (χ^2(2) = 8.82, p = .012). Post-hoc tests revealed that participants spent significantly more time fixating outside areas during Cognitive Load (M = 11.95%, SD = 21.79), compared to Baseline (M = 0.00%, SD = 0.00, p = .014, r = 0.59), with a further trend when Cognitive Load was compared to Internal (M =

0.82%, *SD* = 2.53, *p* = .032, *r* = 0.50). There was a lack of significant difference observed between Baseline and Internal (*p* = .09, *r* = 0.36) (see Figure 5.5).

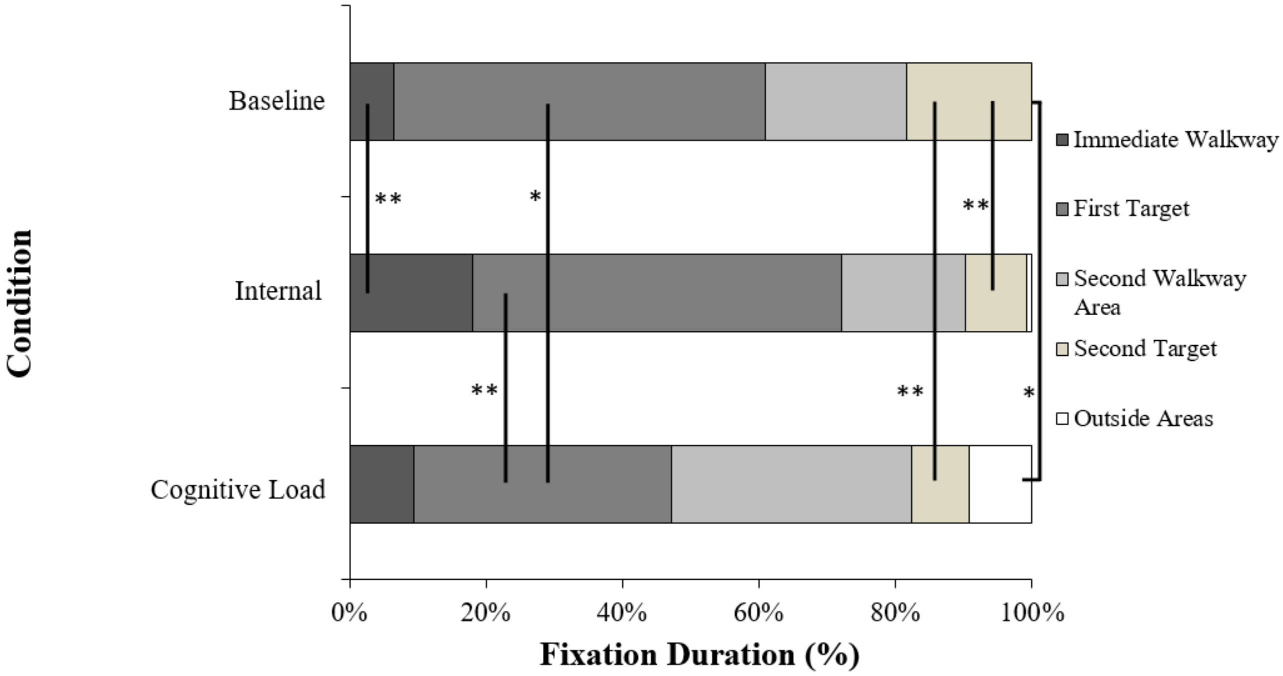


Figure 5.5. Duration (mean duration as a percentage) of time spent fixating the different areas of the walkway under conditions of Baseline, Internal and Cognitive Load, **p*<.017, ***p*<.01.

Visual previewing of future stepping constraints. There was a significant effect of Condition on the numbers of fixations made towards the second target, during the approach to the first target ($\chi^2(2) = 12.63$, *p* = .002). Post-hoc tests revealed that compared to Baseline (*M* = 0.72 fixations per trial, *SD* = 0.46), participants made significantly fewer fixations towards the second target during both Internal (*M* = 0.17 fixations per trial, *SD* = 0.28, *p* = .020, *r* = 0.76) and Cognitive Load (*M* = 0.39 fixations per trial, *SD* = 0.33, *p* = .015, *r* = 0.58). Participants also made significantly fewer fixations towards the second target during Internal, compared to Cognitive Load (*p* = .004, *r* = 0.72). During Internal, eight participants failed to make a single fixation towards the second target during the approach to the first target, compared to two and three participants during Baseline and Cognitive Load, respectively.

Number of gaze transfers between areas of interest. There was no significant effect of Condition on the number of transfers of gaze between areas of interest ($F(2,26) = 0.90$, $p = .42$, $\eta p^2 = 0.07$).

Early transfer of gaze from the first target. There was a significant effect of Condition on the time of early gaze transfer away from the first target ($\chi^2(2) = 8.00$, $p = .018$). Post-hoc tests revealed that participants transferred their gaze away from the first stepping target significantly earlier during Cognitive Load ($M = 546.98$ ms prior to heel contact, $SD = 330.32$), compared to both Baseline ($M = 190.98$ ms prior to heel contact, $SD = 199.40$, $p = .014$, $r = 0.63$) and Internal ($M = 199.77$ ms prior to heel contact, $SD = 108.12$, $p = .002$, $r = 0.84$). There was a lack of significant difference observed between Baseline and Internal ($p = .44$, $r = 0.05$) (see Figure 5.6). During Cognitive Load, early gaze transfer was not significantly correlated with stepping error in either the AP ($r = -0.15$, $p = .32$) or ML direction ($r = 0.31$, $p = .17$).

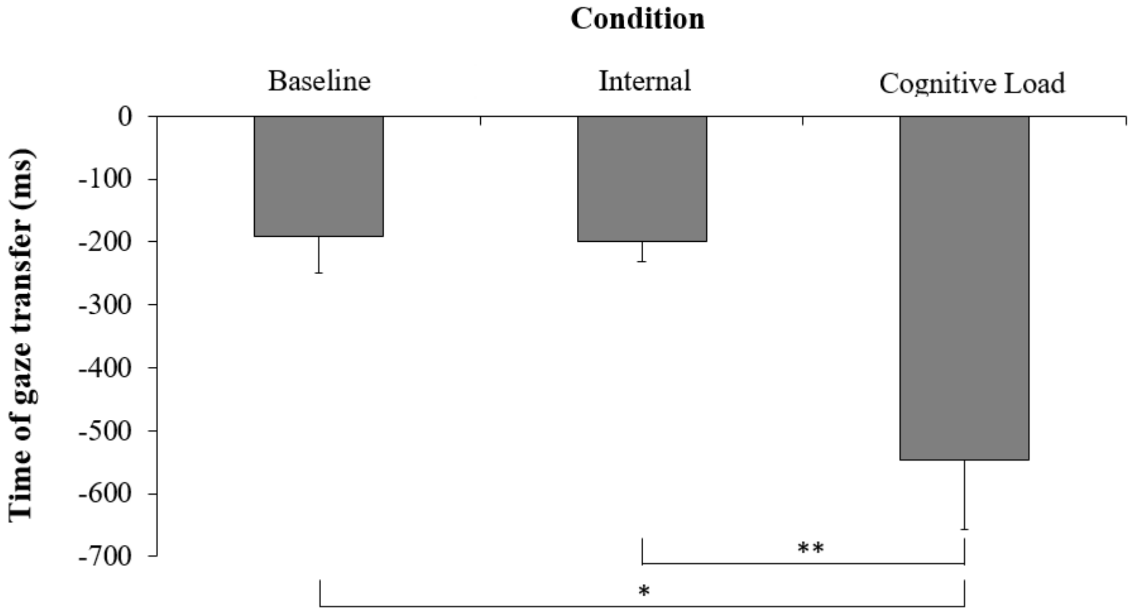


Figure 5.6. Time of gaze transfer away from the first target (ms), in relation to heel contact into the target, under conditions of Baseline, Internal and Cognitive Load (mean ± standard error of the mean). Note, a negative value denotes premature gaze away from the target prior to heel contact, $*p<.017$, $**p<.01$.

5.9 Discussion

As predicted, during Internal, participants' initial fixations were made towards more proximal areas of the walkway nearest their feet. Participants also spent more time fixating the immediate walkway (before the first target) and less time visually previewing the second target (see Figure 5.5), with fewer fixations also made towards the second target. As with the results presented in Experiment 1 during Threat, these findings also seem indicative of participants prioritising the areas of the walkway required to consciously control/monitor individual movements. Participants appeared to prioritise this visual information at the expense of planning future stepping actions. These findings implicate conscious movement processing as one factor underpinning certain anxiety-related changes in visual search. However, despite acquiring limited visual information about the subsequent stepping constraints during Internal, participants did not demonstrate significantly earlier transfers of gaze away from the first target (see Figure 5.6). This was contrary to our predictions and suggests that early transfers of gaze previously observed in anxious young adults in Experiment 1 – and high-risk older adults (Young & Hollands, 2012b; Young et al., 2012) – are not necessarily a direct consequence of restricted visual previewing limiting the acquisition of spatial information about upcoming constraints; as previously assumed (Young & Williams, 2015). Rather, previously observed premature transfers of gaze away from the first target appear to reflect a gaze bias for upcoming threats, thus supporting the predictions presented in ACT/ACTS (Eysenck et al., 2007; Eysenck & Wilson, 2016), whereby anxiety is predicted to result in an increased influence of the stimulus-driven system (at the expense of goal-directed attention, e.g., fixating the first target until the precision step has been completed).

Interestingly, participants did transfer gaze away from the first target significantly earlier during Cognitive Load (compared to both Baseline and Internal; see Figure 5.6), in addition to reducing the number of fixations made towards the second target. Dual-tasking participants also fixated both stepping constraints (first and second target) for significantly shorter durations, instead fixating areas outside the walking path for longer durations (and transferring their gaze away from the first target prematurely, to do so). These findings suggest that visually previewing stepping constraints in a feedforward manner requires attentional resources. As such, unlike the reduced time spent fixating (subsequent) stepping constraints during Internal, we suggest that behaviours observed during Cognitive Load represent a “disengagement” from performing optimal visual planning, in order to “liberate” cognitive resources needed to complete the secondary task (as purported previously in Chapter 3). Consequently, while the outcome (reduced previewing of subsequent constraints) is similar between these two conditions, we argue for differences in the causal mechanisms. While we interpret the reduced previewing observed during Cognitive Load to be indicative of a general disengagement, we view these behaviours during Internal to instead represent changes in prioritisation (with participants visually prioritising the areas necessary for both the planning and on-line control of individual stepping movements, much like during Threat in Experiment 1).

These findings suggest that previously described visual search behaviours observed in high-risk anxious older adults (i.e., early transfers of gaze [Chapman & Hollands, 2010; Young et al., 2012]) may be the consequence of fall-related anxiety (and subsequent attempts to consciously control/monitor movement), age-related decline in cognitive resources, or a combination of both. However, while the results presented in Chapters 3 and 4 indicate that consciously processing movement *can* reduce attentional resources available for processing concurrent tasks, the lack of comparable visual search strategies observed between Cognitive Load and Threat in Experiment 1 suggest that anxiety-related alterations in visual search are unlikely to simply reflect reduced attentional resources available for processing visual information.

Furthermore, previous attempts to interpret anxiety-related changes in visually-guided gait have assumed that behaviours observed are all interlinked (e.g., reduced visual previewing and early transfers of gaze; Young & Williams, 2015). However, the results presented in Experiment 2 suggest that these different behaviours can operate with relative independence and can be mediated by different attentional factors.

5.10 General Discussion

The present experiments evaluated the existence of a causal link between fall-related anxiety and altered patterns of visual search and explored possible mechanisms underpinning these changes. As illustrated in Figures 5.2 and 5.3, participants demonstrated reduced visual previewing during Threat in Experiment 1, prioritising the immediate areas of the walkway at the expense of subsequent stepping constraints (the second target). In addition, they transferred their gaze between the different areas of the walkway significantly less during Threat, indicating reduced visual exploration (see Figure 5.4a). Participants made earlier initial fixations (reductions in the time between the start of the trial and the onset of their initial fixation) towards more proximal areas of the walkway (areas of the walkway closer to the ‘start’ line) and transferred their gaze away from the first target significantly earlier (i.e., before they had stepped into the target; see Figure 5.4b). Based on both the verbal report data presented in Experiment 1, and the altered visual search observed during the experimental manipulations conducted in Experiment 2, we suggest these results implicate an interplay between both distraction and self-focus/explicit monitoring processes as underpinning the anxiety-related changes in visual search reported in Experiment 1. As such, these findings provide strong support for integrated perspectives – specifically ACT/ACTS (Eysenck et al., 2007; Eysenck & Wilson, 2016).

5.10.1 Visual Control of Locomotion when Anxious

Results from Baseline in our present research indicate that when presented with a series of stepping constraints, walkers will use visual information regarding upcoming constraints in a feedforward manner (Matthis et al., 2017). For example, during Baseline participants spent approximately 20% of the approach to the first target fixating the subsequent target (typically representing a distance of three-to-five step lengths distance). In contrast, during Threat, participants spent significantly less time previewing the second target and instead spent significantly more time fixating the walkway prior to the first target. The immediate walkway would have represented a distance of typically 1–2 steps length away. Therefore, we view these anxiety-related changes in visual search as representing an increase in both the short-term planning and on-line visual control of individual stepping movements (i.e., using vision to guide foot placement by fixating the area of the walkway towards which the foot is stepping). This supports previous research indicating that older adults anxious about falling prioritise on-line vision to control stepping (Brown et al., 2006).

We propose that consciously prioritising the visual information needed to consciously process discrete stepping movements disrupts the automatic visuomotor visual processes that typically underpin goal-directed locomotor movements (Hollands, Hollands, & Rietdyk, 2017). Seminal research presented by Wulf and Prinz (2001) describes how consciously attending to on-line movement control during a dynamic balance task can interfere with the “automatic”, lower-level processes through which balance is typically controlled. We suggest that fall-related anxiety may influence visual search behaviour via similar mechanisms; with conscious on-line processing disrupting the automatic, sub-conscious co-ordination between gaze and stepping movements. Actively controlling each individual step through on-line vision, rather than relying on feedforward control to guide movement, will likely reduce both gait stability and, subsequently, safety during locomotion by limiting the individual’s ability to perceive, identify and negotiate subsequent/future threats in a safe and stable manner (Matthis & Fajen, 2014).

Contrary to our predictions, earlier transfers of gaze observed during Threat were not associated with increased stepping error. This was surprising, as previous research demonstrates a causal link between early gaze transfer and suboptimal stepping performance; albeit in older adults (Young & Hollands, 2010). It seems that, unlike older adults (Chapman & Hollands, 2006a), young adults may be able to maintain accurate foot placements during precision stepping without visual feedback of their foot position. Therefore, we may expect healthy young adults to be less susceptible to increased stepping errors following a premature gaze transfer, as requirements to maintain gaze fixation on the target until foot contact are reduced.

5.10.2 Support for Integrated Theoretical Perspectives

As with Threat (Experiment 1), participants reduced visual previewing during Internal, once again prioritising proximal areas of the walkway at the expense of subsequent stepping constraints (Experiment 2). This finding provides evidence of a causal link between consciously processing ones movements and altered visual search. Specifically, these results suggest that conscious movement processing results in the prioritisation of the visual information required to monitor/control individual discrete steps (i.e., an increase in both short-term planning and on-line control mechanisms); with this altered prioritisation occurring at the expense of planning future stepping actions. Based on this causal relationship – combined with anxious participants directing greater attention towards consciously processing individual stepping movements during Experiment 1 – we propose that the comparable reductions in visual previewing observed during Threat in Experiment 1 are due, at least in part, to anxiety-related increases in conscious movement processing. Specifically, we propose that this internal focus of attention manifested itself in the prioritisation of the immediate visual information needed to consciously process each discrete step, with this behaviour detracting from the capacity to perform the proactive, feedforward visual search observed during Baseline.

In Experiment 1, onset times to initial fixations were also significantly shorter during Threat, compared to Baseline. This indicates that, much like with other forms of anxiety (Staab, 2014), fall-related anxiety may induce a hypervigilant gaze response to threatening stimuli (i.e., a visual bias for threatening stimuli, resulting in rapid initial fixations towards potential threats to balance). This idea is further supported by research suggesting that older adults fearful of falling display an attentional bias towards threatening, fall-relevant stimuli (Brown et al., 2011). In Experiment 2, however, onset times to initial fixations were significantly longer during both Internal and Cognitive Load (compared to Baseline). This suggests that the rapid visual fixations observed in Experiment 1 are unrelated to either of these factors (conscious movement processing or reduced cognitive resources). Instead, this supports predictions made in ACT/ACTS (Eysenck et al., 2007; Eysenck & Wilson, 2016), indicating increased sensitivity for the stimulus-driven attentional system.

Participants also transferred their gaze away from the first target significantly earlier during Threat, compared to Baseline (Figure 5.4b), with no such changes observed during Internal (see Figure 5.6). As we observed comparable reductions in visual previewing during both Threat and Internal, participants would have obtained similarly limited visual information about the subsequent stepping constraints in both conditions. This suggests that premature transfers of gaze away from the first target are not the direct result of any failure to obtain information about subsequent stepping constraints; as suggested by Young and Williams (2015). Rather, we interpret this early transfer of gaze during Threat to be indicative of a gaze bias towards upcoming threats to balance – similar to the earlier fixations made towards the immediate walkway at the start each trial (and unlike the early transfer of gaze observed during Cognitive Load, which we interpret as a “disengagement” from proactive feedforward visual search). We argue that this finding provides further support for ACT/ACTS (Eysenck et al., 2007; Eysenck & Wilson, 2016), whereby anxiety is predicted to increase the influence of the stimulus-driven system (at the expense of goal-directed attention, e.g., fixating the first target until the precision step has been completed).

These interpretations clearly highlight an interplay between distraction and self-focus/monitoring factors, thus providing strong support for integrated accounts of anxiety-related disruptions in perceptual-motor performance. Specifically, we suggest that this putative interaction can be placed within the context of ACT/ACTS (Eysenck et al., 2007; Eysenck & Wilson, 2016), which posits that anxiety “causes attention to be directed towards detecting the source of the threat and deciding how to respond” (Wilson, 2008, p. 195). We propose that the initial hypervigilance (as well as premature transfers of gaze towards subsequent stepping constraints) observed during Threat may represent preferential attention allocated towards detecting the source of threat, with subsequent conscious movement control selected as the behavioural response to minimise the risk of falling. It is also possible to place these results within the context of Nieuwenhuys and Oudejans’ (2012) *Integrated Model of Anxiety and Perceptual-Motor Performance*, whereby anxiety is argued to influence the information towards which individuals attend (i.e., hypervigilance towards immediate threats), how this information is then interpreted (i.e., interpreting the raised edges of the targets as threatening, as indicated in the verbal report data from Experiment 1) and the subsequent selection and execution of the motor response (i.e., conscious monitoring/control of individual steps). Our results illustrate a complex picture of multiple, potentially interacting attentional factors which may contribute to the altered gaze behaviour observed when anxious about falling. As such, the results highlight the importance of considering the interplay between a multitude of psychological factors when attempting to conceptualise the impact of fall-related anxiety on locomotion, rather than focusing exclusively on either distraction or self-focus influences.

Participants also transferred their gaze between different areas of the walking environment less during Threat, compared to Baseline. This finding is in line with previous research describing reduced visual exploration in anxious older adults (Young et al., 2012) and individuals suffering from anxiety-related disorders at height (Kugler et al., 2013; 2014). However, no such changes were observed during either Internal or Cognitive Load in Experiment 2. Consequently, we suggest that this 'freezing of gaze' likely reflects an anxiety-related prioritisation of visual stability, in an attempt to reduce potentially destabilising head, and eye-in-head, movements (Staab et al., 2013; Young & Williams, 2015). Indeed, Young and Williams (2015) suggest that anxiety-related reductions in visual exploration may "represent attempts to minimize 'unnecessary' destabilizing movements even when, in the instance of visual search, they are required for picking up external information and movement planning during adaptive gait" (p. 9). Alternatively, it is possible that reduced visual exploration may reflect anxiety-related inefficiencies within the 'shifting' function of the central executive (i.e., optimally allocating attention within and between tasks), as proposed by ACT/ACTS (Eysenck et al., 2007; Eysenck & Wilson, 2016). For example, Eysenck and Wilson (2016) suggest that anxiety may lead to "[…] inefficient shifting between cues" (p. 340) which during locomotion may include different areas of the walking path. This interpretation would suggest that anxiety may impair a walker's ability to shift attention between the immediate areas of the walkway needed for: (a) the conscious processing of individual steps; and (b) the distal areas of the walking environment required for effective feedforward planning.

5.10.3 Future Directions

In the current study we manipulated and evaluated behaviours in healthy young adults, in an attempt to establish causal links between fall-related anxiety and behaviours previously observed in clinical populations that also present countless potential confounding factors (e.g., age-related decline in visuomotor processing; Young & Hollands, 2012a). Consequently, it is possible that behaviours observed in the present research, in addition to subsequent interpretations, may not generalise to older adults and other clinical populations. Furthermore, it is possible that high-risk older adults may allocate attention differently to young adults when anxious about falling. For example, Tinetti and Powell (1993) characterise fear of falling as a lasting concern about falling. It is, therefore, possible that older adult fallers may prioritise attending to worrisome thoughts related to these concerns when their balance is threatened; potentially resulting in different patterns of anxiety-related attentional processing and subsequent alterations in visuomotor behaviour. As such, internal, task-irrelevant distracters – such as ruminative worries/concerns about falling – may be of more relevance for high-risk older adults and clinical populations. Future chapters in the present programme of research will thus attempt to replicate these findings in older adults deemed to be at a high risk of falling; exploring the changes in both attention and visuomotor behaviour which occur when high-risk older adults become anxious about falling.

5.11 Conclusions

Our results demonstrate a causal link between fall-related anxiety and previously described patterns of visual search observed in both high-risk, anxious older adults (Young et al., 2012; Young & Hollands, 2012b) and individuals suffering from clinical anxiety disorders (Kugler et al., 2013; 2014); specifically relating to reduced visual previewing and an early transfer of gaze away from stepping targets to view upcoming constraints. Based on the gaze behaviour data from Experiments 1 and 2, and the verbal report data from

Experiment 1, we propose an interplay between distraction and self-focus/explicit monitoring processes. Specifically, we suggest that when anxious, participants displayed increased initial hypervigilance towards immediate threats to balance, reducing their visual exploration in an attempt to limit potentially destabilising movements. Motivated to avoid falling, participants subsequently attempted to consciously control their walking. We propose that this heightened conscious movement processing manifested itself in the increased reliance on short-term planning and on-line vision to consciously control each individual step (with this behaviour detracting from the capacity to perform the proactive, feedforward planning observed during Baseline). This mode of visual control persisted until participants perceived that the immediate threat (first stepping target) had been negotiated (i.e., once they had stepped towards it), whereby they directed their gaze prematurely towards the next immediate threat to their balance. We suggest that these findings provide strong support for integrated accounts of anxiety-related disruptions in perceptual-motor performance – specifically ACT/ACTS (Eysenck et al., 2007; Eysenck & Wilson, 2016).

The current findings demonstrate that both fall-related anxiety and consciously processing walking movements can disrupt the maintenance of proactive, feedforward visual search during adaptive gait, supporting previous claims that altered visual search observed in high-risk older adults may be a consequence of anxiety-related changes within attentional processing (Young & Williams, 2015). Identifying factors that underpin anxiety-related disruption of effective gaze behaviour during locomotion is an essential step in developing future rehabilitation strategies. Consequently, aside from the theoretical implications of this work, the current findings will contribute to the development of empirically grounded falls-prevention tools aimed at reducing reliance on explicit conscious movement control (Kal et al., 2013; Lam, Maxwell, & Masters, 2009; Zhu, Poolton, Wilson, Masters, & Maxwell, 2011).

Chapter 6: Exploring Attentional Focus of Older Adult Fallers During Heightened Postural Threat

Study 4 was published in *Psychological Research*

(see Section List of Thesis Publications)

6.1 Introduction

It is widely accepted that anxiety can influence both cognition and behaviour; inducing changes in attentional focus which may subsequently disrupt movement coordination (for overviews, see: Eysenck & Wilson, 2016; Nieuwenhuys & Oudejans, 2012). Empirical support for these conclusions are drawn largely from research evaluating the execution of ontogenetic skills, such as sporting movements during high-pressure situations (e.g., Beilock & Carr, 2001; Wilson, Vine et al., 2009). However, anxiety's negative effect on how we think and move is not just confined to sport. An emerging body of research demonstrates the detrimental effects that anxiety can also exert on daily activities, such as controlling posture and gait.

Fall-related anxiety, or fear of falling, has been shown to disrupt attentional processing during gait in older adults (Gage et al., 2003), leading to behavioural adaptations which may, paradoxically, increase the risk of falling (Young & Williams, 2015).[6] Recent findings from the domain of posture and gait indicate that fall-related anxiety may impair attentional processing efficiency by virtue of individuals directing attentional focus internally, in an attempt to consciously control or monitor movement (Huffman et al., 2009;

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[6] While fear of falling may in some instances serve a protective effect (e.g., heightened fear may be a normal adaptive response to a realistic threat, which may prevent an individual with poor balance from undertaking an activity where there is a high chance of falling), older adults frequently display disproportionate levels of fear relative to their physiological fall-risk (Delbaere, Close, Brodaty, Sachdev, & Lord, 2010a). Excessive fear is associated with both behavioural responses to postural threats likely to reduce stability (Delbaere et al., 2009), and an increased risk of falling (Delbaere et al., 2010a). Indeed, as Delbaere et al. (2009) describe, "…when concern about falls is excessive, the associated adaptive behaviours might actually increase falls risk, rather than protect against it" (p. 241).

Young et al., 2016; Zaback et al., 2015). For example, Chapter 4 described heightened conscious movement processing during conditions of fall-related anxiety, as well as reductions in processing efficiency. This experimental chapter also reported that attentional processing efficiency was, however, equally impaired during conditions of conscious movement processing (in the absence of anxiety); with a positive association also occurring between decrements in processing efficiency and state conscious movement processing.

These findings broadly support *self-focus* theories of anxiety-related performance breakdown (Beilock & Carr, 2001). For example, Reinvestment Theory (Masters & Maxwell, 2008) – one such self-focus theory – postulates that anxiety leads the performer to direct conscious attention towards monitoring or controlling movements regulated largely by "automatic" processes. Adopting such an attentional strategy is argued to disrupt movement execution (Masters & Maxwell, 2008) which, in the context of older adults, may lead to behavioural adaptations which reduce safety when walking (Young & Williams, 2015). For example, consciously controlling movement has been suggested to contribute to postural "stiffening" (Young & Williams, 2015), whereby individuals freeze the degrees of freedom in the kinematic chain, effectively serving to reduce movement amplitude and fluency. While this postural control strategy may be beneficial in accommodating destabilising factors during static postural tasks (for example, maintaining stability when a bus goes over a speed-bump), postural stiffening will likely increase the possibility of falling during dynamic tasks (such as walking along an uneven pavement), where co-ordinated, skilled, and sometimes rapid movements are required to maintain safety (Young & Williams, 2015).

Research also suggests that attempting to consciously process walking/stepping movements may impair movement planning. For example, Chapter 5 described that consciously processing stepping movements is associated with a reduction in proactive visual search during adaptive gait. Specifically, rather than previewing future stepping constraints approximately four-steps ahead, these individuals instead fixated their gaze on the ground one-step ahead. Consequently, Uiga, Capio et al. (2015) propose that such internal focus may increase fall-risk by increasing the likelihood that these individuals will miss external information necessary for successful locomotion.

Alternatively, rather than performance disruptions resulting from directing *too much* on-line attention towards movement execution (as hypothesised by self-focus accounts), *distraction* theories propose that anxiety disrupts performance as a result of directing *too little* attention towards movement. Specifically, these theories hold that anxious individuals will preferentially direct attention towards threatening, task-irrelevant cues, which reduces the attentional resources available for processing task-relevant information necessary for successful task performance (Wine, 1971). These stimuli can be either internal (e.g., worries or disturbing thoughts relating to task-failure) or external (threatening task-irrelevant environmental distracters). Attentional Control Theory (ACT; Eysenck et al., 2007), however, posits that anxious individuals can overcome these distractions by using compensatory self-regulatory strategies, however, doing so is cognitively taxing and further reduces cognitive resources available for directing attention towards the primary task. This could be particularly troublesome for older adults, given both the age-related decrease in working memory capacity (e.g., Schneider-Garces et al., 2010), and the age-related increase in the minimum level of cognitive input required to maintain postural stability (Boisgontier et al., 2013; Woollacott & Shumway-Cook, 2002). Therefore, processing worries related to falling – and the subsequent cognitively taxing self-regulatory strategies employed to overcome such ruminative thoughts – can be viewed as a separate, secondary task; in that doing so will further reduce the already limited cognitive resources available for postural control, thereby resulting in greater postural instability and compromised safety.

Despite these contrasting theoretical stances, little attempt has been made to investigate likely changes in attention that occur in older adults during anxious gait. Instead, the limited research which has studied anxiety-related changes in attention during postural tasks has, hitherto, restricted these investigations to healthy young adults during conditions of artificially manipulated fall-related anxiety (Johnson, Zaback, Tokuno, Carpenter, & Adkin, 2019b; Zaback et al., 2016). For example, while the results presented in Chapter 5 provide some insight into the specific changes in attentional focus which occur when anxious about falling, the sample studied were healthy young adults completing a constrained, unnatural experimental task. As such, it cannot be assumed that observed results will generalise to older adults experiencing threats to their balance in a complex setting typical of daily life (e.g., traversing a set of uneven paving stones in a crowded street). Therefore, the primary aim of this present research was to investigate how heightened postural threat (and subsequent increases in fall-related anxiety) modifies older adults' self-reported attentional allocation during locomotion in real-world settings.

The secondary aim was to identify how older adults at a high-risk of falling, such as those who have previously fallen (Dionyssiotis, 2012; Nevitt, Cummings, & Hudes, 1991) or individuals with a propensity to consciously control or monitor their movements (Wong, et al., 2008; Wong, Masters, Maxwell, & Abernethy, 2009; Young et al., 2016), alter their allocation of attention when their balance is threatened. For example, as older adult fallers are more likely to experience fear of falling (Friedman et al., 2002) – characterised by Tinetti and Powell (1993) as a lasting concern about falling – it is possible that these individuals will allocate greater attention towards worrisome thoughts about both their previous falls and possible future accidents, especially when their balance is threatened. Similarly, Reinvestment Theory (Masters & Maxwell, 2008) posits that individuals with a propensity to consciously control/monitor their movements will direct greater attention towards conscious movement processing when anxious.

Owing to difficulties (both experimentally and ethically) of inducing fall-related anxiety in older adults in a naturalistic setting, we employed retrospective methods in a manner similar to that described by Oudejans et al. when investigating anxiety-related changes in allocation of attention in athletes (Oudejans, Kuijpers, Kooijman, & Bakker, 2011) and musicians (Oudejans, Spitse, Kralt, & Bakker, 2017). In the present research, older adults were asked to describe their thoughts and attention during a scenario when there is a very high-risk of falling and their anxiety is at a peak. This retrospective verbal reports approach has been highlighted as a viable method for exploring "thoughts and attention without explicitly manipulating attention" (Oudejans et al., 2011, p. 62). We predicted older adults would direct greater attention towards both movement processing and threats to balance during High-threat situations, and less attention towards task-irrelevant thoughts. However, we also predicted that fallers would allocate additional attention towards worries related to falling, and self-regulatory strategies designed to overcome such distractive ruminations. Finally, we predicted that a higher trait propensity to consciously control/monitor movements would be associated with greater attention directed towards movement processing during High-threat situations.

6.2 Method

6.2.1 Participants

Forty community-dwelling older adults (aged > 60; female/male: 28/12; mean ± SD age: 76.50 ± 8.84) were recruited from sheltered residential accommodation schemes and community exercise classes. Chapter 5 reported effect sizes ($r=Z/\sqrt{N}$) between .57 and .60 for key, comparable variables. Consequently, a power analysis conducted with G*Power (Faul et al., 2009) determined that between 18 and 21 participants (per group) would be required to obtain 80% power (Cohen, 1988).

All participants were free from any neurological impairment or musculoskeletal condition that prohibited them from walking in daily life. Participants were excluded if they demonstrated major cognitive impairment (MiniCog score of < 3 [Borson, Scanlan, Brush, Vitaliano, & Dokmak, 2000; Borson, Scanlan, Chen, & Ganguli, 2003; Borson, Scanlan, Watanabe, Tu, & Lessig, 2006]). Institutional ethical approval was obtained from the local ethics committee and the research was carried out in accordance with the principals laid down by the Declaration of Helsinki. All participants provided written informed consent.

6.2.2 Assessments

The Movement Specific Reinvestment Scale (MSRS; Masters et al., 2005) was used to assess participants' trait movement reinvestment (Masters & Maxwell, 2008). This 10-item questionnaire consists of two 5-item subscales: conscious motor processing (i.e., 'movement control'; R-CMP) and movement self-consciousness (i.e., 'movement monitoring'; R-MSC). Items are rated on a 6-point Likert scale (1 = *strongly disagree*; 6 = *strongly agree*). Both subscales range from 5-30, with higher scores reflecting a higher propensity for reinvestment.

The Falls Efficacy Scale-International (FES-I; Yardley et al., 2005) was used to assess participants' balance confidence. The 16-item questionnaire measures the level of concern about falling during a range of different activities, both inside and outside the home. Items are rated on a 4-point Likert scale (1 = *not at all concerned*; 4 = *very concerned*). Scores range from 16-64, with higher scores reflecting greater concern relating to balance (i.e., lower levels of balance confidence). The questionnaire has been recommended as an appropriate screening tool for fall-related concern in both research and clinical settings (Delbaere et al., 2010b).

Cognitive functioning was assessed with the MiniCog (Borson et al., 2000). The MiniCog is a composite of delayed three-item recall and clock drawing (participants are instructed to draw a clock with the hands pointing to a specified time on a blank clock-face). The maximum score possible is 5, with 1-point assigned for every correctly recalled item and 2-points assigned for a correctly drawn clock. This assessment (when using a cutpoint of 3) has been demonstrated to have similar levels of sensitivity at detecting cognitive impairment as the Mini-Mental State Examination (Borson et al., 2003).

Physical functioning was assessed using the Timed Up and Go test (TuG; Podsiadlo & Richardson, 1991). In this test, participants are timed while they stand up from a chair (approximate seat height 46 cm), walk 3-metres at a comfortable and safe pace, turn around, return to the chair, and sit back down. The test is commonly used in both clinical and research settings as a means of assessing physical functioning (Gates, Smith, Fisher, & Lamb, 2008; Podsiadlo & Richardson, 1991). Data from these assessments are presented in Table 6.1.

Participants were classified as fallers (one or more falls; *n* = 18) or non-fallers (zero falls; *n* = 22) based on the number of times they recalled falling in the past 12 months. A fall was defined as an event in which the individual unintentionally came to rest on the ground, floor, or another lower level (Koski, Luukinen, Laippala, & Kivela, 1996). Four fallers had experienced an injurious fall, resulting in hospitalisation. However, all participants had been discharged from hospital and had returned to independent community living by the time of participation.

Table 6.1. Participant characteristics

Measure: mean (± standard deviation)	Non-faller group (n=22)	Faller group (n=18)
Age	76.55 (± 9.14)	76.44 (± 8.99)
Gender (females)	13	15
Number of falls (past 12 months)	0	1.56 (± 1.25)
TuG (seconds)	11.02 (± 5.52)	12.64 (± 4.89)
MiniCog	4.30 (± 0.80)	4.53 (± 0.64)
FES-I	27.41 (± 9.72)	32.94 (± 9.78)*
R-CMP	17.18 (± 7.69)	19.62 (± 6.78)
R-MSC	12.23 (± 6.87)	12.78 (± 8.18)

*$p < .05$.

6.2.3 Verbal Reports Procedure

Participants were asked to imagine themselves walking during two scenarios: Low- and High-threat. For Low-threat, participants were presented with the following scenario:

> *Think about a moment during walking when you are completely relaxed and there is a low chance of tripping or falling. For example, you could be walking on a flat, even surface or walking in a familiar, safe environment.*

Participants were then asked two questions to explore their attentional focus: "When you are completely relaxed, what do you think about and focus your attention to? What do you do to ensure that you do not trip or fall?" Participants were instructed to provide at least one answer for each question. For the High-threat condition, participants were presented with the following scenario:

> *Think about an important moment during walking, when your anxiety is very high and there is a very strong chance of tripping or falling if you do not execute the next step well. For example, you could be walking through a busy crowd, stepping off a high curb, or walking on a slippery (wet or icy) or uneven surface.*

Participants were then asked two questions: “When your anxiety is at its peak, what do you think about and focus your attention to during these important moments? What do you do to try and prevent yourself from tripping or falling?” As with the Low-threat condition, participants were instructed to provide at least one answer for each question. The order in which participants were presented the Low- and High-threat scenarios was counterbalanced.

To ensure that participants could relate to the scenarios presented, the example scenarios provided were designed to feature activities that are frequently encountered by community-dwelling older adults (such as walking along a flat surface/uneven surface/through a crowd, etc.). Pilot testing further confirmed the suitability of these scenarios for a cohort of community-dwelling older adults. These scenarios and follow-up questions were derived from those previously used by Oudejans et al. (2011, 2017), with the second question similarly included to provide participants with an additional prompt. While it was hypothesised that this second question would be more relevant for the High-threat scenario, it was included for both conditions to allow us to establish a Low-threat baseline against which we could compare threat-related behaviours. For example, while older adults may report that they control their movement and step carefully when their balance is threatened, it is possible that they may also display these behaviours when relaxed and there is a low perceived risk of falling. As per Zaback et al. (2016), a simple probe (“Can you please explain what you mean by this statement?”) was used in instances where answers provided required further clarification. Please see Appendix A for an example of the verbal reports protocol administered to participants.

6.2.4 Data Analysis

Verbal reports were analysed by two independent observers (authors TJE and AJC). As both questions served the same purpose, answers to each were combined and analysed together (as per Chapter 5). Both observers produced a list of statements from the verbal reports. This process involved separating the verbal reports into single, codeable statements (allowing each statement to be coded into a single category), as well as omitting any statement describing something towards which attentional focus could not be directed (Oudejans et al., 2011, 2017). The two statement lists of both observers showed a high inter-observer reliability of 93.6%. Any discrepancies between the two lists were discussed until agreements were reached, leading to a final list of 226 statements.

As with Chapter 5, each statement was categorised into one of the five following attentional categories:

1. *Movement processes* (thoughts relating to consciously controlling or monitoring movement, e.g., “I focus on picking up my feet” or “I focus on walking slowly”)
2. *Threats to balance* (thoughts about environmental threats to balance, e.g., an uneven paving stone or an approaching cyclist)
3. *Worries or disturbing thoughts* (e.g. thoughts relating to falling and the potential negative consequences of this)
4. *Self-regulatory strategies* (positive self-talk statements, as well as thoughts adopted to enhance concentration, e.g., “I concentrate on making my breathing more controlled”)
5. *Task-irrelevant information* (statements unrelated to walking or maintaining balance, e.g., an individual thinking about what they are having for dinner or letting one’s mind wander)

Statements were categorised by two observers (TJE and AJC) independently, resulting in 97.1% inter-observer reliability. Any disagreements were discussed until an agreement was met. Examples of categorised statements from the present study are presented in Table 6.2.

Table 6.2. Example items (coded statements from the present research) for each attentional category.

Attentional categories	Examples
Movement processes	Participant 31: *“Step more deliberately (control where I am stepping).”* Participant 32: *“I always focus on lifting my right foot to make sure it doesn’t catch on anything.”*
Threats to balance	Participant 8: *“Even when I am relaxed while walking in the flat or along the road, park, anywhere, I keep my eyes down for potential threats.”* Participant 37: *“Looking at the ground to make sure there is nothing to trip me up.”*
Worries or disturbing thoughts	Participant 2: *“I fell outside the main door and spent 3 weeks in hospital with two fractures... I think about that every time I go out the door.”* Participant 35: *“Thinking about falling and injuring myself. I’ve had some very nasty falls... I will never forget the times I fell down the marble stairs.”*
Self-regulatory strategies	Participant 38: *“Tell myself to ‘come on and do it’ and continue despite the anxiety.”* Participant 40: *“Thinking what might be causing anxiety so as to help me relax.”*
Task-irrelevant information	Participant 10: *“General thoughts about plans for the day.”* Participant 11: *“Often let my mind wander, what to have for dinner, who I need to contact, etc.”*

6.2.5 Statistical Analysis

As all verbal report data were non-normally distributed, it was not possible to use multiple 2x2 (Low/High-threat x Faller/Non-faller) ANOVAs to compare within- and between-group differences for each of the five attentional categories. Therefore, the statistical analyses were separated into three sections: (1) general changes in attentional focus; (2) faller vs. non-faller comparisons, and; (3) correlational analyses.

General changes in attentional focus. Wilcoxon tests were used to determine the Low- to High-threat change in the number of verbal reports generated for each of the five attentional categories (as per Chapter 5). As the assumption of normality was violated, effect size is reported as $r=Z/\sqrt{N}$ (Fritz et al., 2012).

Faller vs. Non-faller comparisons. For each attentional category, two separate Mann-Whitney U tests were used to explore between-group (Faller/Non-faller) differences for the number of reports generated; one test for Low- and one test for High-threat (Oudejans et al., 2017). Separate Wilcoxon tests for Fallers and Non-fallers were then used to determine within-group changes between Low- and High-threat for each attentional category. Bonferroni was corrected to .0125 for all analyses, based on the four separate analyses conducted for each category: (1) Between-group analysis comparing Fallers vs. Non-fallers at Low-threat (Mann-Whitney *U* test); (2) Between-group analysis comparing Fallers vs. Non-fallers at High-threat (Mann-Whitney *U* test); (3) Within-subject change (Low- to High-threat) for Fallers (Wilcoxon test); (4) Within-subject change (Low- to High-threat) for Non-fallers (Wilcoxon test). Effect size is reported as $r=Z/\sqrt{N}$.

Correlational analyses. Separate partial Spearman's correlations were used to compare the relationships between participant characteristics (Number of falls, R-CMP, R-MSC, and FES-I) and the number of verbal reports generated for each attentional category (during both Low- and High-threat), while controlling for the potential following confounds:

age, TuG and MiniCog scores. Correlations were only completed on verbal report categories containing a minimum number of 20 statements (see Table 6.3). This decision was made to ensure that results were not confounded by conducting correlations on categories with, for example, only 5 items (e.g., movement processes or self-regulatory strategies during Low-threat). This resulted in correlations being used to compare participant characteristics and the following attentional categories: Threats to balance (Low-threat); Task-irrelevant information (Low-threat); Movement processes (High-threat); Threats to balance (High-threat); Worries or disturbing thoughts (High-threat), and; Self-regulatory strategies (High-threat). Based on the highly correlated nature of numerous participant characteristics, in any instances where an attentional category was significantly correlated with two or more participant characteristics, separate follow-up non-parametric partial correlations controlling for any other significantly correlated participant characteristic (in addition to age, TuG and MiniCog scores) were conducted. For example, if R-CMP and FES-I were both significantly correlated with movement processing statements, then two separate follow-up correlations would be conducted: one correlating R-CMP and number of movement processing statements, controlling for FES-I, age, TuG and MiniCog scores; and another correlating FES-I and number of movement processing statements, controlling for R-CMP, age, TuG and MiniCog scores).

6.3 Results

6.3.1 General Changes in Attentional Focus

Attention directed towards movement processes was more often reported in conditions of High-threat comparted to Low-threat ($Z = -4.62$, $p < .001$, $r = .73$). During High-threat, participants also reported directing more frequent attention towards threats to balance ($Z = -3.65$, $p < .001$, $r = .58$), worries or disturbing thoughts ($Z = -3.44$, $p = .001$, $r = .54$) and self-regulatory strategies ($Z = -2.50$, $p = .006$, $r = .40$). They also reported directing significantly less attention towards task-irrelevant information ($Z = -5.30$, $p < .001$, $r = .84$). These data are presented in Table 6.3.

Table 6.3. Number (and percentage) of statements in each attentional category, and the number (and percentage) of participants producing these statements, for both Low- and High-threat

	Low-Threat		**High-Threat**	
Attentional category	Number of statements	Number of participants	Number of statements	Number of participants
Movement processes ***	5 (5.5%)	5/40 (12.5%)	44 (32.6%)	30/40 (75.0%)
Threats to balance ***	22 (24.2%)	17/40 (42.5%)	42 (31.1%)	29/40 (72.5%)
Worries or disturbing thoughts **	5 (5.5%)	3/40 (7.5%)	25 (18.5%)	17/40 (42.5%)
Self-regulatory strategies **	5 (5.5%)	5/40 (12.5%)	22 (16.3%)	17/40 (42.5%)
Task-irrelevant information ***	54 (59.3%)	33/40 (82.5%)	2 (1.5%)	1/40 (2.5%)
Total	91 (100%)		135 (100%)	

**$p < .01$, ***$p < .001$ (when the number of statements produced was statistically compared between Low- and High-threat).

6.3.2 Faller vs. Non-Faller Comparisons

Between-group differences. Compared to Non-fallers, Fallers reported directing significantly greater attention towards worries or disturbing thoughts during both Low- ($U = 154.00$, $Z = -2.30$, $p = .011$, $r = .36$) and High-threat ($U = 63.50$, $Z = -4.13$, $p < .001$, $r = .65$). Fallers also reported significantly less attention directed towards task-irrelevant information during Low-threat ($U = 96.00$, $Z = -3.02$, $p = .002$, $r = .48$). No other between-group differences were found for faller-status, Us ≥ 157.00, Zs ≤ -1.27, ps $\geq .13$, rs $\leq .36$. These data are presented in Table 6.4.

Within-group changes (Fallers). Compared to during Low-threat, Fallers reported significantly more attention directed towards both movement processes ($Z = -2.71$, $p = .004$, $r = .64$) and worries or disturbing thoughts ($Z = -3.03$, $p = .001$, $r = .71$) during high-threat. They also directed significantly less attention towards task-irrelevant information ($Z = -3.45$, $p < .001$, $r = .81$) during High-threat. No other differences were found when comparing changes between Low- and High-threat for Fallers, *Z*s ≤ -2.00, *p*s ≥ .023, *r*s ≤ .47. These data are presented in Table 6.4.

Within-group changes (Non-fallers). During High-threat Non-fallers directed significantly more attention towards both movement processes (*Z* = -3.82, *p* < .001, *r* = .81) and threats to balance (*Z* = -3.35, *p* < .001, *r* = .71), and directed significantly less attention towards task-irrelevant information (*Z* = -4.41, *p* < .001, *r* = .94). No other differences were found when comparing changes between Low- and High-threat for Non-fallers, *Z*s ≤ -1.73, *p*s ≥ .042, *r*s ≤ .37. These data are presented in Table 6.4.

Table 6.4. Number (and percentage) of statements in each attentional category, and the number (and percentage) of participants producing these statements, for Non-fallers and Fallers.

	Low-Threat		**High-Threat**	
Attentional category	Number of statements	Number of participants	Number of statements	Number of participants
Non-fallers				
*Movement processes ****	3 (5.7%)	3/22 (13.6%)	27 (39.7%)	18/22 (81.8%)
*Threats to balance ****	8 (15.1%)	7/22 (31.8%)	24 (35.3%)	18/22 (81.8%)
Worries or disturbing thoughts	0 (0%)†	0/22 (0%)	3 (4.4%)†††	3/22 (13.6%)
Self-regulatory strategies	3 (5.7%)	3/22 (13.6%)	12 (17.7%)	8/22 (36.4%)
*Task-irrelevant information ****	39 (73.6%)††	21/22 (95.5%)	2 (2.9%)	1/22 (4.6%)
Total	53 (100%)		68 (100%)	
Fallers				
*Movement processes ***	2 (5.3%)	2/18 (11.1%)	17 (25.4%)	12/18 (66.7%)
Threats to balance	14 (36.8%)	10/18 (55.6%)	18 (26.9%)	11/18 (61.1%)
*Worries or disturbing thoughts ****	5 (13.2%)†	3/18 (16.7%)	22 (32.8%)†††	14/18 (77.8%)
Self-regulatory strategies	2 (5.3%)	2/18 (11.1%)	10 (14.9%)	9/18 (50.0%)
*Task-irrelevant information ****	15 (39.5%)††	12/18 (66.7%)	0 (0%)	0/18 (0%)
Total	38 (100%)		67 (100%)	

$^{**}p < .01$, $^{***}p \leq .001$ (when the number of statements produced was statistically compared between Low- and High-threat, for both Fallers and Non-Fallers, i.e., within-group comparisons)

$^{\dagger}p < .0125$, $^{\dagger\dagger}p < .01$, $^{\dagger\dagger\dagger}p < .001$ (when Fallers were statistically compared to Non-Fallers, for that respective Condition, i.e., between-group comparisons).

6.3.3 Correlational Analyses

Only significant correlations are reported in this section. Please see Table 6.5 for a complete list of *r*-values and *p*-values for all analysed correlations. All correlations are reported while controlling for age, TuG and MiniCog scores.

Threats to balance (Low-threat). During Low-threat, a significant positive association was observed between the number of statements related to threats to balance and both R-CMP ($r = .36$, $p = .019$) and R-MSC scores ($r = .48$, $p = .002$). However, when controlling for each significantly correlated participant characteristic, only R-MSC remained significantly correlated with attention directed to threats to balance ($r = .39$, $p = .013$).

Task irrelevant information (Low-threat). During Low-threat, a significant negative association was observed between the number of task-irrelevant information statements and: number of falls ($r = -.47$, $p = .003$); FES-I scores (i.e., greater fall-related concerns, $r = -.47$, $p = .003$), and; R-CMP scores ($r = -.39$, $p = .013$). However, when controlling for other significantly correlated participant characteristics, only number of falls remained significantly correlated with Low-threat task-irrelevant information ($r = -.41$, $p = .01$).

Worries or disturbing thoughts (High-threat). During High-threat, a higher number of falls was significantly correlated with the number of worries or disturbing thoughts reported ($r = .70$, $p < .001$).

Table 6.5. Relationships between participant characteristics and the number of verbal reports for attentional categories with a minimum of 20 statements.

		Low-Threat		**High-Threat**			
		Threats to balance	Task-irrelevant information	Movement processes	Threats to balance	Worries or disturbing thoughts	Self-regulatory strategies
Number of falls	*r* =	.250	**-.472**	-.073	-.145	**.703**	.036
	p =	.080	**.003**	.344	.210	**<.001**	.421
FES-I	*r* =	.230	**-.471**	.167	.076	.191	-.111
	p =	.099	**.003**	.177	.338	.143	.268
R-CMP	*r* =	**.362**	**-.390**	-.121	.095	.224	.153
	p =	**.019**	**.013**	.251	.299	.105	.197
R-MSC	*r* =	**.482**	-.034	-.090	-.026	.022	.164
	p =	**.002**	.425	.310	.444	.451	.181

6.4 Discussion

The results demonstrate significant alterations in how older adults report directing their attention during scenarios where their balance is threatened and their anxiety about falling is high. The results also highlight marked differences in how individuals who have previously fallen allocate their attention. These findings extend the findings presented in Chapter 5, with only investigated attentional changes during anxious gait in young adults.

6.4.1 General Changes in Attentional Focus

As predicted, older adults reported directing greater attention towards both movement processes and threats to balance, and less attention towards task-irrelevant thoughts, when their balance was threatened (see Table 6.3). Increased attention towards the control and/or perception of movement when anxious supports Reinvestment Theory (Masters & Maxwell, 2008). In the present research, it is likely that increased attention was directed towards conscious movement processing in an attempt to minimize the likelihood of a fall occurring. However, as consciously controlling movement is associated with behavioural adaptations which may reduce safety during gait – such as postural ‘stiffening’ (Young & Williams, 2015) and disrupted movement planning (Chapter 5) – this attentional strategy may, paradoxically, increase the likelihood that an individual will fall. Although, given the lack of significant between-group difference observed in the number of movement processing statements reported during High-threat scenarios, with both Fallers and Non-fallers reporting significantly more movement processing statements during High-threat, it is also possible that in some instances such attempts to consciously control movement may serve a functional benefit (for example, if the individual possesses the cognitive resources required to simultaneously consciously process movement and plan future actions, or in instances where reductions in movement amplitude/fluency carry limited negative consequences). As such, we propose that it may be possible to view conscious movement processing as a behavioural trade-off between attempts to consciously negotiate an ongoing threat, and the negative consequences associated with either reductions in movement amplitude/fluency or disrupted movement planning. While traditional conceptualisations have viewed any attempts to consciously control/monitor dynamic gait-related tasks as a maladaptive process (e.g., Young & Williams, 2015), future work is needed to better understand the behavioural consequences of anxiety-related increases in conscious movement processing.

During High-threat participants also reported directing greater attention towards both worries/disturbing thoughts, and self-regulatory strategies. These results support predictions made by ACT (Eysenck et al., 2007), which posits that anxiety may disrupt attentional processing as a result of directing preferential attention towards worries or disturbing thoughts. Processing these thoughts imposes not only "substantial demands on the processing and storage capacity of working memory…[but] an additional burden on the self-regulatory mechanism inhibiting such thoughts" (Eysenck et al., 2007, p. 337). Directing attention towards worries or disturbing thoughts, as well as the subsequent direction of attention towards self-regulatory strategies, will likely reduce the cognitive resources available for postural control and consequently reduce safety in this population, as older adults require increased cognitive input to effectively control posture and gait (Boisgontier et al., 2013; Woollacott & Shumway-Cook, 2002).

6.4.2 Can Observations in Young Adults be Translated to Older Adults?

When completing an adaptive gait task under experimentally manipulated conditions of postural threat, we have previously reported (in Chapter 5) that young adults will similarly direct greater attention towards both movement processes and threats to balance, and less attention towards task-irrelevant thoughts. However, unlike the older adults studied in the present research, this young adult cohort did not report directing greater attention towards either worries or disturbing thoughts, or self-regulatory strategies. This suggests that differences may exist between how young and older adults allocate attention during gait when anxious about falling. Indeed, a large number of the worries or disturbing thoughts reported by the older adults in the present research were ruminations on previous falls (see Table 6.2). These results clearly demonstrate that personal experiences influence how attention is allocated during conditions of imagined postural threat.

It is also possible that these age-related differences may be partially attributed to differences in environmental context. For example, the older adults studied in the present research would have likely imagined a complex, challenging scenario during which there would have been a high chance of falling. In contrast, the young adults studied in Chapter 5 would have likely viewed the laboratory-based experimental task used as representing both a lesser challenge and a smaller threat to balance. However, recent work conducted by Johnson, Zaback, Tokuno, Carpenter, and Adkin (2019a) highlights differences between how young and older adults allocate attention when performing an identical postural control task (i.e., no differences in environmental context). This suggests that differences in attentional allocation observed in the older adults in the present study, when compared to young adults in previous research (Chapter 5), are unlikely to primarily be a consequence of different environmental contexts. Instead, we suggest that these differences are more likely underpinned by differences in personal experience.

Based on these present findings, we suggest that one must be cautious when attempting to generalise work carried out in young adults to make inferences about how attentional allocation may compromise safety in older adults. While it may be possible to produce situations that induce fear of falling in young adults (for example, those used in Chapter 5), due to the marked differences in previous personal experiences, it is unlikely that the subsequent attentional (and behavioural) response in this population will represent anxiety-related changes identical to those observed in older adults at risk of falling.

6.4.3 Attentional Focus During Gait is Dependent upon Previous Fall-Experience

Our results demonstrate that attentional allocation, during both Low- and High-threat, is dependent on previous personal experiences with falls. We observed significant differences in how older adult fallers allocate attention, compared to non-fallers (see Table 6.4). During Low-threat, Fallers directed greater attention towards worries/disturbing thoughts, and less attention towards task-irrelevant information, when compared to Non-fallers. They also directed greater attention towards worries/disturbing thoughts during High-threat. In contrast, no such significant changes were observed in Non-fallers. This indicates that the significant threat-related increase in the amount of attention directed towards worries or disturbing thoughts described in the present cohort, when analysed as an overall group, is driven primarily by changes occurring within participants who have previously fallen.

These results further reinforce the dramatic adverse effects that falling can have for older adults. Previous research illustrates that falling can have a major negative influence on older adults' quality of life, leading to both activity restriction and a loss of independence which extend beyond any consequences of physical injury resulting from the fall (Vellas, Wayne, Romero, Baumgartner, & Garry, 1997). Our present results extend these findings and highlight ruminative thoughts relating to the fall itself – thoughts which persist even during situations where the chance of falling is low – as one potential explanation as to why older adults who have previously fallen avoid even low-risk, everyday activities critical for independent living. Previous research has also highlighted a relationship between falling and the extent to which an older adult engages in thoughts unrelated to their behavioural goal (also termed 'mind-wandering' [Nagamatsu, Kam, Liu-Ambrose, Chan, & Handy, 2013]). However, the content of these thoughts was not explored. Consequently, we suggest that these worries or disturbing thoughts observed during the present research represent one, potentially prevalent, form of mind-wandering, and may contribute to reduced safety while walking.

Interestingly, when the present cohort were analysed as an overall group we observed threat-related increases in attention directed towards threats to balance. However, these changes appear to be confined to the older adults who had not previously fallen, with no such significant changes observed in Fallers. This was unexpected, as it is logical to assume that in the presence of increased threats to balance, individuals would direct greater attention towards such stimuli; in order to plan the postural adjustments necessary to ensure that the threat does not result in a loss of balance. However, it seems that older adults who have previously fallen may prioritise the processing of worries and disturbing thoughts (e.g., internal threats) at the expense of attending to the increased threats to their balance (e.g., external threats). While future research is needed to confirm this suggestion, failure to attend to relevant threats to balance when anxious will likely compromise safety by virtue of neglecting and failing to accommodate external information necessary for avoiding environmental hazards.

These findings indicate that during conditions of imagined postural threat, older adults who have not recently fallen will allocate attention in a manner similar to that previously described in healthy young adults during experimental conditions of increased postural threat (Chapter 5). Specifically, they focus greater attention towards both identifying threats to their balance and subsequent attempts to consciously process movement, and less attention towards task-irrelevant thoughts. Given that these threat-related alterations in attention correspond to those previously reported in young adults, we propose that these changes may in fact reflect a protective/adaptive mechanism which might enhance safety. For example, although conscious movement processing has been shown to disrupt movement planning (Chapter 5), perhaps far greater negative behavioural outcomes would occur if walkers prioritised the planning of future actions rather than allocating attention to immediate postural threats and ensuring that each individual step was effectively programmed. Thus, it is possible that the negative behavioural outcomes associated with such mode of motor control (e.g., Young & Williams, 2015) become evident only in instances where conscious control/monitoring persists for longer than 'necessary' (e.g., beyond the navigation of a postural threat). Future work is needed to further explore this proposal.

The differences observed between how older adults (analysed as an overall group), when compared to the young adults studied previously in Chapter 5, report attention during conditions of postural threat appear to be driven largely by attentional changes occurring in older adult fallers. We suggest that these differences are a likely consequence of previous (unsuccessful) experiences of encountering postural threats. For example, while the Non-fallers likely imagined a previous situation where they successfully navigated a postural threat, Fallers likely drew on a previous unsuccessful experience where they fell and subsequently attributed failure either internally (e.g., blaming their poor balance) or externally (e.g., blaming the poorly maintained pavement). Thus, while Non-fallers report attentional responses that may have a protective benefit, we suggest that Fallers would be more likely to report combinations of worries/disturbing thoughts and either movement processes (if attributing failure internally towards balance deficits) or threats to balance (if attributing failure externally towards environmental factors). While this speculative proposal indicates that Fallers and Non-fallers may have drawn upon different previous experiences when imagining scenarios of heightened postural threat, we do not view this as a confound. Instead, we suggest that – much like during other modes of motor control (e.g., highly-pressured sport performance) – previous successful and unsuccessful threat-related experiences influence attentional allocation during subsequent threatening scenarios (real or imagined). As such, it is logical to assume that older adults who have fallen will ruminate about previous falls in instances where their balance is threatened, regardless of whether these threats are imagined or real (much like athletes who have previously ‘choked’ under pressure will often ruminate on previous failures during subsequent high-pressured situations [Hill, Hanton, Matthews, & Fleming, 2010]).

These results highlight that previous observations made regarding how young adults allocate attention when their balance is threatened may translate to cohorts of highly-functioning older adults who have not recently fallen. However, the observed Faller/Non-faller differences also highlight the need to study high-risk older adults, such as those who have previously fallen, when attempting to make inferences about how changes in attention may influence fall-risk.

6.4.4 Trait-Movement Reinvestment

Contrary to our predictions, we failed to observe an association between trait movement reinvestment and the amount of attention directed towards movement processes during High-threat. This was unexpected, as an individual’s propensity to consciously monitor and control their movements when anxious has been argued to be a dimension of personality (Masters & Maxwell, 2008). Research has demonstrated greater attention directed towards movement processing in older adults with higher levels of trait movement reinvestment (Uiga, Capio et al., 2015; Wong et al., 2009). However, this previous research did not investigate attentional focus during conditions of postural threat/anxiety. Therefore, it is possible that when fall-related anxiety is high and individuals are highly motivated to avoid a fall, older adults direct proportionate levels of attention towards movement processes regardless of their trait level of movement reinvestment. Higher levels of conscious movement processing have also been reported in older adults who have previously fallen (Wong et al., 2008, 2009). However, our results are contrary to these findings, with both older adult fallers and non-fallers reporting directing statistically comparable levels of attention towards movement processes during both Low- and High-threat scenarios. While our present results do highlight the importance of considering state levels of conscious movement processing within the context of older adult falls, the predictions presented within Reinvestment Theory (Masters & Maxwell, 2008) regarding trait movement reinvestment – as measured through the MSRS (Masters et al., 2005) – appear to be less relevant within this context. This is an important issue, as previous research has concluded that the "MSRS [a measurement of trait movement reinvestment] shows potential as a clinical tool with which to predict falls in the elderly" (Wong et al., 2008, p. 410).

6.4.5 Limitations

One limitation of the present research was the use of retrospective self-reports to investigate attentional focus. The aim of this study was to explore changes in attentional focus during ecologically valid situations of postural threat, thus avoiding potential confounds related to experimentally inducing fall-related anxiety (e.g., Chapter 5). Owing to the difficulties (both experimentally and ethically) of inducing fall-related anxiety in older adults in a naturalistic setting, we thus selected retrospective self-reports as the most appropriate methodology to answer our research question. While this method has been used previously to describe anxiety-related changes in attention in both athletes (Oudejans et al., 2011) and musicians (Oudejans et al., 2017), and is argued to be a viable method for exploring "thoughts and attention without explicitly manipulating attention" (Oudejans et al., 2011, p. 62), we are unable to determine the true extent to which retrospective self-reports reflect attentional allocation during daily life. This is particularly relevant for the present research, given the possibility that certain participants may have been unable to reliably recall and report attentional focus due to age-related cognitive decline. However, participants were excluded from participation if they demonstrated major cognitive impairment (MiniCog score of < 3 [Borson et al., 2000, 2003, 2006]). Furthermore, the imagined scenarios were designed to feature frequently occurring, everyday experiences. Consequently, we reasoned that participants would have been able to relate to the imagined scenarios, resulting in accurate recollection and description of attentional allocation. Indeed, it is worth noting that our overall results are in-line with those recently published by Johnson et al. (2019a), who found that older adults exposed to experimentally-induced conditions of postural threat rated directing greater attention towards movement processes, threat-related stimuli (which included both external threats and internal worries) and self-regulatory strategies, and less attention directed towards task-irrelevant information[7]. As such, despite the retrospective nature of the present research, we suggest the findings presented by Johnson et al. (2019a) further highlight the validity of our data. Regardless, further research is needed which ethically manipulates fall-related anxiety in older adults during real-world scenarios, in order to evaluate attentional processes in 'real-time'.

Another limitation of using retrospective self-reports relates to the possibility that the specific scenario imagined during both the Low- and High-threat conditions differed between Fallers and Non-fallers. However, as we wanted the scenarios that participants generated to be individually meaningful and relevant, we reasoned that it would have been a greater confound had we constrained participants to recall their attentional focus during a single, uniform scenario; a scenario which the participant may or may not have experienced. While we acknowledge that direct assessment of the specific scenarios which participants imagined may have provided further insight in to the previously reported between-group differences, we deemed this unnecessary on the basis that the descriptions provided for the High-threat scenarios were designed to all include an external threat which needed to be navigated/avoided. As such, while the threat itself likely differed across participants, all

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[7] Note, Johnson et al. (2019a) did not separate participants into fallers/non-fallers. As such, a further sub-group comparison to our Faller/Non-faller data is not possible.

imagined scenarios would have featured comparable opportunities for the individual to worry, consciously process movement, engage in self-regulatory strategies, and so on.

Finally, exploring attentional allocation through retrospective self-report does not allow for the investigation into how these changes in attention subsequently influence posture and gait-related behaviours. Future research should examine how fear of falling influences both the attention and behaviour (for example, visual search behaviour and stepping characteristics) of older adults during adaptive gait. The current findings can inform the most appropriate outcome measures and predictions in this future work.

6.5 Conclusions

This study presents the first exploration of how older adults, specifically those at an increased risk of falling, reallocate attention when their balance is threatened during locomotion. The present results highlight that when their balance is threatened, much like the young adults studied in Chapter 5, older adults are less likely to direct attention towards task-irrelevant information, and more likely to focus on movement processes and threats to balance. However, these results also indicate that the amount of attention directed towards ruminative worries or disturbing thoughts are dependent on previous personal experiences with falling. Contrary to our predictions, trait movement reinvestment was not associated with the reporting of greater attention directed towards movement processes when threatened; indicating that the studying of state, rather than trait, movement reinvestment may be of more relevance for the context of older adult falls. As processing worries or disturbing thoughts will likely reduce the attentional resources available for effective postural control, thus compromising safety, we highlight this as one potential area in which to target interventions aimed at reducing the likelihood of repeated falling. Furthermore, as certain changes are dependent on previous personal experiences with falling, we suggest that one must be cautious when attempting to generalise work carried out in young adults to make inferences about fall-risk in older adults. Given the subjective, retrospective nature of the measures assessed in the present research, objective ‘real-time’ measures of both attention and gait are needed to further explore these conclusions.

Chapter 7: Evidence of a Link Between Fall-Related Anxiety and High-Risk Patterns of Visual Search in Older Adults During Adaptive Locomotion

Study 5 was published in *The Journals of Gerontology: Series A, Biological and Medical Sciences*

(see Section List of Thesis Publications)

7.1 Introduction

Falls in older adults most commonly occur during walking (Berg et al., 1997; Robinovitch et al., 2013), with trips, slips and misplaced steps accounting for the majority of incidences (Berg et al., 1997). Safely navigating complex environments requires a walker to sample visual information in a manner that allows for planning future actions (Matthis & Fajen, 2014; Young et al., 2012). For example, a task as simple as walking through a residential common-area will present various constraints that need to be navigated, such as stepping around a chair leg or avoiding an oncoming walker. During such situations, it is imperative that visual information is sampled in a 'feedforward' manner, allowing sufficient time for the walker to make proactive adjustments to safely avoid environmental constraints (Matthis & Fajen, 2014). Despite the importance of feedforward planning, older adults deemed to be at a high risk of falling often display visual search behaviours likely to reduce their ability to perceive, plan, and subsequently adapt their stepping movements to negotiate environmental constraints (Chapman & Hollands, 2006b; Young et al., 2012). For example, Young et al. (2012) found that, when approaching a series of stepping constraints, low-risk older adults displayed proactive patterns of visual exploration; fixating, and transferring their gaze between, subsequent stepping constraints. In contrast, their high-risk counterparts directed their gaze predominantly towards the proximal constraint and displayed reduced visual previewing of subsequent obstacles. During complex tasks requiring the navigation of multiple environmental hazards, such reduced previewing/planning will likely impair the walker’s ability to navigate future constraints (Young & Williams, 2015). As such, there is a clear need to identify the underlying factors contributing to these altered patterns of visual search.

Researchers have proposed increased fall-related anxiety, or fear of falling, as one potential mechanism underpinning these ‘high-risk’ behaviours (Young & Williams, 2015). For example, as the high-risk older adults studied by Young et al. (Young et al., 2012) also reported significantly greater levels of state anxiety compared to their low-risk counterparts, the authors attributed the observed reductions in visual previewing to heightened fear of falling. While these findings highlight an association between fear of falling and altered gaze behaviour when walking, they fail to establish a causal link; a process that necessitates both the direct experimental manipulation of fall-related anxiety and the measurement of visual search. While Chapter 5 described a link between fall-related anxiety and altered visual search behaviours in young adults completing an adaptive locomotion task, the results from Chapter 6 highlight that one cannot assume that findings observed in healthy young adults will necessarily translate to older adults – particularly those deemed to be at a high risk of falling.

An extensive body of research has, however, described the dramatic changes in walking behaviours adopted by older adults during conditions of experimentally induced fear of falling. For example, when walking along a walkway elevated 0.6 m above the laboratory floor, older adults will adopt more cautious gait, displaying slower gait speed, shorter steps and spending longer in double-limb support (Delbaere et al., 2009). While this body of work demonstrates that fear of falling can alter how older adults walk on a flat path, it remains unknown how experimentally induced fall-related anxiety will influence older adults’ visuomotor control of locomotion during more complex, adaptive gait tasks.

Therefore, the current study aimed to evaluate a possible causal link between fall-related anxiety and altered patterns of visual search in older adults when navigating a series of stepping constraints. Specifically, we explored whether the patterns of visual search behaviours previously observed in high-risk older adults (Chapman & Hollands, 2006b, 2007; Young et al., 2012) could be induced in a group of low-risk older adults during conditions designed to elicit fall-related anxiety.

7.2 Method

7.2.1 Participants

Forty-four community-dwelling older adults (aged > 60; female/male: 30/14; mean ± *SD* age: 74.61 ± 6.83) were recruited from local community groups. Chapter 5 reported effect sizes between 0.57 and 1.38 for key, comparable variables. Consequently, a power analysis determined that 19 participants per-group (Low-/High-risk) would be required to obtain 80% power. Participants were deemed to be at a high-risk of falling if they had experienced two or more falls within the past 12 months ($N = 10$), or if they presented two or more of the following risk factors ($N = 10$): one fall within the past 12 months; slow walking speed, determined by a Timed up and Go (TuG) score > 12 seconds (Lusardi et al., 2017), or; low strength (Landi et al., 2012; Scott et al., 2014; Zhang et al., In Press), determined by dominant handgrip strength < 22kgf for females/32kgf for males (Bahat et al., 2016; Zhang et al., In Press). Handgrip strength was used to provide further sensitivity to the classification algorithm; however, every individual classified as ‘high-risk’ had either recently fallen and/or exhibited slow gait, independent of low grip-strength. Consequently, 24 participants were classified as ‘Low-risk’ and 20 participants were classified as ‘High-risk’. Prior to participation, participants also completed the Falls-Efficacy Scale International (FES-I; Yardley et al., 2005). Demographic information for each group is reported in Table 7.1.

Table 7.1. Participant characteristics.

Measure: mean (± *SD*)	Low-risk group (*n* = 24)	High-risk group (*n* = 20)
Age**	72.04 (± 5.74)	77.70 (± 6.88)
Gender (males)	9 (37.5%)	5 (25%)
Number of fallers (past 12 months)	1/24	12/20
TuG (seconds)***	9.33 (± 1.29)	13.22 (± 2.88)
Grip strength (kgf)**	29.20 (± 10.75)	20.76 (± 4.29)
MiniCog	4.25 (± 0.79)	4.25 (± 0.79)
FES-I***	19.83 (± 3.10)	26.25 (± 5.32)

Notes. $^{**}p < .01$, $^{***}p < .001$.

Participants were free from any neurological, cardiovascular or musculoskeletal impairment that prohibited them from walking 10m without a walking aid. Participants were excluded if they demonstrated major cognitive impairment (MiniCog score of > 3 [Borson et al., 2003]), or if they were currently prescribed anxiety or dizziness medication. All participants were free from significant deficits in either visual acuity (20/40 vision or better) or contrast sensitivity[8]. Institutional ethical approval was obtained from the local ethics committee and the research was carried out in accordance with the principles laid down by the Declaration of Helsinki. All participants provided written informed consent prior to participation.

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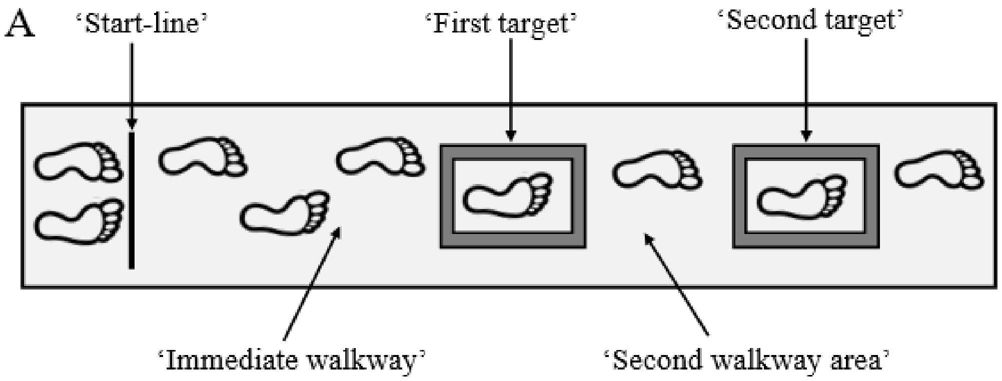
[8] Individuals who required the use of glasses during daily locomotion were screened for compatibility with the eye-tracking equipment, and invited to participate if it was possible to calibrate the eye-tracker over their glasses. Five participants (three Low-risk and two High-risk) wore glasses during testing. Of these, one High-risk and one Low-risk wore bifocal glasses, while the remainder wore single lens glasses for distant vision. Participants requiring the use of glasses during daily locomotion completed tests of visual acuity and contrast sensitivity and while wearing their glasses.

7.2.2 Protocol

On arrival, participants were fitted with reflective markers placed on the heel, mid-foot and toe of both feet, and then with a Mobile Eye-XG portable eye-tracking system (ASL, Bedford, MA). As per Chapters 4 and 5, the experimental task involved walking at a comfortable, self-determined pace along a wooden walkway (width of 40 cm and length of 3.4 m) and stepping into two foam rectangular targets (Figure 7.1a). Targets could appear in two possible locations (midpoint of first target: either 1.5 m or 1.4 m from the walkway start-line; midpoint of second target: either 2.5 m or 2.4 m from the start-line). Target locations were rearranged after every third trial to reduce familiarisation. The foam targets had raised borders to impose a degree of postural threat (foam border width and height = 4cm), and the inside target area was 19 cm x 41.5 cm (width and length, respectively; see Figure 7.1a). Participants were instructed to step into the targets as centrally as possible, with whichever foot they wished. Prior to the start of each trial, participants stood at a ‘start-line’ with their eyes closed, to prevent them from visually previewing the walkway. Following an auditory ‘go’ tone, participants opened their eyes and commenced walking. Prior to data collection, participants completed three familiarisation trials.

Low-risk participants completed the protocol under two conditions: (1) Ground (walkway at ground level), and (2) Threat (walkway elevated 0.6 m above the laboratory floor; see Figure 7.1b). Participants completed one 5-trial block of walks for each condition, and the presentation order of these conditions was counterbalanced across participants. In contrast, High-risk participants completed a single block of five walks at Ground. All trials were completed in the absence of a safety harness. To enhance safety, two experimenters were present at all times, and participants were reminded of their right to withdraw from the study.



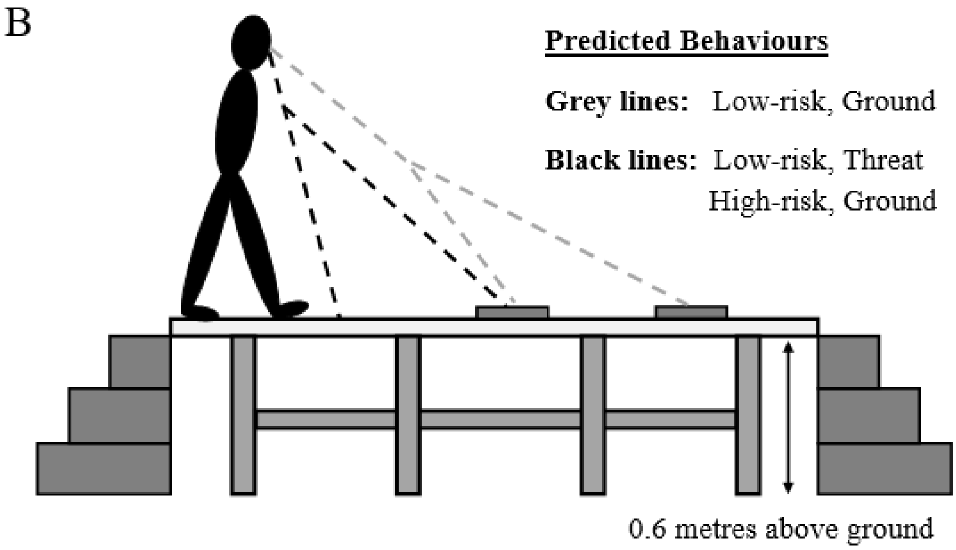


Figure 7.1a. Schematic diagram of the walking task. The arrows denote the different areas of interest for which the walkway was separated into for the gaze analysis.
Figure 7.1b. Schematic diagram of the raised walkway during Threat. The black dashed lines represent the 'restricted' visual previewing/planning predicted in both the Low-risk participants during Threat, and the High-risk participants during Ground trials. In contrast, the grey dashed lines represent the 'proactive' visual search predicted in Low-risk participants during Ground trials.

7.2.3 State Psychological Measures

To assess concern about falling, participants reported state levels of both balance confidence and fear of falling (Zaback et al., 2015). Prior to each block, participants rated their confidence to maintain balance and avoid a fall. Scores ranged from 0% (*not at all confident*) to 100% (*completely confident*). After each block, participants rated their fear of falling (averaged across the previous five trials) on a scale ranging from 0% (*not at all* *fearful*) to 100% (*completely fearful*). After each block participants also rated, on an 11-point Likert scale (1 = *never*, 11 = *always*), the degree to which they were thinking about, or paying attention to: Movement processes; Threats to balance; Worries or disturbing thoughts; Self-regulatory strategies, and; Task-irrelevant information. These categories, and the descriptions provided to participants, were based on results from Chapters 5 and 6. This specific questionnaire can be found in Appendix B. To explore the impact of fall-related anxiety on processing efficiency (the amount of mental effort required to maintain effective task performance), participants also completed the Rating Scale of Mental Effort (Zijlstra, 1993). This involved participants rating the level of mental effort required to complete the previous 5 trials, on a single continuum scale ranging from 0 to 150.

7.2.4 Motor Performance

The following motor performance variables were calculated: (1) Time to complete the walking trial (s); (2) Stance duration preceding the first and second target; and; (3) Stepping error (mm) in both anterior-posterior (AP) and medio-lateral (ML) directions for the first and second target. Kinematic data were collected at 100Hz using a Vicon motion capture system (Oxford Metrics, England) and passed through a low-pass Butterworth filter with a cut-off frequency of 5 Hz (as per Chapters 4 and 5). Time to complete the walking trial was calculated as the time between the ‘go’ tone and heel contact of the final step on the walkway. ‘Stance durations’ were defined as the duration between heel contact and toe-off of the foot initiating the target step. Stepping error was calculated by subtracting the co-ordinate of the mid-foot marker from the co-ordinate of the centre of the target, in AP and ML directions, respectively (as per Chapters 4 and 5). Kinematic data were assigned a randomised code, to allow for blinded analysis, and variables were averaged across conditions. Due to technical limitations, 1 High-risk participant was excluded from kinematic data analyses.

7.2.5 Gaze Behaviour

Fixation locations were classified as one of four areas of interest (see Figure 7.1a): (1) immediate walkway area (the walkway area prior to the first target); (2) the first target; (3) second walkway area (the walkway between the first and second target), and; (4) the second target. These areas of interest were used to determine the duration spent fixating each location during the approach to the first target (until heel contact into this target). Fixation duration data were normalised to individual trial length by presenting data as the percentage of time spent fixating each area of interest. As a further measure of visual previewing, the number of fixations made towards the second target (until heel contact into the first target) were also calculated. The location of the first fixation was also assessed. To determine this variable, each area of interest was allocated a number from 1–4 (immediate walkway = 1; first target = 2; second walkway area = 3; second target = 4), with lower numbers indicating that the first fixation occurred towards more proximal walkway areas. Finally, the number of gaze transfers between the four areas of interest per-second were also calculated to indicate the extent of visual exploration.

Variables were averaged across trials within each condition. Trials where the point-of-gaze crosshair disappeared for the duration of four frames or more were discarded (as per previous eye-tracking chapters. Participants with a trial-discard rate higher than 40% were excluded from all eye-tracking analyses. This procedure resulted in one High-risk participant's data being excluded. A total of 81 trials were analysed for High-risk participants at Ground (M = 4.50 trials per participant), while for Low-risk participants, 110 trials were analysed at Ground (M = 4.35 trials per participant) and 108 analysed for Threat (M = 4.55 trials per participant).While attempts were made to blind the assessor to experimental conditions, this was not possible given between-condition differences in the environmental scene.

7.2.6 Statistical Analysis

Between-group Ground comparisons. Separate independent samples *t*-tests were used to compare High- and Low-risk participants for all aforementioned variables during Ground trials. Where data were non-normally distributed, separate Mann-Whitney U tests were used instead. For all statistical comparisons, effect sizes are reported as Cohen's *d*, unless the assumption of normality is violated, whereby effect sizes are reported as $r=Z/\sqrt{N}$. Separate partial correlations (controlling for age, TuG and MiniCog scores) were used to compare the relationships between any state-psychological measures for which a statistically significant between-group difference was observed, and all statistically significant (between-group difference) motor performance and gaze behaviour variables. Where data were non-normally distributed, analyses were conducted using Spearman's correlation.

Within-subject (Low-risk) Ground-Threat comparisons. Separate paired-samples *t*-tests were used to explore within-subject Ground-Threat changes in all variables. Where data were non-normally distributed, separate Wilcoxon tests were used instead. One Low-risk participant did not wish to complete Threat trials, resulting in within-subject analyses being conducted on the remaining 23 Low-risk participants.

7.3 Results

Please see Table 7.2 for mean (and standard error) values for all assessed variables.

7.3.1 Between-Group Ground Comparisons

State psychological measures. Compared to Low-risk participants, High-risk participants reported significantly lower balance confidence (U = 114.50, p = .001, r = 0.46), significantly higher fear of falling (U = 76.50, p < .001, r = 0.64), and significantly greater mental effort (U = 86.50, p < .001, r = 0.56). High-risk participants also reported directing significantly greater attention towards movement processes (U = 63.50, p < .001, r = 0.64), threats to balance (U = 85.00, p < .001, r = 0.58), worries/disturbing thoughts (U = 131.00, p

< .001, *r* = 0.50), and self-regulatory strategies (*U* = 151.50, *p* = .011, *r* = 0.35). There was a lack of significant between-group difference in attention directed towards task-irrelevant thoughts (*U* = 216.00, *p* = .17, *r* = 0.14).

Motor performance measures. Compared to Low-risk participants, High-risk participants took significantly longer to complete the walking task (*t*(41) = -4.92, *p* < .001, *d* = 1.44). They also exhibited significantly longer stance durations preceding both the first (*U* = 108.00, *p* = .003, *r* = 0.45) and second target (*t*(41) = -4.54, *p* < .001, *d* = 1.39). High-risk participants also had significantly greater ML stepping errors when stepping into the second target (*U* = 150.00, *p* = .028, *r* = 0.29; Figure 7.2b). There was, however, no significant between-group difference for AP (*U* = 180.00, *p* = .12, *r* = 0.18) and ML (*U* = 188.00, *p* = .17, *r* = 0.15) stepping errors into the first target, or AP stepping errors into the second target (*U* = 223.00, *p* = .45, *r* = 0.02). Motor performance data are presented in Figure 7.2.

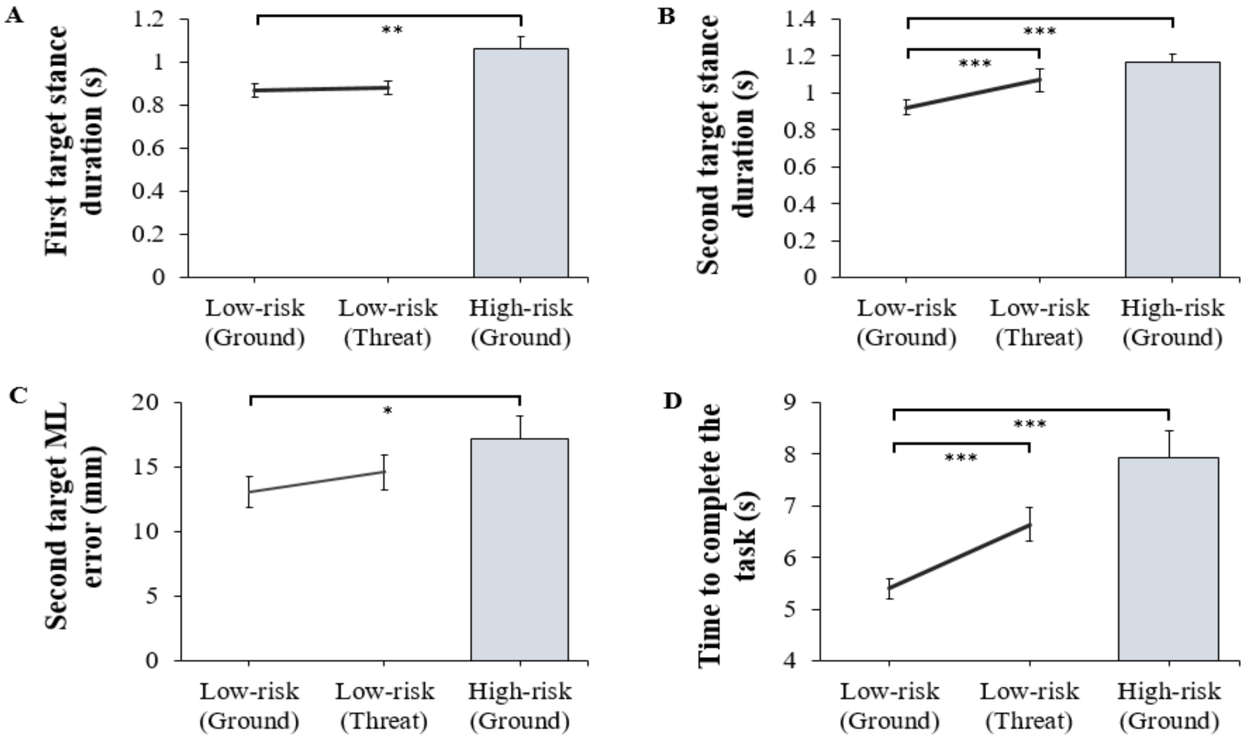


Figure 7.2. Comparisons of Low- and High-risk participants at Ground (between-group analysis), and Low-risk participants at Ground and Threat (within-subject change), for stance durations preceding the first (A) and second target (B), ML stepping error into the second target (C) and time to complete the task (D), **p* < .05, ***p* < .01, ****p* < .001 (mean ± standard error of the mean).

Gaze behaviour measures. Compared to their Low-risk counterparts, High-risk participants' first fixations were located towards more proximal walkway areas (*U* = 89.50, *p* < .001, *r* = 0.52). High-risk participants also spent a significantly greater percentage of time fixating the immediate walkway (*U* = 77.00, *p* < .001, *r* = 0.56), and a significantly smaller percentage of time fixating the second target (*U* = 103.00, *p* = .001, *r* = 0.47). High-risk participants also exhibited significantly fewer previewing fixations towards the second target (*U* = 106.50, *p* = .001, *r* = 0.46; see Figure 7.3b), with 52.63% of High-risk participants failing to make a single previewing fixation towards the second target (compared to 13.04% of Low-risk participants). High-risk participants also transferred their gaze between the different areas of the walkway significantly less (*U* = 137.00, *p* = .013, *r* = 0.34). There was no significant between-group difference in time spent fixating either the first target (*t*(41) = 1.75, *p* = .09, *d* = 0.54) or the second walkway area (*U* = 201.00, *p* = .51, *r* = 0.10). Gaze data are presented in Figure 7.3.

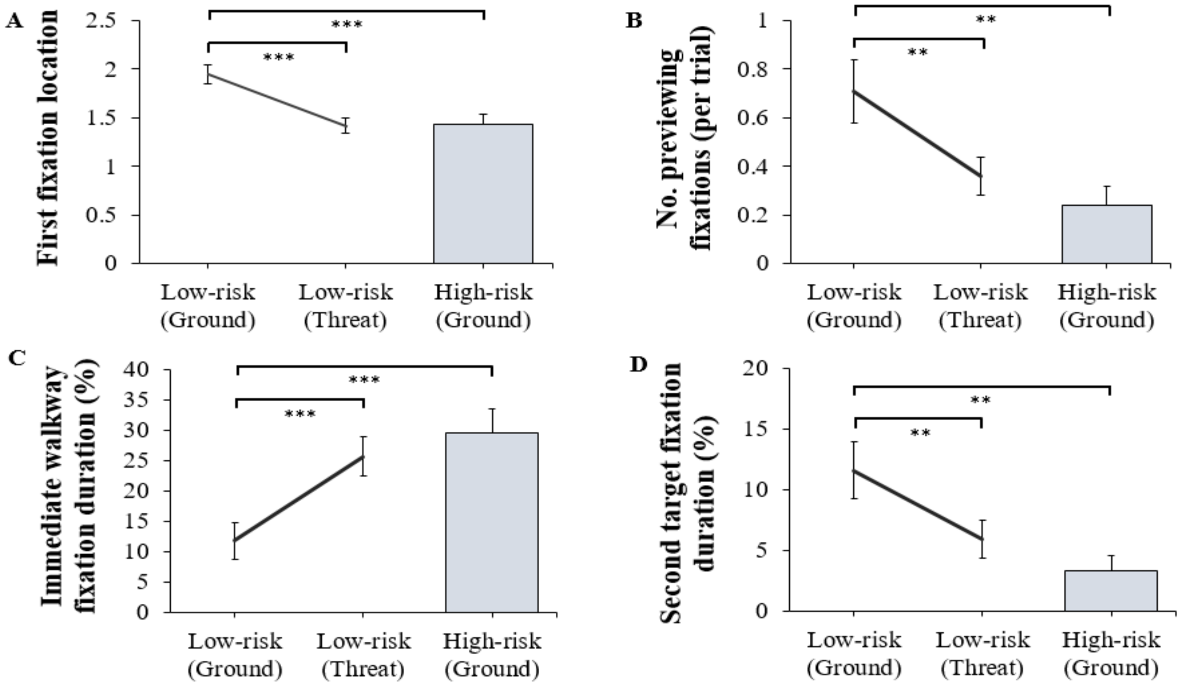


Figure 7.3. Comparisons of Low- and High-risk participants at Ground (between-group analysis), and Low-risk participants at Ground and Threat (within-subject change), for first fixation location (with lower values indicating fixations towards more proximal areas; A), number of previewing fixations towards the second target (average per trial; B), and duration

of fixations (as a %) towards both the immediate walkway (C) and second target (D), $**p < .01$, $***p < .001$ (mean ± standard error of the mean).

Correlational analyses. Only significant correlations are reported in this section. Please see Tables 7.3 and 7.4) for a complete list of *r*-values for all analysed correlations. All correlations are reported while controlling for age, TuG and MiniCog scores.

Regarding motor performance variables, greater trial completion times were associated with greater fear of falling ($r = .294$, $p = .033$), mental effort ($r = .385$, $p = .014$) and attention directed towards both movement processes ($r = .479$, $p = .001$) and threats to balance ($r = .353$, $p = .013$). Greater stance durations preceding the first target were associated with lower balance confidence ($r = -.335$, $p = .017$) and greater attention towards movement processes ($r = .264$, $p = .050$), while greater stance durations preceding the second target were associated with greater mental effort ($r = .342$, $p = .031$) and attention towards movement processes ($r = .461$, $p = .001$).

Regarding gaze behaviour, greater attention directed towards threats to balance was associated with first fixations occurring towards more proximal walkway areas ($r = -.308$, $p = .027$). Longer times fixating the immediate walkway were associated with both lower balance confidence ($r = -.351$, $p = .013$) and greater attention towards movement processes ($r = .386$, $p = .007$). Both the duration and frequency of fixations on the second target were associated with greater attention towards both movement processes ($r = -.331$, $p = .019$ and $r = -.284$, $p = .038$, respectively) and self-regulatory strategies ($r = -.332$, $p = .036$ and $r = -.376$, $p = .016$, respectively).

Table 7.2. Mean, standard error of the mean (*SEM*) and *p* values (for each comparison) for state psychological measures, motor performance measures and gaze variables.

	High-risk		**Low-risk**				**Comparison**	
	Ground		**Ground**		**Threat**		**1**[a]	**2**[b]
	Mean	*SEM*	Mean	*SEM*	Mean	*SEM*	*p*	*p*
Balance confidence (%)	56.32	6.03	85.00	4.17	65.65	5.02	.001	<.001
Fear of falling (%)	31.05	4.95	2.50	1.09	16.96	3.95	<.001	<.001
Mental effort (0-150)	47.37	5.40	20.00	4.04	35.22	4.66	<.001	<.001
Attention directed towards…								
…Movement processes (1-11)	8.90	0.55	4.25	0.66	5.87	0.72	<.001	.003
…Threats to balance (1-11)	6.37	0.76	1.96	0.48	3.26	0.60	<.001	.009
…Worries or disturbing thoughts (1-11)	3.27	0.67	1.08	0.06	1.74	0.37	<.001	.021
…Self-regulatory strategies (1-11)	4.58	0.81	1.88	0.30	3.48	0.50	.011	.003
…Task-irrelevant information (1-11)	1.27	0.13	1.71	0.50	1.44	0.24	.17	.23
Time to complete the task (s)	7.93	0.53	5.40	0.20	6.64	0.32	<.001	<.001
Stance duration (s), first target	1.06	0.06	0.87	0.03	0.88	0.03	.002	.34
Stance duration (s), second target	1.17	0.04	0.92	0.04	1.07	0.06	<.001	<.001
First target, AP stepping error (mm)	32.23	3.62	26.74	3.19	26.00	2.82	.12	.48
First target, ML stepping error (mm)	17.89	1.79	15.00	1.27	17.15	1.51	.17	.10
Second target, AP stepping error (mm)	33.29	4.44	32.05	3.55	26.91	2.71	.45	.08
Second target, ML stepping error (mm)	17.20	1.72	13.09	1.22	14.62	1.34	.028	.14
First fixation location (1-4)	1.43	0.11	1.95	0.10	1.42	0.08	<.001	<.001
Immediate walkway fixation duration (%)	29.69	3.88	11.87	3.02	25.68	3.24	<.001	<.001
First target fixation duration (%)	61.67	3.39	70.12	3.34	60.29	3.75	.09	.002
Second walkway fixation duration (%)	5.36	1.99	6.40	1.57	8.06	1.56	.51	.31
Second target fixation duration (%)	3.29	1.28	11.62	2.39	5.97	1.58	.001	.002
No. previewing fixations (avg. per trial)	0.24	0.08	0.71	0.13	0.36	0.08	.001	.001
No. gaze transfers (per/s)	0.45	0.06	0.68	0.09	0.55	0.04	.013	.13

Notes: [a] When Low- and High-risk are compared at Ground (between-group comparison), [b] When Low-risk are compared between Ground and Threat (within-group comparison).

Table 7.3. Relationships (when controlling for age, Timed up and Go, and MiniCog scores) between state-psychological measures and all motor performance variables for which a significant between-group difference was observed at Ground.

		Time taken to complete	**Stance duration (first target)**	**Stance duration (second target)**	**ML stepping error (second target)**
Balance confidence	*r*	-.233	**-.335**	-.172	-.064
	p	.074	**.017**	.144	.347
Fear of falling	*r*	**.294**	-.011	.152	.219
	p	**.033**	.473	.175	.087
Mental effort	*r*	**.385**	.021	**.342**	.170
	p	**.014**	.899	**.031**	.293
Attention directed to…					
…Movement processes	*r*	**.479**	**.264**	**.461**	.206
	p	**.001**	**.050**	**.001**	.101
…Threats to balance	*r*	**.353**	.012	.194	.234
	p	**.013**	.471	.115	.073
…Worries or disturbing thoughts	*r*	.234	-.011	.103	-.050
	p	.146	.946	.528	.759
…Self-regulatory strategies	*r*	.286	.043	.258	.260
	p	.073	.794	.108	.106

Table 7.4. Relationships (when controlling for age, Timed up and Go, and MiniCog scores) between state-psychological measures and gaze behaviour variables for which a significant between-group difference was observed at Ground.

		First fixation location	**Fixations on immediate walkway**	**Fixations on second target**	**No. of previews**	**No. gaze transfers**
Balance confidence	*r*	-.002	**-.351**	.091	.093	-.100
	p	.495	**.013**	.287	.284	.270
Fear of falling	*r*	.046	.230	-.018	.015	-.018
	p	.389	.077	.457	.464	.455
Mental effort	*r*	-.013	.059	-.140	-.160	-.189
	p	.938	.718	.388	.324	.244
Attention directed to…						
…Movement processes	*r*	-.229	**.386**	**-.331**	**-.284**	-.174
	p	.078	**.007**	**.019**	**.038**	.142
…Threats to balance	*r*	**-.308**	.214	-.040	-.109	-.254
	p	**.027**	.092	.403	.251	.057
…Worries or disturbing thoughts	*r*	-.102	.089	.022	.018	-.074
	p	.266	.293	.448	.457	.326
…Self-regulatory strategies	*r*	-.288	.162	**-.332**	**-.376**	-.222
	p	.072	.316	**.036**	**.016**	.168

7.3.2 Within-Subject (Low-Risk) Ground-Threat Changes

State psychological measures. During Threat, participants reported significant reductions in balance confidence ($Z = -3.43$, $p < .001$, $r = 0.72$), and significant increases in both fear of falling ($Z = -3.60$, $p < .001$, $r = 0.75$) and mental effort ($Z = -3.41$, $p < .001$, $r = 0.71$). They also reported directing significantly greater attention towards movement processes ($Z = -2.75$, $p = .003$, $r = 0.57$), threats to balance ($Z = -2.36$, $p = .009$, $r = 0.49$), worries/disturbing thoughts ($Z = -2.03$, $p = .021$, $r = 0.42$), and self-regulatory strategies ($Z = -2.79$, $p = .003$, $r = 0.58$). There was a lack of significant change in attention directed towards task-irrelevant information ($Z = -0.73$, $p = .23$, $r = 0.15$).

Motor performance measures. Participants took significantly longer to complete the walking task during Threat ($t(22) = -5.57$, $p < .001$, $d = 0.99$). While there was no significant Ground-Threat change in stance durations preceding the first target ($t(22) = -0.44$, $p = .34$, $d = 0.08$), stance durations preceding the second target were significantly longer during Threat ($Z = -3.50$, $p < .001$, $r = 0.74$). Stepping errors in all directions for both the first target (AP: $Z = -.06$, $p = .48$, $r = 0.01$; ML: $Z = -1.28$, $p = .10$, $r = 0.27$) and the second target (AP: $Z = -1.40$, $p = .08$, $r = 0.29$; ML: $Z = -1.10$, $p = .14$, $r = 0.23$) remained unchanged. Motor performance data are presented in Figure 7.2.

Gaze behaviour measures. Participants' first fixations were located towards more proximal walkway areas during Threat ($Z = -4.02$, $p < .001$, $r = 0.84$). Participants also spent a significantly greater percentage of time fixating the immediate walkway ($Z = -3.74$, $p < .001$, $r = 0.78$), and a significantly smaller percentage of time fixating both the first target ($t(22) = 3.53$, $p = .002$, $d = 0.57$) and second target ($Z = -2.95$, $p = .002$, $r = 0.62$). During Threat, participants also exhibited significantly fewer previewing fixations towards the second target ($Z = -3.06$, $p = .001$, $r = 0.64$; see Figure 7.3b), with 39.13% of participants failing to make a single previewing fixation towards the second target during Threat trials (compared to only 13.04% during Ground). Both the number of gaze transfers (Z = -1.13, p = .13, r = 0.24) and the percentage of time spent fixating the second walkway area (Z = -1.01, p = .31, r = 0.21) remained unchanged. Gaze data are presented in Figure 7.3.

7.4 Discussion

The aim of this study was to evaluate a possible link between fall-related anxiety and visual search behaviours reported previously in high-risk older adults during adaptive location (Chapman & Hollands, 2006b, 2007; Young et al., 2012) . We observed significant between-group differences (based on fall-risk) in visual search behaviours during trials at ground level. Specifically, High-risk participants directed their gaze initially towards more proximal areas of the walkway – indicative of a gaze bias for immediate threats to balance (behaviours also reported in anxious young adults in Chapter 5). Following these initial fixations, they continued to visually prioritise proximal areas of the walking path (immediate walkway), at the expense of previewing future stepping constraints (second target; see Figure 7.3). These behaviours likely represent a compensatory mechanism serving to reduce the immediate risk of producing a misplaced step. In some situations, particularly those without the need for extensive feedforward planning, such behaviours may enhance safety. However, in the present research, this restricted feedforward planning appeared to reduce safety – with High-risk participants exhibiting significantly greater ML stepping errors for the second target. Given the lack of significant between-group difference in either AP or ML stepping error for the first target (which accompanied the lack of significant between-group difference in time spent fixating this constraint), we argue that the increased stepping errors for the second target are unlikely to simply reflect a general inability to produce an accurate step. Rather, we suggest that these unsafe stepping behaviours are the likely consequence of a suboptimal visual planning strategy.

As with previous research (Young et al., 2012), High-risk participants reported greater state fear of falling, and lower balance confidence, when completing an adaptive gait task at ground level. When walking at height, Low-risk participants too reported reduced state balance confidence and greater fear of falling. They also adopted patterns of gaze behaviour largely reminiscent of those observed in High-risk participants during Ground trials (see Figure 7.3). While we acknowledge that factors other than anxiety will have likely contributed to and/or exacerbated these behaviours in the High-risk group, these results nonetheless highlight a link between heightened fall-related anxiety and ‘high-risk’ behaviours reported both previously (Young et al., 2012) and herein.

The gaze behaviours observed in both High-risk participants at Ground, and Low-risk participants during Threat, are also comparable to those reported previously in young adults during experimental conditions inducing the conscious processing of stepping movements, in the absence of anxiety (Chapter 5). Interestingly, both High-risk participants at ground level, and Low-risk participants walking at height, reported directing greater attention towards consciously processing walking movements. Based on the results presented in Chapter 5, we propose that older adults anxious about falling will consciously process individual stepping movements, visually prioritising areas of the walking environment needed to do so (e.g., looking 1–2 steps ahead to ensure accurate placement of individual steps). The correlational analyses conducted in the present study provide preliminary support for such an assumption. When controlling for age, cognitive and physical functioning, we found significant positive associations between self-reported conscious movement processing and the time spent fixating the proximal walkway, during ground level walks. During Threat trials, Low-risk participants also reported heightened conscious movement processing, providing further support for the assumption that these gaze behaviours might be a consequence of anxious individuals prioritising the visual information needed to consciously process individual stepping movements.

High-risk participants exhibited longer stance durations preceding both stepping targets, with correlational analyses associating these behaviours with heightened conscious movement processing (when controlling for, among other variables, gait speed). This latter finding is consistent with previous research (Uiga et al., 2018). We suggest that High-risk participants likely prolonged the stance phase of these steps in an attempt to (consciously) maximise stepping accuracy into the target. Nonetheless, significantly greater stepping errors were observed in High-risk participants when stepping into the unpreviewed second target. This indicates that despite prolonged stance phases preceding the second target (indicating increased preparation/pre-programming of the following target step; Lyon & Day, 1997), High-risk participants might require visual information prior to this phase in the gait cycle to step accurately. Alternatively, it is possible that High-risk participants merely required longer stance durations than those exhibited to acquire the relevant visual information.

In contrast, anxious Low-risk participants appeared able to successfully adapt and refine stepping actions to compensate for restrictions in visual previewing and feedforward planning. Specifically, our results indicate these individuals were able to successfully obtain the visual information needed for successful negotiation by increasing the stance durations preceding the unpreviewed target (see Figure 7.2b). While both groups increased stance durations preceding the unpreviewed second target, these increases were proportionately larger in Low-risk participants. For example, during Threat trials, Low-risk participants' stance durations preceding the second target were on average over 20% longer than those preceding the first target. In contrast, stance durations between the previewed first target, and the unpreviewed second, differed by only 10% in High-risk participants. Perhaps High-risk participants might have similarly been able to compensate for reductions in feedforward planning by further increasing the duration of these stance phases. If so, then this raises the interesting question as to why these individuals were unable to determine that they had acquired insufficient visual information to plan and prepare the subsequent precision step.

It is, however, noteworthy that while Low-risk participants were able to counteract such restricted visual search patterns during the present task through compensatory adaptive strategies, this came at a cost to movement efficiency (e.g., increased stance durations). It is, therefore, likely that failing to preview upcoming constraints in a feedforward manner will nonetheless lead to negative behavioural consequences in this population during more complex locomotive tasks (e.g., tasks requiring rapid, accurate, and possibly reactive stepping movements).

One limitation of this study is the variables used to categorise participants as either high- or low-risk. For example, while TuG is a commonly used screening tool for fall-risk in both research and clinical settings (Lusardi et al., 2017; Panel on Prevention of Falls in Older Persons, American Geriatrics Society and British Geriatrics Society, 2011), a more thorough assessment of functional balance would have nonetheless allowed for greater sensitivity when determining an individual's physical risk of falling. Relatedly, while low handgrip strength is associated with increased fall-risk (Scott et al., 2014), this assessment nonetheless remains less of an established risk-factor than either previous falls or walking speed. However, as grip strength was used to categorise participants in conjunction with these other well-established risk-factors, we do not consider this to be a major weakness of the study. Finally, while the current results describe associations between self-reported conscious movement processing and numerous anxiety-related gaze behaviours, such analyses provide only weak evidence of a causal relationship. Future research should, therefore, look to experimentally manipulate levels of conscious movement processing in older adults, independent of anxiety.

7.5 Conclusions

In conclusion, our findings highlight a link between fall-related anxiety and ‘high-risk’ visual search behaviours. Specifically, our results indicate that older adults anxious about falling (either High-risk participants walking at ground level, or Low-risk participants walking at height) will display an initial gaze bias for immediate threats to their balance, prioritising initial fixations towards proximal walkway areas/threats. To overcome these heightened threats, it appears that anxious older adults will then attempt to consciously process individual steps – visually prioritising the proximal walkway areas needed for such conscious processing (e.g., the walkway 1–2 steps ahead). However, the current results also highlight that such behaviours may paradoxically reduce stepping safety by virtue of restricting the visual information obtained about subsequent stepping constraints. Such restricted feedforward planning seemingly impaired the walker’s ability to perceive, plan, and negotiate upcoming environmental hazards. Thus, while these behaviours likely represent a compensatory mechanisms serving to reduce the immediate risk of falling, they may subsequently increase future risk. This information enhances our understanding of why high-risk older adults are less able to safely navigate environmental constraints, and suggests that strategies targeting fall-related anxiety may be an effective strategy for reducing unsafe stepping behaviours in older adults.

Chapter 8: Conscious Movement Processing, Fall-Related Anxiety, and the Visuomotor Control of Locomotion in Older Adults

Study 6 is submitted to peer-review in *The Journals of Gerontology: Series B, Psychological and Social Sciences*

(see Section List of Thesis Publications)

8.1 Introduction

Given both the high prevalence of falls in older adults (Lord et al., 1993; Tromp et al., 2001), and the negative psychological, physical and social impact associated with experiencing a fall (Białoszewski et al., 2008; Hadjistavropoulos et al., 2011), it is not surprising that older adults will often consciously process walking movements in an attempt to avoid falling (Wong et al., 2008). However, rather than enhancing safety, such conscious control strategies may ironically compromise the control of balance and gait during certain situations. For example, Uiga, et al. (2018) described that older adults with a trait propensity to consciously process their movements will take longer to plan and prepare stepping movements yet display increased stepping errors likely to reduce safety. Relatedly, a recent study conducted by Mak et al. (2019) reported both reduced postural stability and increased gait variability in older adults during experimentally induced conditions of conscious movement processing. The authors proposed that such attempts to consciously control movement likely disrupted the subconscious, lower-level processes through which complex, highly coordinated motor actions (such as locomotion) are typically regulated (Mak et al., 2019; Masters & Maxwell, 2008).

Conscious movement strategies may also reduce safety during locomotion through mechanisms other than direct disruption to movement execution. For example, research indicates that directing attention internally towards movement reduces the walker's ability to attend to their environment, and extract relevant information from it (Uiga, Capio et al., 2015;

Young et al., 2016). More specifically, Clark (2015) suggests that during "… the [conscious] control of the basic walking pattern, there is a heightened risk that hazards may be overlooked or ignored […] resulting in slips, trips, collisions and falls" (p. 2). Indeed, Chapter 5 highlights that young adults who consciously process their walking movements will often do so at the expense of visually fixating upcoming environmental stepping constraints.

The above findings suggest that conscious movement strategies may reduce the walker's ability to utilise vision in a *feedforward* manner to plan future stepping movements – perhaps due to a prioritisation of *on-line* visual control (Chapter 5). On-line control refers to the use of vision to regulate an ongoing action (e.g., directing vision towards an obstacle as you step over it; Chapman & Hollands, 2006a, 2006b). Such visual control is important for fine-tuning stepping movements (Chapman & Hollands, 2006a, 2006b; Reynolds & Day, 2005). However, the ability to pre-plan movements using feedforward visual control (e.g., looking multiple steps ahead to identify and programme the adaptations needed to avoid trip hazards) seems critically important to maximise gait stability, safety and efficiency (Barton, Matthis, & Fajen, 2019; Matthis et al., 2015; 2017; Matthis & Fajen, 2014). Thus, by reducing an individual's opportunity to use feedforward control, conscious movement processing may paradoxically impact safety of movement. Chapter 7 provided indirect evidence for this hypothesis, by showing that reduced feedforward planning is associated with both heightened conscious movement processing, and increased stepping errors, in older adults at a high-risk of falling. However, no direct evidence is available that shows if (and how) consciously processing walking movements influences the manner in which older adults visually control locomotion.

Chapters 6 and 7 described how older adults anxious about falling will often consciously control movements in an attempt to avoid falling. Indeed, fearful older adults generally demonstrate comparable decrements in gait stability and efficiency as compared to older adults who consciously control gait in low-anxiety conditions (Ayoubi et al., 2015; Mak et al., 2019). This suggests that the previously reported anxiety-related gait behaviours may in fact be underpinned, to some degree, by attempts to consciously process movement. While Chapter 7 presented evidence to suggest that fall-related anxiety can disrupt older adults' visual search behaviours during adaptive locomotion, the question remains if we can also attribute these findings to heightened conscious movement processing, or whether other anxiety-related processes underpin these behaviours. Chapter 5 described that young adults do display comparable visual search behaviours between experimentally induced conditions of both conscious movement processing and fall-related anxiety – thus indicating some degree of shared underlying mechanism. However, we cannot assume that such observations will translate to an older adult population. It has also been proposed that fall-related anxiety may alter visual search behaviours via processes other than conscious movement processing, such as a gaze bias for threatening stimuli (Staab, 2014). It is therefore necessary to evaluate the relationship between conscious movement processing, fall-related anxiety, and visual search during locomotion in older adults.

Thus, the present study sought to: (a) explore the influence that consciously processing walking movements exerts on older adults' visual search during an adaptive locomotive task, and; (b) examine the extent to which previously observed anxiety-related alterations in older adults' visual search might be a consequence of heightened conscious movement processing. Healthy older adults without a history of falling completed an adaptive locomotion task which required them to step into two raised targets. As described previously, it is possible that fall-related anxiety influences visual search behaviours through attentional mechanisms other than conscious movement processing. Therefore, walks were completed at both ground level (low-threat, during a condition where participants received specific instructions to consciously process movements) and while walking on a walkway elevated 0.6 m (high-threat, thus inciting increased conscious control; as per Chapter 7). Participants also completed baseline walks at ground level, without instructions to consciously process their walking movements. Reasoning that conscious movement processing is largely responsible for the previously described anxiety-related alterations in the visuomotor control of locomotion, we predicted that visual search behaviour would be equivalent during experimentally-induced conditions of conscious movement processing and postural threat (given that participants would be consciously processing movement in both conditions). Specifically, we predicted that participants would direct preferential attention towards the immediate areas of the walkway needed to consciously process discrete stepping movements, at the expense of previewing future stepping constraints. Any differences between conditions would indicate the influence of other anxiety-related processes.

8.2 Method

8.2.1 Participants

Eighteen community-dwelling older adults without a history of falling (aged > 60; female/male: 11/7; mean ± *SD* age: 71.22 ± 5.75) were recruited from the ‘low fall-risk’ subset of a previous study (Chapter 7). Chapter 5 reported large effect sizes ($r=Z/\sqrt{N}$) for key, comparable variables when exploring the effect of experimentally-induced conscious movement processing on visual search behaviour during locomotion. Consequently, a power analysis conducted with G*Power (Faul et al., 2009) determined that 14 participants would be required to obtain 80% power for a repeated measures ANOVA (Cohen, 1988). Institutional ethical approval was obtained from the local ethics committee and the research was carried out in accordance with the principles laid down by the Declaration of Helsinki. All participants provided written informed consent prior to participation.

All participants were free from any neurological, cardiovascular or musculoskeletal impairment that prohibited them from walking 10m without a walking aid. Participants were excluded if they demonstrated major cognitive impairment (MiniCog score of < 3 [Borson et al., 2000; 2003]), or if they were currently prescribed anxiety or dizziness medication. Individuals who required the use of eye glasses during daily locomotion were pre-screened for compatibility with the eye-tracking equipment, and invited to participate if it was possible to calibrate the eye-tracker over their glasses (as per Chapter 7). Two participants completed walks while wearing single-distance lens glasses. All participants were free from significant deficits in either visual acuity (20/40 vision or better) or contrast sensitivity. Participants requiring the use of glasses during daily locomotion completed these tests while wearing their glasses. Participant demographics are reported in Table 8.1.

Table 8.1. Participant characteristics.

Measure	Mean (± *SD*)
Age	71.22 (± 5.75)
Gender (males)	7/18
Number of fallers (past 12 months)	0
Timed up and go (seconds)	9.38 (± 1.28)
Grip strength (kgf)	29.96 (± 11.24)
MiniCog	4.39 (± 0.78)
Falls Efficacy Scale-International	18.83 (± 2.20)

8.2.2 Protocol

The walking task and threat manipulation were identical to that used previously in Chapter 7. Participants had to walk along a wooden path (width = 40 cm; length = 3.4 m) and step as accurately as possible into two rectangular foam targets, with whatever foot they wished. Each target was placed in one of two possible locations (midpoint of first target: either 1.5 m or 1.4 m from the walkway start-line; midpoint of second target: either 2.5 m or 2.4 m from the start-line). Target locations were rearranged after every third trial to reduce familiarisation – with the location of these targets randomised across participants. The foam targets had raised borders to impose a degree of postural threat (foam border width and height = 4 cm), and the inside area of the target was 19 cm x 41.5 cm (width and length, respectively). Prior to the start of each trial, participants stood on the 'start-line' with their eyes closed. This ensured that participants did not begin visually previewing the walkway prior to the start of the trial. Following an auditory 'go' tone, participants opened their eyes and commenced the walking task. Participants completed one 5-trial block of walks under three counterbalanced conditions: (a) Baseline (walkway at ground level); (b) Conscious movement processing (CMP; walking at ground level while directing conscious attention towards movement; see below section 8.2.3 entitled "Conscious Movement Processing"); and (c) Threat (walkway elevated 0.6 m above the laboratory floor). All trials were completed in the absence of a safety harness.

8.2.3 Conscious Movement Processing

Walks were completed under conditions designed to ensure that equal attention was directed towards movement processing during both CMP and Threat trials; thus allowing for the isolation of behaviours casually associated with heightened conscious movement processing from those associated with other anxiety-related processes (as per Jackson et al., 2006). Chapter 7 described marked differences in older adults' visual search during conditions of low- and high-threat (using an identical experimental threat manipulation as utilised in the present chapter). It was thus reasoned that any comparable gaze behaviours observed between CMP (at ground level/during conditions of low-threat) and Threat in the present research are likely underpinned by a shared mechanism of heightened conscious movement processing. Any remaining differences between conditions would indicate the influence of other anxiety-related processes.

Heightened conscious movement processing was achieved by informing participants that they were required to direct conscious attention towards their movements, as they would be asked questions relating to their movement after certain trials. Participants were "informed" that any trials in which they answered incorrectly would be repeated. While this deception was used to ensure engagement with the manipulation, participants' response accuracy was recorded as an additional manipulation check (see Results Section 8.3.1). These questions were based on those used previously to determine "internal awareness" of movements (Uiga, Capio et al., 2015; Young et al., 2016), and were designed to encourage consciously processing movements throughout each trial. Examples included: "How many steps did you take during the trial?" and "Which of your feet did you step between the two targets with?" Internal awareness questions were presented to participants after three randomised CMP trials, and the questions asked were the same for all participants. This experimental manipulation has been validated previously in Chapter 4 and 5 as a method to successfully induce levels of heightened conscious movement processing, and subsequent changes in behaviour, comparable to those observed when anxious about falling. In order to ensure parity in the level of conscious movement processing between CMP and Threat conditions, participants were also asked internal awareness questions after three randomised Threat trials.

8.2.4 State Psychological Measures

To assess concern about falling, participants reported state levels of both balance confidence (prior to each experimental block) and fear of falling (following each experimental block). These measures are described in more detail in Chapter 7. In an attempt to explore the attentional mechanisms which may underpin any differences in visual search behaviour between CMP and Threat, a state measure of attentional allocation was collected after each block (as per Chapter 7; see Appendix B). This involved participants rating, on an

11-point Likert scale (1 = *never*, 11 = *always*), the degree to which they thought about or paid attention to the following sources of information during the previous 5 trials: Movement processes; Threats to balance; Worries or disturbing thoughts; Self-regulatory strategies, and; Task-irrelevant information. Participants also completed the Rating Scale of Mental Effort (RSME; Zijlstra, 1993) after each block of walks. This assessment required participants to rate the level of mental effort required to complete the previous 5 trials.

8.2.5 Motor performance

Participants completed all walks while fitted with reflective markers placed on the heel, mid-foot and toe of both feet (see Chapter 7). Kinematic data were collected at 100Hz using a Vicon motion capture system (Oxford Metrics, England) and passed through a low-pass butterworth filter with a cut-off frequency of 5 Hz (as per Chapter 7). The following motor performance variables were calculated: (1) Time to complete the walking trial (s); (2) Stance duration preceding the first and second target; and; (3) stepping error (mm) in both the anterior-posterior (AP) and medio-lateral (ML) planes for the first target and second target. These variables were calculated in an identical manner to that described previously in Chapter 7. Kinematic data were assigned a randomised code, to allow for blinded analysis, and variables were averaged across conditions.

8.2.6 Gaze Behaviour

Walks were also completed while wearing a Mobile Eye-XG portable eye-tracking system (ASL, Bedford, MA). Fixation locations were classified as one of four areas of interest (identical to Chapter 7): (1) immediate walkway area (the walkway area prior to the first target); (2) the first target; (3) second walkway area (the walkway between the first and second target), and; (4) the second target. These areas of interest were used to determine the duration spent fixating each location during the approach to the first target (until heel contact into the first target, calculated as the maximum vertical acceleration of the heel marker).

Fixation duration data were normalised to individual trial length by presenting data as the percentage of time spent fixating each area of interest. As a further measure of visual previewing, the number of fixations made towards the second target (until heel contact into the first target) were also calculated. The location of the first fixation was also assessed. To determine this variable, each area of interest was allocated a number from 1–4 (immediate walkway area = 1; first target = 2; second walkway area = 3; second target = 4), with lower numbers indicating that the first fixation occurred in an area of interest closer to the walker's feet.

Variables were averaged across the analysed trials for each condition. Trials in which the point of gaze crosshair disappeared for the duration of four frames or more were discarded (as per all other experimental chapters using eye tracking). Participants with a trial-discard rate higher than 40% (i.e., two trials) for either condition were excluded from all eye-tracking analyses. However, as each participant had a trial-discard rate lower than 40%, all 18 participants were included for analysis. A total of 76 trials were analysed for Baseline (*M* = 4.22 trials per participant), while 84 trials were analysed for both CMP and Threat, respectively (*M* = 4.67 trials per participant for both conditions). While attempts were made to blind the assessor to experimental conditions, this was not possible given the between-condition differences in the environmental scene present in the eye-tracking videos.

8.2.7 Statistical Analysis

Separate repeated-measure ANOVAs (effect size reported as partial eta squared; Bonferroni post-hoc tests used to follow up any statistically significant results) were used to explore between-condition differences in all variables. Where data were non-normally distributed, separate Friedman tests were used instead. In these instances, any significant effects were followed up by separate Wilcoxon tests comparing each of the three conditions: Baseline, CMP and Threat (Bonferroni corrected to 0.017). Due to the difficulties associated with calculating effect size for Friedman tests, effect sizes were calculated (and reported as $r=Z/\sqrt{N}$) instead for any Wilcoxon test follow-ups (as recommended by Field, 2009).

8.3 Results

8.3.1 State Psychological Measures

All means (and standard error of the mean) values for state psychological measures are presented in Table 8.2.

Fall-related anxiety. There was a significant main effect of Condition on balance confidence ($\chi^2(2) = 20.47$, $p < .001$). Post-hoc tests revealed that participants reported significantly lower balance confidence during Threat, when compared to both Baseline ($Z = -3.31$, $p < .001$, $r = 0.78$) and CMP ($Z = -2.83$, $p = .003$, $r = 0.67$). There was no significant difference between Baseline and CMP ($Z = -1.87$, $p = .061$, $r = 0.44$). There was also a significant main effect of Condition on fear of falling ($\chi^2(2) = 12.00$, $p = .002$). Post-hoc tests revealed that participants reported significantly greater fear of falling during Threat, when compared to both Baseline ($Z = -2.23$, $p = .013$, $r = 0.55$) and CMP ($Z = -2.23$, $p = .013$, $r = 0.55$). There was no significant difference between Baseline and CMP ($Z = 0.00$, $p = 1.00$, $r = 0.00$).

Attentional focus. There was a significant main effect of Condition on the amount of attention directed towards movement processes ($\chi^2(2) = 14.00$, $p = .001$). Compared to Baseline, participants reported directing significantly greater attention towards movement processes during both CMP ($Z = -2.52$, $p = .006$, $r = 0.59$) and Threat ($Z = -3.12$, $p = .001$, $r = 0.74$). Participants reported statistically comparable levels of conscious movement processing during CMP and Threat ($Z = -0.05$, $p = .96$, $r = 0.01$). There was a significant main effect of Condition on the amount of attention directed towards self-regulatory processes ($\chi^2(2) = 10.87$, $p = .004$). During Threat, participants reported directing significantly greater attention towards self-regulatory processes than during both Baseline ($Z = -2.67$, $p = .004$, $r = 0.63$)

and CMP (Z = -2.39, p = .69, r = 0.56). Participants reported statistically comparable levels of self-regulatory strategies during CMP and Threat (Z = -0.71, p = .48, r = 0.17). There was also a significant main effect of Condition on the amount of attention directed towards worries/disturbing thoughts ($\chi^2(2) = 6.50$, p = .039). However, subsequent post-hoc tests revealed no significant differences between any conditions (ps > .033, rs > 0.44). There were no significant main effects of Condition on the amount of attention directed towards either threats to balance ($\chi^2(2) = 0.74$, p = .69) or task-irrelevant information ($\chi^2(2) = 1.08$, p = .58).

Internal awareness response accuracy. Mean response accuracy for internal awareness questions was identical in both CMP and Threat (*Median* = 3 out of 3, *Interquartile Range* = 1.00, Z = 0.00, p = 1.00); with 5 participants providing a single incorrect answer during CMP, and 5 other participants answering a single question incorrect during Threat.

Mental effort. There was a main effect of Condition on mental effort ($\chi^2(2) = 16.57$, $p < .001$). Compared to Baseline, participants reported significantly greater mental effort during both CMP (Z = -2.68, p = .004, r = 0.63) and Threat (Z = -3.27, $p < .001$, r = 0.77). Participants reported statistically comparable levels of mental effort between CMP and Threat ($t(17) = -1.53$, p = .14, d = 0.19).

8.3.2 Motor Performance Measures

All means (and standard error of the mean) values for motor performance variables are presented in Table 8.2.

Time to complete the walking task. There was a significant main effect of Condition on the time taken to complete the walking task ($F(1.37,23.35) = 15.09$, $p < .001$, $\eta p^2 = 0.47$). Participants took significantly longer to complete the task during both CMP (p = .015) and Threat (p = .001), compared to Baseline. Completion times during Threat were also significantly longer than those during CMP (p = .020).

Stance times. There was a significant main effect of Condition on stance durations preceding the first target (*F*(2,34) = 16.84, $p < .001$, $\eta p^2 = 0.50$). Stance durations were significantly longer during both CMP ($p < .001$) and Threat ($p < .001$), compared to Baseline; but were comparable between CMP and Threat ($p = .88$). These data are presented in Figure 8.1A. There was also a significant main effect of Condition on stance durations preceding the second target (*F*(2,34) = 21.95, $p < .001$, $\eta p^2 = 0.56$). Stance durations were significantly longer during both CMP ($p = .002$) and Threat ($p < .001$), compared to Baseline. Stance durations were also significantly longer during Threat, compared to CMP ($p = .022$). These data are presented in Figure 8.1B.

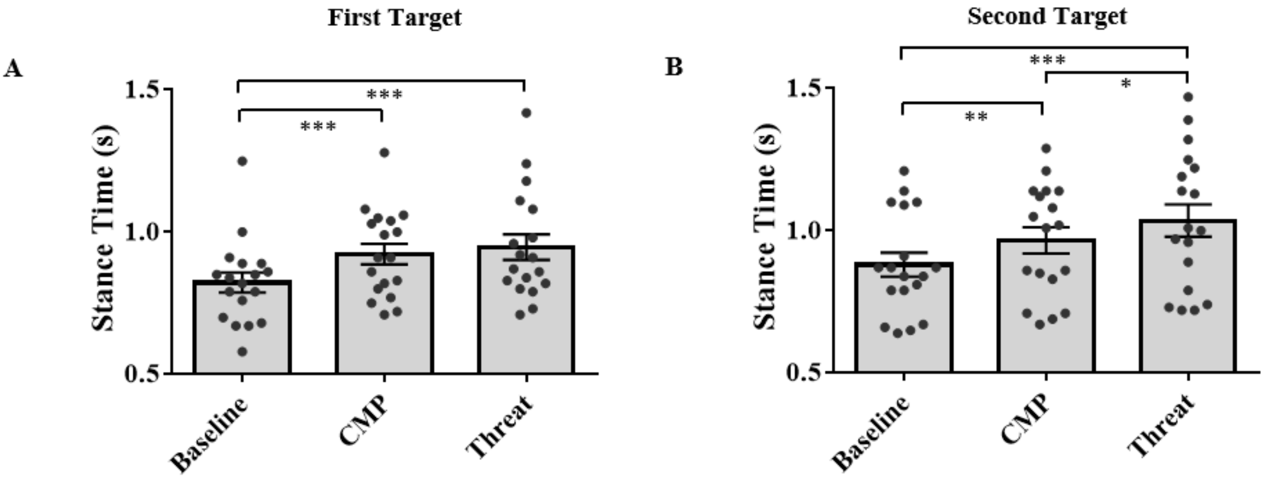


Figure 8.1A. Stance durations (s) preceding the first target, during conditions of Baseline, CMP and Threat, ***$p < .001$ (mean ± standard error of the mean, and individual data points). *Figure 8.1B.* Stance durations (s) preceding the second target, during conditions of Baseline, CMP and Threat, *$p < .05$, **$p < .01$, ***$p < .001$ (mean ± standard error of the mean, and individual data points).

Stepping error. There was a significant main effect of Condition on AP stepping errors into the first target (*F*(2,34) = 2.53, $p = .040$, $\eta p^2 = 0.17$). However, subsequent post-hoc tests revealed no significant differences between any conditions (all *p*s > .069). There was also a significant main effect of Condition on ML stepping errors for the first target ($\chi^2(2) = 7.11$, $p = .029$). However, post-hoc follow-up tests revealed were no significant differences between any conditions (*p*s > .053, *r*s > 0.42). Regarding the second target, there was a lack of significant main effect for stepping errors in either the AP (*F*(2,34) = 0.22, *p* = .81, ηp^2 = 0.01) or ML direction (χ^2(2) = 3.44, *p* = .18).

3.3 Gaze Behaviour Measures

All means (and standard error of the mean) values gaze behaviour outcomes are presented in Table 8.2.

First fixation location. There was a main effect of Condition on the location of participants' first fixation (χ^2(2) = 19.32, *p* < .001). Compared to Baseline, participants' first fixation occurred significantly closer to the start of the walkway during both CMP (*t*(17) = 2.68, *p* = .016, *d* = 0.48) and Threat (*Z* = -3.46, *p* < .001, *r* = 0.82). Participants' first fixations were also located significantly closer to the start of the walkway during Threat, compared to CMP (*Z* = -2.50, *p* = .007, *r* = 0.59).

Fixation durations. There was a main effect of Condition on the percentage of time spent fixating the immediate walkway (χ^2(2) = 12.80, *p* = .002). Compared to Baseline, participants spent a significantly greater percentage of time fixating the immediate walkway during both CMP (*Z* = -3.21, *p* < .001, *r* = 0.76) and Threat (*Z* = -2.85, *p* = .002, *r* = 0.67). The percentage of time spent fixating the immediate walkway was, however, statistically comparable between CMP and Threat (*t*(17) = 0.24, *p* = .81, *d* = 0.05). These data are illustrated in Figure 8.2A. There was a lack of significant main effect of Condition on the percentage of time spent fixating either the first target (*F*(2,34) = 0.34, *p* = .71, ηp^2 = 0.02) or the second walkway area (χ^2(2) = 3.13, *p* = .21). While Figure 8.2B illustrates an overall trend for participants to reduce the amount of time spent fixating the second target during CMP and Threat to 0%, the main effect of Condition on the overall percentage of time spent fixating the second target was, however, non-significant (χ^2(2) = 4.97, *p* = .08).

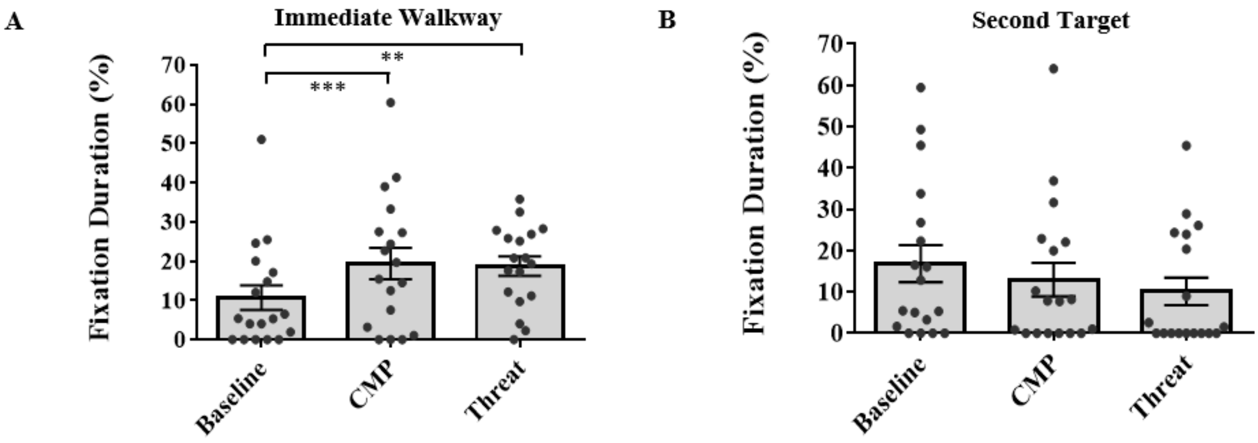


Figure 8.2A. The percentage of time spent fixating the immediate walkway area (preceding the first target) during Baseline, CMP and Threat conditions, ***p* < .01, ****p* < .001 (mean ± standard error of the mean, and individual data points).
*Figure 8.2B***.** The percentage of time spent fixating the second target during Baseline, CMP and Threat conditions (mean ± standard error of the mean, and individual data points).

Visual previewing of future stepping constraints. While Figure 8.3 illustrates an overall trend for participants to reduce the number of previewing fixations made towards the second target during CMP and Threat to zero, the main effect of Condition on the overall number of previewing fixations made towards the second target was non-significant ($\chi^2(2) = 4.19$, $p = .12$).

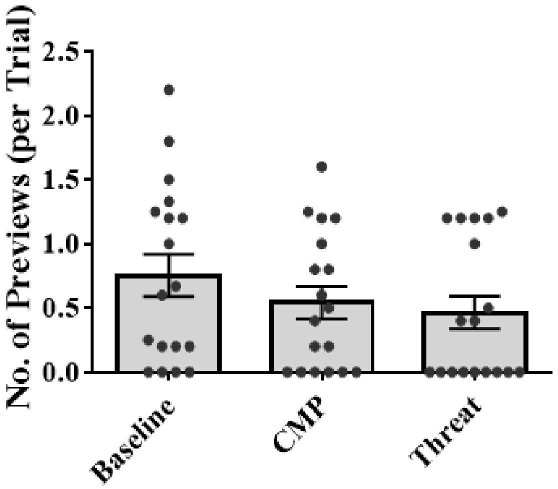


Figure 8.3. Average number of fixations (per trial) made towards the second target during, during the approach to the first target, during conditions of Baseline, CMP and Threat (mean ± standard error of the mean, and individual data points).

Table 8.2. Mean, standard error of the mean (*SEM*) and main-effect *p* values for comparisons between Baseline, CMP and Threat trials for all state measures, motor performance measures and gaze variables.

	Baseline		**CMP**		**Threat**		
	Mean	*SEM*	Mean	*SEM*	Mean	*SEM*	*p*
Balance confidence (%)	92.61	3.03	87.50	4.68	77.22[†ʚ]	4.97	<.001
Fear of falling (%)	1.48	0.81	1.11	0.76	9.44[†ʚ]	3.66	.002
Mental effort (0-150)	18.89	4.65	31.94[†]	5.24	36.11[†]	5.14	<.001
Attention directed towards…							
…Movement processes (1-11)	4.22	0.74	7.00[†]	0.81	7.00[†]	0.69	.001
…Threats to balance (1-11)	1.61	0.45	1.28	0.18	1.89	0.49	.692
…Worries or disturbing thoughts (1-11)	1.11	0.11	1.06	0.06	1.72	0.42	.039
…Self-regulatory strategies (1-11)	2.06	0.42	2.22	0.36	3.17[†ʚ]	0.47	.004
…Task-irrelevant information (1-11)	1.56	0.44	1.11	0.11	1.06	0.06	.584
Time to complete the task (s)	5.28	0.22	5.70[†]	0.23	6.51[†ʚ]	0.39	<.001
Stance duration (s), first target	0.82	0.04	0.92[†]	0.04	0.95[†]	0.05	<.001
Stance duration (s), second target	0.88	0.04	0.97[†]	0.05	1.04[†ʚ]	0.06	<.001
First target, AP stepping error (mm)	29.53	3.23	29.61	3.48	24.41	2.63	.040
First target, ML stepping error (mm)	14.00	1.93	16.22	1.67	18.69	1.65	.029
Second target, AP stepping error (mm)	33.96	4.41	36.10	4.36	35.23	3.42	.805
Second target, ML stepping error (mm)	14.47	1.61	17.78	2.04	16.45	1.80	.179
First fixation location (1-4) (1) Immediate walkway (2) First target (3) Second walkway (4) Second target	2.10[a]	1.16[b]	1.90[a†]	1.10[b]	1.60[a†ʚ]	0.65[b]	<.001
Immediate walkway fixation duration (%)	10.69	3.13	19.43[†]	3.98	18.75[†]	2.45	.002
First target fixation duration (%)	61.35	5.39	59.11	4.31	58.90	4.31	.714
Second walkway fixation duration (%)	11.11	2.47	8.49	1.91	12.22	2.29	.209
Second target fixation duration (%)	16.86	4.46	12.97	4.10	10.13	3.34	.084
No. previewing fixations (avg. per trial)	0.76	0.16	0.54	0.13	0.46	0.13	.123

Note: [a] = median (rather than mean), [b] = interquartile range (rather than *SEM*), [†] = statistically different from Baseline, [ʚ] = statistically different from CMP

8.4 Discussion

The present study aimed to investigate the relationship between conscious movement processing, fall-related anxiety and visual search in older adults. Specifically, we explored the extent to which the visual search patterns observed previously in anxious older adults during Chapter 7 – behaviours likely to reduce safety during locomotion (Young & Williams, 2015) – might be a consequence of attempts to consciously process walking movements. Given the identical mean levels of self-reported state movement processing observed between CMP and Threat (and identical response accuracy to the internal awareness questions), the experiment was successful in broadly equalising levels of conscious movement processing between these conditions (and increasing conscious movement processing from Baseline). However, given the significant between-condition differences in both fear of falling and balance confidence during Threat (compared to both Baseline and CMP), we propose that any differences in visual search observed between CMP and Threat would indicate the influence of anxiety-related processes other than conscious movement processing.

As predicted, we observed largely comparable gaze behaviours between CMP and Threat. Chapter 7 reported that older adults will display markedly altered visual search behaviour during conditions of heightened fall-related anxiety. Specifically, anxious older adults will typically direct preferential attention towards proximal areas of their walking path, at the expense of previewing future environmental constraints. In Chapter 5, we suggested that these behaviours may represent a prioritisation of the visual information needed to consciously control/monitor each individual step, at the expense of planning future stepping actions. The present results provide strong support for such interpretation. Despite the threat manipulation successfully increasing fall-related anxiety, we observed a general lack of any differences in visual search that can independently be attributed to anxiety (i.e., not observed in CMP condition). During both experimental conditions, participants appeared to visually prioritise proximal walkway areas (1–2 steps ahead) to a greater extent than during Baseline. Chapter 5 described that such prioritisation (in young adults, at least) comes at the expense of previewing future/distal stepping constraints, such as the second target in the present research. However, the present results showed more variable patterns of behaviour in an older adult cohort. While Figures 8.3B and 8.4 illustrate that some participants did indeed decrease both the number and duration of fixations made towards the second target during CMP and Threat, these figures also illustrate that a number of other participants exhibited zero previewing fixations towards the second target during Baseline to begin with. Consequently, during CMP and Threat, these ‘non-previewing’ individuals appeared to instead decrease the duration spent fixating the first target. Regardless, the present results illustrate that older adults consciously processing their walking movements will visually prioritise proximal, rather than distal, areas of the walking path.

We interpret these findings to represent a visual prioritisation of the walkway areas needed to regulate/control ongoing stepping movements (e.g., fixating 1–2 steps ahead), at the expense of previewing future stepping actions (whether the first or second target). These findings are in line with Chapter 7, which reported significant associations (when controlling for age, physical and cognitive functioning) between self-reported state conscious movement processing and gaze behaviours indicative of heightened on-line, and reduced feedforward, control of locomotion. Taken together, these results strongly implicate heightened conscious movement processing as a key factor underpinning the anxiety-related visual search behaviours observed during Chapter 7.

The singular significant difference in visual search observed between CMP and Threat related to the location of the first fixation. Participants’ first fixation occurred significantly closer to the start of the walkway during Threat. Staab (2014) has previously proposed an anxiety-related attentional bias for external threat-related stimuli – with anxious older adults argued to direct preferential attentional towards immediate upcoming threats to balance. We thus interpret these more proximal first fixations to represent an initial hypervigilance towards immediate threats to balance (i.e., the immediate walkway when walking on the elevated walkway in the present study; or, for example, the immediate ground if walking on an uneven surface in a real-world setting). These findings support those described previously in young adults during experimentally-induced conditions of fall-related anxiety in Chapter 5; with anxious individuals displaying rapid initial fixations towards immediate threats to balance. Interestingly, participants in the present study reported a lack of significant increase in attention directed towards external threats to balance during Threat. This raises one possible suggestion that such hypervigilance may represent an automatic, subconscious behavioural response to increased perceived threat.

This proposed hypervigilance to immediate threats is in line with the predictions presented in Attentional Control Theory (ACT; Eysenck et al., 2007), which suggests that anxiety increases the influence of the stimulus-driven attentional system (e.g., immediate/salient threats) at the expense of the goal-directed system (e.g., proactively scanning one’s whole environment and planning future stepping actions). Following this initial hypervigilance towards the salient threat, we propose that anxious older adults will subsequently prioritise the visual information required to consciously control/monitor each individual step – in a manner similar to when consciously processing walking movements during conditions of low-threat/anxiety (i.e., during CMP trials). This appeared to constitute an increase in both short-term planning (e.g., planning individual steps rather than planning future adaptive stepping movements) and on-line control (e.g., guiding the trajectory of the step itself). ACT (Eysenck et al., 2007) posits that anxiety “causes attention to be directed towards detecting the source of the threat and deciding how to respond” (Wilson, 2008, p. 195). As such, we propose that the initial hypervigilance observed during conditions of heightened fall-related anxiety likely represents preferential attention allocated towards detecting the source of threat, with subsequent conscious on-line (visual) control selected as the behavioural response to mitigate this perceived threat and avoid a fall occurring.

It is worth noting that another study has recently reported a lack of association between conscious movement processing and visual search during adaptive locomotion in older adults (Uiga et al., 2018). However, this study restricted analyses to self-reported trait levels of conscious movement processing (i.e., the degree to which an individual typically consciously controls/monitors movement in everyday life). This is an issue, as it is unlikely that a trait propensity to consciously monitor/control movements will be pervasive across all motor actions, or in each scenario during which that action is performed. Consequently, it is possible that participants studied by Uiga et al. (2018) simply completed the experimental task without consciously processing individual stepping movements. Indeed, the results from Chapter 6 indicate that state levels of conscious movement processing are likely more informative for gait-specific research than measures which assess an individual's trait propensity to consciously process their movements in daily life.

In addition to the aforementioned significant between-condition differences in initial fixation locations, participants also displayed some significantly different walking behaviours between CMP and Threat. Specifically, participants took longer to complete the walking task during Threat, in addition to displaying significantly longer stance durations preceding the second target. We propose two possible explanations for such differences. On the one hand, these behavioural differences may indicate the contribution of an anxiety-related process in addition to, or other than, conscious movement processing. For example, the increased muscular co-contraction of the lower leg muscles typically observed in individuals anxious about falling (Adkin & Carpenter, 2018; Staab et al., 2013) may serve to reduce movement velocity, thereby resulting in decreased walking speeds and increased stance durations.

Alternatively, given the increased negative consequences associated with a misplaced step while walking on the elevated walkway, it is possible that these slower adaptive stepping movements may merely represent a compensatory response to ensure that these actions are correctly programmed and executed. While stance durations preceding the first target were statistically comparable between CMP and Threat conditions, stance phases preceding the second target were significantly longer during Threat (although both were significantly longer than during Baseline). Interestingly, when one compares Figures 8.1B and 8.2B, it becomes evident that the increases in stance durations are proportionate to the (non-significant) decreases in the percentage of time spent fixating the second target. This strongly implies that participants increased the durations of the stance phase preceding the second target, in order to ensure that the visual information required to plan and initiate the precision step was effectively acquired. It is likely that this cautious, compensatory strategy was initiated in this condition given that the costs associated with a misplaced precision step would have been far greater when walking on the raised walkway.

While self-reported levels of conscious movement processing were equivalent between CMP and Threat, as were the large majority of eye-tracking variables, we nonetheless propose that the nature of conscious movement processing may have been qualitatively different between experimental conditions. While previous research has reported increased internal awareness in older adults during conditions of postural threat (as indicated by increased accuracy on comparable internal awareness questions; Young et al., 2016), it is also possible that such awareness of movement may be a consequence of conscious attempts to *control* individual stepping actions – rather than being the conscious movement strategy itself. In other words, while the older adults in the present research experienced heightened conscious movement processing at ground level during CMP trials, as indicated by comparable levels of internal awareness between CMP and Threat conditions, this may not necessarily reflect fully the conscious movement strategies utilised when anxious about falling. We decided against utilising “conscious control” instructions in the present research, as we deemed that such manipulations, whereby individuals are instructed to focus on controlling a certain aspect of their movement (e.g., Mak et al., 2019), were also unlikely to capture the complex, multifaceted nature of such conscious movement strategies. However, future work should look to compare older adults’ visuo-locomotor control during a range of experimental manipulations designed to induce ecologically valid forms of conscious movement processing.

If, as the previous paragraph suggests, such anxiety-related conscious movement strategies do indeed reflect an adaptive behavioural response to a perceived postural threat, the question arises as to whether such strategies should be encouraged or discouraged in older adults. Research from the domain of motor learning (e.g., Beilock, Carr, MacMahon, & Starkes, 2002; Jackson et al., 2006) would imply that older adults with balance deficits may benefit from such conscious movement strategies during locomotion, given the reduction in “automatic” postural control (Boisgontier et al., 2013). However, the results from Chapter 7 indicate that the visual search patterns associated with consciously processing walking movements (i.e., increased on-line visual control of individual steps at the expense of feedforward planning) can paradoxically serve to reduce safety in older adults at a high risk of falling. Specifically, high-risk older adults appear unable to adapt their movement to compensate for this reduction in planning (e.g., failing to slow down when approaching an un-previewed stepping constraint, to ensure adequate acquisition of the visual information needed to step accurately). In contrast, the results from Chapter 7 imply that highly functioning older adults appear able to adapt their stepping behaviours to safely overcome such reduced feedforward movement planning; albeit, at the cost of reduced movement and processing efficiency. Thus, for high-risk older adults, the question remains why such conscious movement strategies, and subsequent changes in visuomotor control, appear to reduce stepping safety.

For highly functioning older adults (such as those studied in the present research), the visual search patterns associated with conscious movement processing do not appear to directly reduce safety (given the lack of increased stepping errors observed from Baseline). The present experimental data does, however, indicate that such movement strategies are associated with both impaired attentional processing efficiency (i.e., increased mental effort required to complete the task during both CMP and Threat, compared to Baseline) and reduced movement efficiency (i.e., increased stance durations into the first and second target during CMP and Threat, compared to Baseline). These findings indicate that such movement strategies are both cognitively demanding and less efficient. As such, we suggest that consciously processing walking movements will likely reduce safety during particularly complex locomotor tasks, such as those requiring rapid stepping movements, or during scenarios where the mental resources required for conscious movement processing are unavailable. Indeed, Chapter 4 described significantly greater stepping errors in young adults consciously processing their stepping movements while performing a cognitively demanding simultaneous task.

While participants were asked “internal awareness” questions following both CMP and Threat trials (to ensure parity in the level of conscious movement processing between experimental conditions), we deemed it unlikely that these questions would have altered conscious movement processing during Threat trials – given that participants would have likely engaged in conscious movement processing during this condition regardless. Nonetheless, it is possible that by asking participants such internal awareness questions during Threat, we may have exaggerated the amount of conscious movement processing utilised in this condition; possibly diminishing the effect of other anxiety-related processes on visual search and stepping behaviour. However, as every participant in the present research had previously participated in a study whereby they completed 5-trials of the protocol during conditions of Threat without answering “internal awareness” questions (‘Control-Threat’; see Chapter 7), it was possible to also compare variables between Threat and Control-Threat. This analysis showed no significant difference in any visual search or motor performance variable between Threat and Control-Threat (please see Appendix C for all Threat to Control-Threat analyses). Therefore, this indicates that these internal awareness questions presented during Threat did not significantly alter older adults’ spontaneous “natural” anxious behaviour.

Another potential limitation relates to the power analysis conducted. This analysis provided us with the number of participants (*n* = 14) that we would need to detect a significant *difference* of the order of magnitude typically seen in visual search measures with anxiety/conscious movement processing manipulations, when compared to baseline conditions. Yet, a considerably larger sample is required to claim statistical *equivalence* between conditions. On the other hand, the visual search patterns between CMP, Threat, and Threat-Control were virtually identical; aside from the location of the first fixation, all comparisons were non-significant and had a small effect size. We therefore believe that it is highly likely for conscious movement processing to be the main, shared mechanism driving the visual search patterns in these conditions.

8.5 Conclusions

The present research provides strong support for the assumption that conscious movement processing underpins the (suboptimal) visual search patterns typically observed in older adults fearful of falling. Specifically, our results indicate that consciously processing walking movements results in increased conscious control of individual stepping movements (i.e., increased time spent fixating immediate walkway areas 1–2 steps ahead); with these behaviours appearing to occur at the expense of feedforward visual planning. Such behaviours are associated with reduced stepping safety in older adults deemed to be at a high risk of falling (as described in Chapter 7). Future research should therefore directly assess whether reducing conscious movement processing can help enhance visuomotor control and stepping performance during adaptive gait in older adults deemed to be at a high risk of falling.

Chapter 9: General Discussion

This chapter will briefly summarise the aims of the thesis with reference to the key findings, before discussing both the theoretical and applied implications of this programme of research. Within these sections, particular importance will be placed on presenting a new conceptual framework to account for the anxiety-related changes in the control of locomotion; in addition to discussing the degree to which findings observed in a healthy young adult cohort translate to an older adult population. Finally, the limitations of this work are also considered, along with proposed directions for future research.

9.1 Aims of the Thesis

The overarching aim of the present body of work was to investigate the relationship between fall-related anxiety, subsequent changes in attentional focus, and altered patterns of locomotion in both young and older adults. Throughout this programme of research, particular focus was placed on exploring visuomotor behaviours during adaptive locomotion. More specifically, the first aim was to provide a detailed account of the changes in attention that occur when fearful of falling (Chapter 4, 5 and 6), and to explore how these changes impact an individual’s ability to carry out concurrent tasks/processes while walking (Chapter 3, 4 and 5). The second aim was to examine possible causal links between fall-related anxiety and altered visuomotor control of adaptive locomotion (Chapter 5 and 7). The final aim of the thesis was to explore the attentional factors that may underpin any observed anxiety-related alterations in gaze behaviour (Chapter 5, 7 and 8). Specifically, this final aim sought to answer whether any anxiety-related changes were a consequence of: (a) heightened conscious movement processing; (b) a bias for threatening stimuli (either internal worries/rumination or a gaze bias for external threatening stimuli); (c) reduced cognitive resources (resulting from either conscious movement processing or anxiety-related worries/rumination); or, (d) a combination of interacting factors.

9.2 Summary of the Main Findings

In Chapter 3, young adult participants performed an adaptive locomotor task that required them to traverse a non-linear walking path, and step accurately onto two precision targets. Walks were completed during conditions of both baseline (single-task) and cognitive load (a cognitive dual-task). During conditions of cognitive load, participants increased the number and duration of fixations towards task-irrelevant areas outside of their walking path. These "outside" fixations were accompanied by both increased stepping error rate and time to complete the walking task. Correlations revealed that both the number and duration of these outside fixations were positively associated with trait-reinvestment scores (movement self-consciousness subscale). Finally, analyses confirmed a temporal relationship between outside fixations and dual-task performance (i.e., greater time spent fixating task-irrelevant outside areas in temporal time-bins preceding the verbalisation of the dual-task calculation). These findings support the assumption that maintaining effective visual search during adaptive locomotion requires attentional resources. They also suggest that consciously processing movement may place additional demands on attentional resources – thereby reducing the resources available for carrying out concurrent tasks (e.g., the maintenance of effective gaze behaviour).

Chapter 4 extended these findings and confirmed, through an experimental manipulation, that consciously processing walking movements does indeed place an additional demand on attentional resources in young adults. Here, we observed significantly poorer cognitive dual-task performance during conditions of conscious movement processing, compared to baseline conditions. These findings also suggest that the previously observed decreases in attentional processing efficiency during conditions of fall-related anxiety (e.g., Gage et al., 2003) are likely underpinned by such anxiety-related increases in conscious movement processing – with comparable reductions in processing efficiency, and increases in conscious movement processing, observed between experimentally-induced conscious movement processing and threat (fall-related anxiety) conditions. Finally, these findings also highlight significantly greater stepping errors during both conscious movement processing and threat dual-task trials. This suggests that consciously processing one's movement, while simultaneously performing an attentionally demanding task, can reduce stepping safety.

Chapter 5 consisted of two related experiments that explored how anxiety and changes in attention influence the visuomotor control of locomotion during adaptive gait in young adults. Chapter 5: Experiment 1 provided, for the first time, evidence of a causal relationship between fall-related anxiety and patterns of visual search reported previously in older adults deemed to be at a high-risk of falling (e.g., Chapman & Hollands, 2006b, 2007; Young et al., 2012). Specifically, when walking during conditions of heightened postural threat/fall-related anxiety (walkway elevated 1.1 m), young adults visually prioritised more immediate walkway areas (e.g., 1–2 steps ahead), at the expense of previewing future stepping constraints (e.g., the second target). This appeared to constitute an increase in both short-term planning (e.g., planning individual steps rather than planning future adaptive stepping movements) and on-line control (e.g., guiding the trajectory of the step itself). Anxious participants also exhibited rapid initial fixations towards proximal stepping constraints, implying a hypervigilance towards immediate threats. A verbal reports protocol suggested that these changes in visual search were likely underpinned by increased attention directed towards both threats to balance and subsequent attempts to consciously process stepping movements (i.e., controlling ongoing movements rather than previewing upcoming stepping constraints and planning future actions).

Chapter 5: Experiment 2 sought to shed further light on the attentional mechanisms underpinning these anxiety-related changes. Here, participants completed the same task during experimentally-induced conditions of conscious movement process (in the absence of anxiety). During these conditions, participants exhibited gaze behaviours which were largely comparable to those observed previously during conditions of threat/fall-related anxiety in Chapter 5: Experiment 1. These results strongly implicate conscious movement strategies as one mechanism underpinning anxiety-related changes in young adults' visuomotor control of locomotion. The results from previous chapters (Chapter 3 and 4) implied that consciously processing walking movements can reduce the cognitive resources available for carrying out concurrent tasks. Therefore, participants also completed walks under conditions of reduced cognitive resources (cognitive dual-task). However, during these conditions, we observed a general absence of visual search behaviours comparable to those observed previously during conditions of threat/fall-related anxiety in Chapter 5: Experiment 1. As such, these results indicate that consciously processing movement influences visual search via altered prioritisation (i.e., participants visually prioritising the walkway areas needed to consciously process ongoing stepping movements), rather than merely reflecting a reduction in attentional resources available for planning future stepping actions.

Chapter 6 sought to translate the verbal reports findings from Chapter 5 (Experiment 1) to an older adult population deemed to be at both a low- and high-risk of falling. This was achieved by comparing older adult fallers and non-fallers. As with the young adults measured in Chapter 5, older adult non-fallers reported directing increased attention towards both movement processes and threats to balance, and reduced attention towards task-irrelevant information, during (retrospective) high-anxiety scenarios where they felt their balance was threatened. In contrast, while fallers also reported directing increased attention towards movement processes when threatened, they also reported directing increased attention towards worries/disturbing thoughts related to falling. Specifically, the large proportion of these ruminative thoughts related to previous experience/s of falling. These findings provide the first evidence that high-risk older adults' attentional response to postural threat may differ from individuals deemed to be at a low risk of falling (including both low-risk older adults and healthy younger adults).

Chapter 7 attempted to extend the visual search results from Chapter 5 (Experiment 1) to an older adult population, and explore the existence of a link between the patterns of visual search observed previously in high-risk older adults (e.g., Chapman & Hollands, 2006b, 2007; Young et al., 2012) and heightened fall-related anxiety. As expected, this research revealed significantly different visual search behaviours when comparing low- and high-risk older adults performing a precision stepping task during baseline conditions (walking at ground level). Specifically, high-risk older adults spent longer fixating the immediate walkway areas (1–2 steps ahead) at the expense of previewing future stepping constraints. This reduced long-term planning appeared to negatively impact safety, with greater stepping errors observed when negotiating future constraints. High-risk older adults also reported greater fear of falling, and reduced balance confidence, during these trials. However, when completing walks during conditions of heightened threat/fall-related anxiety (walkway elevated 0.6 m), low-risk participants adopted visual search behaviours comparable to their high-risk counterparts. Here, low-risk individuals similarly prioritised fixating the immediate walkway areas, at the expense of planning future stepping actions. Finally, correlational analyses (when controlling for age, cognitive and physical functioning) highlighted associations between conscious movement processing and the amount of time spent fixating both immediate walkway areas (positive relationship) and future stepping constraints (negative relationship). These findings highlight a clear link between ‘high-risk’ visual search behaviours and heightened fall-related anxiety (and subsequent changes in attention).

Finally, Chapter 8 explored the degree to which the visual search behaviours reported in anxious older adults during Chapter 7 are a likely consequence of heightened conscious movement processing (as indicated by the significant correlations). In accordance with Chapter 7, participants completed an adaptive gait task during conditions of baseline (ground level) and heightened threat/fall-related anxiety (elevated walkway). However, participants also completed walks during a condition designed to induce conscious movement processing at ground level, thus independent from fall-related anxiety. The results revealed that the patterns of visual search behaviours observed when participants consciously processed stepping movements at ground level were largely comparable to those observed during conditions of heightened threat/fall-related anxiety (during which participants also reported consciously processing their movements). Specifically, these results described that older adults consciously processing their walking movements will visually prioritise the walkway areas needed to regulate/control short-term stepping movements (e.g., fixating 1–2 steps ahead), at the expense of previewing future stepping actions (whether the first or second target). These findings, combined with the correlational analyses presented in Chapter 7, provide strong support for the assumption that the previously reported anxiety-related changes in visual search are underpinned by attempts to consciously process stepping movements.

Overall, these findings highlight that when anxious about falling, younger and older adults alike will consciously process stepping movements, in an attempt to avoid the occurrence of a fall. The results presented in this body of work strongly imply that such conscious movement strategies manifest as heightened visual prioritisation of the immediate walkway areas (e.g., looking 1–2 steps ahead to ensure accurate placement of individual steps). This appears to constitute an increase in both short-term planning (e.g., planning individual steps rather than solely planning adaptive stepping movements over an obstacle, etc.), and on-line control (e.g., guiding the trajectory of the step itself). While both younger adults and low-risk older adults appeared able to adapt their walking behaviours to accommodate such altered patterns of visuomotor control, reduced feedforward planning was associated with increased stepping errors in older adults deemed to be at a high-risk of falling. We propose that these differing behavioural consequences are likely underpinned by between-group differences in attentional responses to fall-related anxiety – with high-risk individuals likely to have been directing additional attentional resources towards processing ruminations/worries about falling (see Section 9.4 for a further discussion).

These findings extend previous research which has restricted explorations of anxiety-related visuomotor behaviours to cross-sectional analyses (e.g., high-risk older adults who were also more anxious about falling; Young et al., 2012), providing clear evidence of a direct link between fall-related anxiety and altered visuomotor control of locomotion. The present programme of research also provides the first description of the specific changes in attention that individuals experience in response to heightened fall-related anxiety.

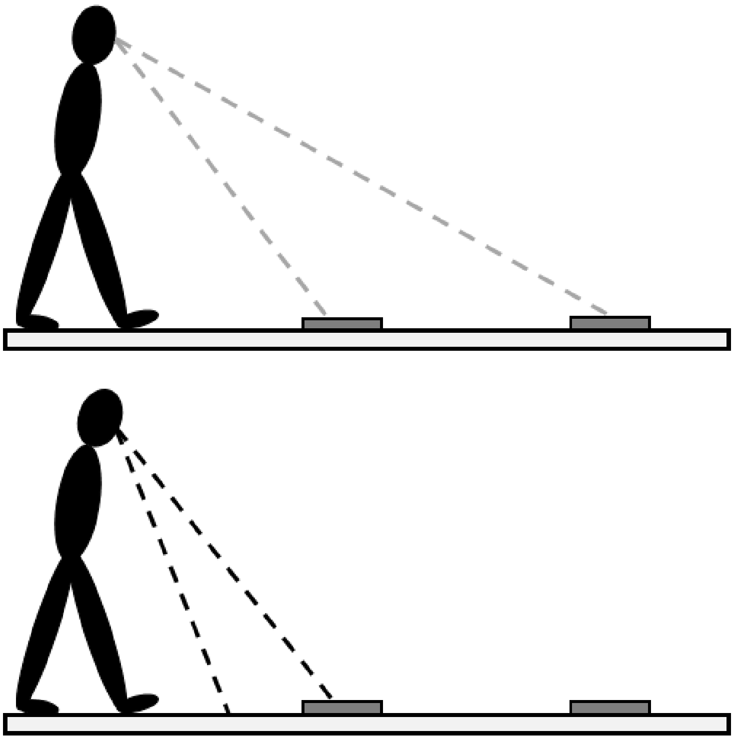


Figure 9.1. Top (grey lines): Visual search behaviours observed in non-anxious individuals throughout this programme of research. Bottom (black lines): Visual search behaviours observed in anxious individuals, as well as in those consciously processing walking movements (in the absence of anxiety).

9.3 Translating Research in Young Adults to Older Adult Populations

To understand how fall-related anxiety, and subsequent changes in attention, alter the production and execution of walking movements, we deemed it first necessary to evaluate causal changes in a healthy young adult ‘model’ unaffected by countless confounding factors related to age or fall-risk (such as cognitive decline or deficits in visuomotor processing). Consequently, the first half of the thesis evaluated changes in young adults during manipulations designed to induce either fall-related anxiety or altered attentional focus (Chapters 3–5), before attempting to translate these findings to an older adult population (Chapters 6–8). Thus, while not a primary aim of the present work, such an approach allowed us to also evaluate the degree to which research conducted in healthy younger adults translates to an older adult (high-risk) population.

Within posture and gait research, it is common for researchers to examine how healthy young adults behave during experimental conditions designed to mimic the experiences of high-risk, anxious older adults (see Adkin & Carpenter, 2018, for a review). For example, much of what is known about how fall-related anxiety alters the control of balance is derived from research conducted in healthy young adults while standing on elevated platforms designed to induce a fear of falling (e.g., Adkin et al., 2000, 2002; Huffman et al., 2009; Zaback et al., 2015). Similarly, the most thorough and comprehensive explorations of how fall-related anxiety influences attentional allocation during balance tasks have also been conducted in young adult populations (e.g., Zaback et al., 2016; Johnson et al., 2019b). While not necessarily intended to relate directly to ageing populations, these findings are frequently used to draw inferences about how fall-related anxiety may influence behaviour and fall-risk in both older adult and clinical populations (e.g., Adkin & Carpenter, 2018; Young & Williams, 2015). However, the findings from this present work suggest that observations made in healthy young adults – as well as those made in older adults deemed to be at a low risk of falling – may not necessarily translate to populations highly prone to falling.

Chapter 5 described changes in young adults' attentional allocation during conditions of experimentally-induced fall-related anxiety. Specifically, these individuals reported directing greater attention towards both movement processes and threats to balance, and less attention towards task-irrelevant information. There was no change in the amount of attention directed to either worries/disturbing thoughts or self-regulatory strategies. These results mirror those observed in high-functioning, low-risk older adults ("non-fallers") during a retrospective verbal reports protocol (Chapter 6). In this chapter, we asked participants to imagine a highly threatening, "real-world" anxiety-inducing scenario (in contrast to directly manipulating anxiety) and report what sources of information they would be likely to direct attention towards. Much like the healthy young adults in Chapter 5, these high-functioning older adults reported directing heightened attention towards both movement processes and threats to balance, and reduced attention towards task-irrelevant information when anxious.

This chapter described that older adults deemed to be at a high-risk of falling ("fallers") will similarly report directing greater attention towards movement processes and less attention towards task-irrelevant information when anxious about falling. However, they also reported directing greater attention towards ruminative thoughts related largely to previous experiences of falling. For example, Participant 2 had recently returned home from an extended stay in hospital following a fall, which resulted in numerous fractures and a ruptured spleen. She now requires a walking-aid and disclosed ruminating heavily on this previous fall whenever she encounters a situation similar to the one in which she fell: "I fell outside the main door and spent 3 weeks in hospital […] I think about that every time I go out the door. I laid out in the entrance for 1 hour until the ambulance arrived." Participant 35 had also experienced two recent falls: one while walking on an uneven pavement and another while descending a flight of marble stairs. Thus, despite displaying a low level of physiological fall-risk (e.g., a TuG score of 8.89 s), this participant reported that during situations posing even a minor potential postural threat, she would constantly be “thinking about falling and injuring [herself].”

These findings imply that previous experiences of falling may cause individuals to interpret anxiety-inducing situations as posing a considerable threat to their balance, leading to heightened attention being directed towards ruminations about falling. Such findings clearly highlight that previous experiences of falling can influence attentional responses to postural threats and heightened anxiety. The findings from this programme of research imply that it may be possible to translate findings from young adults to older adults deemed to be at a low-risk of falling. Nonetheless, research conducted in young adults (or low-risk older adults) may not necessarily translate to high-risk older adults anxious about falling – owing to the marked differences in previous personal experiences (e.g., previous falls).

Chapter 7 highlighted further difficulties associated with translating findings to older adults at an increased risk of falling. During experimentally-induced conditions of fall-related anxiety (walking on an elevated platform), both young adults (Chapter 5) and low-risk older adults (Chapter 7) displayed visual search behaviours indicative of reduced feedforward planning and heightened on-line processing of individual stepping movements. These visual search behaviours mirrored those observed in an anxious group of high-risk older adults performing the same task at ground level (Chapter 7). However, despite the largely comparable visual search behaviours observed across groups, the behavioural consequences (increased stepping errors) of such reductions in feedforward planning were only observed in high-risk individuals (see Section 9.4 for a discussion as to the reason for these differences).

These findings suggest that while it may be possible to manufacture situations in the laboratory that induce fear of falling in both young adults and low-risk older adults, due to the marked differences in previous personal experiences (e.g., previous falls), it is unlikely that the subsequent attentional (and behavioural) responses in these populations will represent anxiety-related changes observed in older adults at risk of falling. Such a proposal is also supported by previous research that has highlighted differences in young and older adults' behavioural responses when anxious about falling. For example, increased postural sway has been reported in anxious high-risk older adults (Maki, Holiday, & Topper, 1991), in contrast to postural stiffening commonly observed in anxious young adults (Adkin & Carpenter, 2018). While certain anxiety-related responses were comparable across populations in the present programme of research (e.g., visual search, heightened conscious movement processing, etc.), the consequences related to such behaviours are, however, unlikely to translate across populations exhibiting different levels of fall-risk. Therefore, we suggest that one must be cautious when attempting to generalise work carried out in young adults – or highly functioning older adults at a low risk of falling – to make inferences about how attentional allocation may compromise safety in high-risk older adults. The next sections will present a conceptual framework that seeks to account for both the anxiety-related changes in the control of locomotion described in this body of work, and the reasons why such alterations appear to negatively affect high-risk older adults to the greatest extent.

9.4 Theoretical Implications

This programme of research described the multifaceted nature in which fall-related anxiety can alter attention and behaviour. As with other areas of perceptual-motor performance (see Nieuwenhuys & Oudejans, 2012 for an overview), researchers from the domain of posture and gait have typically used numerous independent psychological theories to account for the influence of fall-related anxiety on attention and behaviour (e.g., Young & Williams, 2015). This section will first contextualise the behaviours observed in the present work with reference to Nieuwenhuys and Oudejans' (2012) Integrated Model of Anxiety and

Perceptual-Motor Performance. Specifically, this framework will be used to categorise observed behaviours as either *perception*, *selection* or *action*. Next, these behaviours will be discussed in the context of existing psychological theories, such as ACT (Eysenck et al., 2007) and Reinvestment Theory (Masters & Maxwell, 2008). Finally, this section will present a new conceptual framework to account for the anxiety-related changes in the control of locomotion – seeking to both consolidate previous literature and existing theoretical perspectives, while accounting for the new findings presented in this programme of research.

9.4.1 Nieuwenhuys and Oudejans' (2012) Categorisation Framework

Nieuwenhuys and Oudejans (2012) view perceptual-motor behaviour as a self-repeating process consisting of: (a) the perception of both task-relevant information and action possibilities (*perception*); followed by (b) the selection of the action (*selection*); and (c) the subsequent use of information to guide movement execution (*action*). The sections that follow will, in turn, describe – using evidence from the present programme of research – the way in which fall-related anxiety can influence the perception, selection and execution of action during adaptive locomotion.

Perception. The results from this programme of research clearly highlight that fall-related anxiety can alter the visual stimuli towards which walkers will direct their attention. Specifically, the results from Chapters 5, 7 and 8 indicate that individuals who are anxious about falling will display a visual hypervigilance towards immediate postural threats – as illustrated by rapid initial fixations towards more proximal areas of the walking path. In other words, anxious individuals were less likely to direct attention initially towards future/distal stepping constraints (i.e., the second target); instead perceiving the first target or the immediate walkway area. As these fixations occurred largely prior to the initiation of gait, we suggest – as per Nieuwenhuys and Oudejans' (2012) framework – that these visual search patterns were integral in the subsequent threat-related behavioural responses (i.e., the selection of cautious stepping behaviours; see below section entitled *Selection*).

The present findings align with Staab's (2014) proposal that individuals anxious about falling will display a hypervigilant visual bias for threatening stimuli. An anxiety-related attentional bias for threatening stimuli also supports previous experimental work presented by Brown et al. (2011). This research described that older adults fearful of falling will display an attentional bias towards threatening, fall-relevant stimuli presented on a computer screen. Related work by Fox and Knight (2005) has illustrated that anxious older adults will display a vigilance to emotionally-congruent threatening stimuli during a computerised dot-probe task. The present findings extend this work and suggest that such attentional bias is not limited to computer-based threatening stimuli – with anxious individuals also likely to display an attentional bias towards *external* threatening stimuli during locomotion.

Selection. As expected, fall-related anxiety led to the selection of more cautious walking behaviours throughout this programme of research. Namely, individuals anxious about falling exhibited increased walking times (indicative of slower walking speeds) and prolonged stance durations preceding stepping targets. It seems likely that individuals selected such cautious gait patterns, taking longer to execute stepping movements, in an attempt to minimise the likelihood of producing a misplaced step; particularly when negotiating the raised targets. These findings support previous research, which has similarly described decreased walking velocity, shorter steps and increased double-limb support (i.e., longer spent with both feet planted on the ground between steps) in individuals anxious about falling (Delbaere et al., 2009; Gage et al., 2003; Hadjistavropoulos et al., 2012).

Action. Finally, these present findings indicate that fall-related anxiety can alter how the selected actions are subsequently executed. Specifically, these results illustrated that walking movements performed in the presence of anxiety will frequently be controlled and/or regulated via conscious on-line processes – with heightened conscious movement processing reliably reported during conditions of fall-related anxiety throughout this programme of research. The results presented in Chapter 7 further identify a number of significant relationships between self-reported conscious movement processing and the previously described cautious gait behaviours. These findings suggest that the cautious gait patterns observed in individuals anxious about falling are a likely controlled/regulated via conscious on-line processes. Supporting this assumption is research that describes “cautious” patterns of gait have also been reported in older adults during experimentally-induced conditions of conscious movement processing, in the absence of fall-related anxiety (Mak et al., 2019).

Much like during other perceptual-motor actions (Nieuwenhuys & Oudejans, 2012), anxious individuals appeared to also alter the perceptual information they used to guide action during locomotion. Specifically, our findings imply that individuals anxious about falling will visually prioritise the areas of the walkway needed to consciously ensure accurate placement of individual steps. Our results, that anxious individuals increase the duration spent fixating 1–2 steps ahead indicates an increase in both short-term planning (e.g., planning individual steps rather than solely planning adaptive stepping movements over an obstacle, etc.) and on-line control (e.g., guiding the trajectory of the step itself). Matthis and colleagues (Matthis & Fajen, 2014; Matthis et al., 2015; 2017) have previously described that precision steps (e.g., stepping accurately onto a target) require visual information from approximately two-steps ahead. We therefore interpret these findings to imply that individuals anxious about falling will view each step as a precision step requiring accurate placement – even when walking on a flat, stable surface (e.g., the immediate walkway prior to the first stepping target).

The increased prioritisation of short-term stepping goals occurred largely at the expense of planning longer-term stepping actions (i.e., reduced visual previewing of future stepping constraints). Therefore, it may also be possible to categorise this reduced feedforward planning as a change in “perception” (given that individuals are failing to perceive future stepping actions). However, we argue that this reduced planning/previewing is more appropriately categorised as a change in “action” – given that this behaviour presumably occurred as a consequence of individuals prioritising the visual information needed to consciously process the execution of an ongoing action. Nonetheless, this highlights the difficulty of attempting to categorise behaviours observed during a continuous perceptual-motor task – such as adaptive locomotion – as a single distinct process (a point made previously during the Review of Literature, Section 2.1.4).

9.4.2 Existing Theoretical Perspectives

PET (Eysenck & Calvo, 1992). According to PET, anxiety disrupts attentional processing by shifting attention towards task-irrelevant, threatening information; namely, worrisome or disturbing thoughts. The results from Chapter 6 provide strong support for such an assumption. Here, we reported that older adults who had recently fallen will direct greater attention towards fall-related ruminations/worrisome thoughts during high-anxiety situations. Similarly, when completing walks at ground level during Chapter 7, high-risk older adults similarly reported both heightened anxiety and increased attention towards worries/disturbing thoughts. PET argues that processing these ruminative thoughts will compromise the capacity of working memory, thus reducing the cognitive resources available for performing other processes necessary for successful task performance. This could be particularly troublesome for older adults, given both the age-related decrease in working memory capacity (e.g., Schneider-Garces et al., 2010), and the age-related increase in the minimum level of cognitive input required to maintain postural stability (Boisgontier et al., 2013; Woollacott & Shumway-Cook, 2002).

One primary assumption of PET is that anxious individuals can use compensatory self-regulatory strategies to overcome these anxiety-related distracting thoughts. The findings from Chapters 6 and 7 support these claims. Here, anxious older adults also reported increased attention directed towards self-regulatory strategies. However, PET argues that such self-regulatory strategies are cognitively taxing, require increased mental effort, and thus further reduce the cognitive resources available for directing attention towards the primary task. The results from Chapter 7 support this notion, as anxious older adults also reported requiring greater mental effort to perform the task (Chapter 7). PET posits that performance effectiveness is likely to decline in situations where the anxious performer is unable to recruit sufficient cognitive resources. We propose that this might account for the significantly greater stepping errors observed in anxious high-risk older adults during Chapter 7 – with these individuals perhaps unable to recruit the resources necessary to engage the necessary compensatory self-regulatory strategies (much in the same way that anxious young adults experienced decrements in stepping performance during dual-task conditions in Chapter 4).

ACT (Eysenck et al., 2007). ACT builds on the hypotheses presented in PET, and provides a more detailed account of how anxiety can disrupt attentional processing. Consequently, while a number of tenets are shared between theories (e.g., anxiety’s negative impact on processing efficiency), there are a number of theoretical assumptions specific to ACT. Namely, ACT posits that anxiety disrupts the balance between the goal-directed and stimulus-driven attentional systems. As a consequence, it is proposed that anxious individuals are less able to inhibit preferential attention from being directed towards internal or external threat-related stimuli.

The present results provide strong support for these predictions. As noted previously, anxious individuals appeared to direct preferential attention towards both internal (e.g., worries; Chapter 6 and 7) external threatening stimuli (e.g., immediate trip hazards; Chapters 5, 7 and 8). For example, anxious individuals exhibited gaze patterns indicative of a hypervigilance for immediate threats to balance – displaying rapid initial fixations towards more proximal areas of the walking path. The results from Chapter 5 also imply that anxiety impaired participants' ability to maintain goal directed attention – with anxious individuals prematurely transferring their gaze away from an ongoing action (e.g., looking away from a target prior to successful negotiation). Participants appeared to transfer their gaze prematurely from these ongoing actions in order to instead fixate future/upcoming stepping constraints. These findings strongly imply that fall-related anxiety leads to the increased influence of the stimulus-driven attentional system – with participants less able to inhibit the direction of preferential attention towards future/upcoming threatening stimuli.

ACT also proposes that anxiety impairs the shifting function of the central executive, with anxious individuals arguably less able to *shift* attention between different tasks/sub-tasks and cues within the task. The findings presented in Chapter 5 provide some, albeit limited, support for such claim. Here, anxious young adults appeared to "freeze" their gaze towards proximal areas of the walkway, transferring their gaze between different walkway areas less frequently. However, these findings were not replicated in the older adult cohort in Chapter 7. We speculate that this discrepancy may be a consequence of age-related differences in executive function (e.g., Fisk & Sharpe, 2004), with older adults likely to display impaired shifting functionality (compared to young adults) regardless of fall-related anxiety. This suggestion is supported by the present findings: young adults exhibited an average of 0.97 transfers per second during ground level walks (Chapter 5), in comparison to the 0.68 transfers per second observed in low-risk older adults during identical experimental conditions (Chapter 7). Consequently, while both groups decreased their mean gaze transfers to approximately 0.5 transfers per second when anxious (young adults = 0.51 transfers per second; low-risk older adults = 0.55 transfers per second), this decrease was of a smaller, and non-significant magnitude in older adults.

Reinvestment Theory (Masters & Maxwell, 2008). This programme of research consistently highlights that individuals, be they healthy young adults or older adults deemed to be at a high risk of falling, will consciously process their stepping movements when anxious about falling. These findings are consistent with research conducted in other areas of perceptual-motor behaviour (e.g., sporting performance; Masters & Maxwell, 2008; Nieuwenhuys & Oudejans, 2012). They are also broadly supportive of Reinvestment Theory (Masters & Maxwell, 2008), which postulates that anxiety disrupts motor performance by virtue of individuals directing conscious attention towards monitoring or controlling previously “automatic” movement processes. The results from this programme of research also provide strong evidence that heightened conscious movement processing underpins a number of the observed anxiety-related visual search behaviours. Specifically, the findings presented in Chapters 5 and 8 provide a causal link between experimentally-induced conscious movement processing (independent of anxiety) and the reduced feedforward planning observed when anxious (e.g., Chapters 5 and 7). Given that this reduced planning occurred as a result of individuals instead fixating the walkway floor 1–2 steps ahead, we propose that these altered patterns of gaze represent a prioritisation of the visual information needed for the conscious processing of individual stepping movements.

Such conscious modes of motor control are also argued to impair both movement effectiveness and efficiency (Masters & Maxwell, 2008). This a proposal is supported by the positive associations reported between conscious movement processing and both walking completion times and stance durations in Chapter 7. Masters and Maxwell (2008) also argued that cognitive resources are required to consciously attend to the process of moving. This, in turn, is suggested to limit the resources available for other processes that may be necessary for successful task performance. The results from Chapters 3 and 4 provide strong support for such an assumption, highlighting that the conscious processing of walking movements places additional demands on attention. This may lead to impaired stepping behaviours (Chapter 4) and disrupted visual search (Chapter 3) when individuals attempt such conscious modes of motor control while processing a concurrent task.

Integrated perspectives. The previous sections illustrate a complex picture of multiple, potentially interacting attentional factors that may contribute to the altered behaviours observed when an individual is anxious about falling. Consequently, while individual results can be used to support traditional conceptualisations of either “distraction” (e.g., PET/ACT) or “self-focus” perspectives (e.g., Reinvestment Theory), we suggest it more appropriate to place this overall programme of research within a framework capable of integrating both theoretical standpoints, such as ACTS (Eysenck & Wilson, 2016) or Nieuwenhuys and Oudejans’ (2012) Integrated Model of Anxiety and Perceptual-Motor Performance. While independent, both theories make the similar proposition relating to anxious performers being less able to inhibit attention from getting drawn towards task-irrelevant distracters. During perceptual-motor tasks typically governed by automatic, lower-level processes, task-irrelevant distracters have also been argued to include potentially disruptive self-focus movement cues. ACTS also contends that during motor tasks, the extra mental effort used by performers to compensate for heightened anxiety (see above PET/ACT sections) may manifest as skill-focused attention.

The need for considering both distraction and self-focus perspectives within an integrated framework is illustrated in Chapter 4. Here, we reported impaired processing efficiency during conditions of fall-related anxiety – supporting predictions presented in

PET/ACT. However, this chapter suggested that these reductions in processing efficiency were a likely consequence of attempts to consciously process movement. Similarly, Chapters 5 and 7 highlight the need for considering an interplay of both distraction (e.g., gaze bias for threatening stimuli) and self-focus factors (e.g., heightened conscious movement processing) in accounting for the observed anxiety-related changes in gaze behaviour. Here, anxious individuals appeared to first exhibit a gaze bias for threatening stimuli, followed by the direction of gaze towards walkway areas needed for the conscious on-line processing of each individual step. Finally, Chapter 6 highlighted that high-risk older adults will direct increased attention towards both worries/disturbing thoughts (e.g., distraction) and conscious movement processing (e.g., self-focus) when anxious about falling. Together, these findings demonstrate the importance of considering both distraction and self-focus factors when exploring anxiety-related changes in the control of locomotion.

9.4.3 Limitations of Existing Accounts

The previous section describes how existing theoretical accounts – particularly integrated perspectives – can be used to contextualise and provide some level of explanatory account for numerous results presented in this programme of research. Nonetheless, there exist notable caveats that limit the applicability of such theoretical accounts to the study of posture and gait.

Conscious movement processing: Disruptive or adaptive? The previously described theoretical perspectives highlight the disruptive effect that consciously processing “automatic” motor skills can have on performance effectiveness. However, unlike expert sporting performance – from which these theories were developed – effective control of balance frequently requires conscious cognitive input (Boisgontier et al., 2013). While Boisgontier et al. (2013) propose the existence of an age-related increase in the minimum amount of controlled (conscious) processing required to effectively regulate postural stability, the results from the present programme of research illustrate that even healthy young adults require attentional input during adaptive locomotion. For example, the non-linear walking path described in Chapter 3 required postural adaptations and precise stepping actions. If participants had been able to complete this task using solely automatic processes, we would have expected performance to be maintained when they performed a secondary task (as there would have been limited competition for attentional resources). However, both greater stepping errors and increased walking times were observed during dual-task conditions. This implies that the control of locomotion – particularly during complex tasks – is characterised by some level of conscious attentional input, rather than being a purely automatic process. Consequently, how appropriate is it to view conscious movement processing during posture and gait as a failure to “inhibit” attention from being directed towards “task-irrelevant distracters” (e.g., ACTS or the Integrated Model of Anxiety and Perceptual-Motor Performance), if such processing is frequently required for effective task performance?

These findings thus imply that heightened conscious input during posture and gait may serve a functional benefit – at least in certain situations, and for certain individuals. Indeed, the findings presented by Brown et al. (2006) illustrate that the heightened on-line processing associated with increased fall-related anxiety may enhance safety in older adults, by improving the walker’s ability to adapt, modify and correct steps when negotiating environmental constraints. This resulted in fewer misplaced steps when walking on an elevated platform. Relatedly, increased conscious movement processing observed in the present programme of research appeared to manifest as heightened on-line processing of discrete stepping movements (both increased short-term movement planning and heightened on-line visual control). We suggest that these behaviours likely minimised the risk of the walker producing a misplaced step during the approach to the first target. While such conscious on-line processing occurred at the expense of reduced proactive feedforward movement planning, these behaviours were only associated with a negative consequence in a subset of the sample studied (high-risk older adults). This raises an important question: In what circumstances can conscious movement strategies aid the control of locomotion, and when do such processes have a deleterious effect on performance? Existing theoretical perspectives offer little, or no, insight when attempting to answer such a question.

The relevance of "task-irrelevant" threatening distractions. During sporting tasks, threat-related stimuli, whether internal or external, can be largely categorised as task-irrelevant. For example, an anxious soccer player preparing to take a penalty kick during an important cup match might direct attention towards (among other stimuli): internal worries related to failure; feelings of fatigue in their leg muscles; the opponent crowd behind the goal; the opponent goalkeeper (rather than the area of the goal towards which they are aiming the penalty kick); or photographers' camera flashes. In each example, these stimuli can be deemed task-*irrelevant*; in that they will disrupt goal-directed attention and distract the performer from attending to the information needed for successful performance (e.g., a quiet-eye fixation towards the corner of the goal where they wish to aim their penalty kick). However, during posture and gait tasks, threatening stimuli are likely to be largely task-*relevant*; in that successful task performance will typically require the individual to attend to the environmental hazards that threaten their balance.

The results from the present programme of research highlight how individuals anxious about falling will typically direct preferential attention towards the immediate threats to their balance. However, we deem it unsuitable to contextualise these gaze patterns within the framework of ACT/ACTS; as these theories would view such behaviours as a reduction in the central executive's ability to inhibit attention from being directed towards task-irrelevant distracters. Rather, we propose that these rapid fixations towards the salient, threatening areas of the walking path represent an adaptive mechanism, ensuring that the walker has sufficient time to prepare and initiate the appropriate behavioural response to safely negotiate the environmental constraint. In contrast to sporting tasks wherein such threat-related preferential attention will likely disrupt performance (Eysenck & Wilson, 2016), this suggests that directing preferential attention towards threatening stimuli may, in fact, serve a functional benefit during posture and gait tasks.

It is, however, possible that such hypervigilance may eventually become task-irrelevant if, for example, the walker is unable to disengage attention from the threatening stimuli once the perceptual information necessary for effective negotiation has been acquired. Relatedly, the results from Chapter 5 also suggest that such hypervigilance may “distract” attention away from the current goal (e.g., an ongoing step). These findings described that individuals anxious about falling prematurely transferred their gaze away from an ongoing action (the target towards which they were currently stepping) in order to fixate future/upcoming constraints. This behaviour is causally associated with increased stepping errors in older adults (Young & Hollands, 2010). Nonetheless, within the context of posture and gait, we view the direction of attention towards threat-related stimuli to largely be a task-*relevant* process. The key exception to this proposal is the direction of attention towards internal threatening stimuli, such as fall-related worries/ruminations. As per “classic” distraction models (e.g., PET and ACT), we similarly view such internal threat-related processing as being task-irrelevant; given that processing these thoughts will likely reduce the attentional resources available for directing towards processes necessary for successful task performance. Nonetheless, this section highlights the need for the development of a conceptual framework capable of distinguishing between task-relevant adaptive, and task-irrelevant maladaptive, threat-related attention.

An inverted-U hypothesis for conscious movement processing and threat-related attention. Based on these aforementioned points, it would seem that for any given individual, there likely exists an “optimal” level of attention which needs to be allocated towards both external threatening stimuli and movement processes when performing adaptive locomotion. Directing too much attention towards either source of information will likely impair balance performance; but equally, directing too *little* attention will have a similarly deleterious effect. We propose that this optimal level of attentional allocation likely forms an “inverted-U”. For example, if the level of attention allocated towards either external threats or movement processes is insufficient, then the walker might fail to perceive a threat to balance, or fail to effectively modify their motor pattern during a complex scenario requiring heightened cognitive input towards movement. In contrast, if an individual allocates too much attention towards either external threats or movement processes (i.e., beyond the optimal level), then these behaviours might be deemed as being overly cautious and maladaptive; with the walker either “distracted” by a single threat or the ongoing action (and, for example, less able to plan future stepping actions). However, existing theoretical accounts provide little insight into such proposal; with heightened attention directed towards threats and/or movement processes viewed as a maladaptive attentional response.

Individual differences in attentional responses. ACT, ACTS, and Nieuwenhuys and Oudejans’ (2012) Integrated Model all provide some explanation as to why certain individuals experience heightened anxiety during threatening/pressure situations. Similarly, individual differences exist that influence the degree to which a situation is interpreted as a potential threat to one’s balance, thus determining whether fall-related anxiety is experienced or not (Hadjistavropoulos et al., 2011). The present programme of research, however, also highlights that individual differences can influence the attentional responses to fall-related anxiety itself. For example, compared to both healthy young adults and older adults deemed to be at a low risk of falling, high-risk older adults were more likely direct attention towards worries/disturbing thoughts related to falling when anxious about falling (Chapter 6 and 7).

The aforementioned theoretical frameworks, however, offer limited scope when attempting to account for individual differences in attentional responses to fall-related anxiety.

Same behaviours, different consequences. Finally, these existing theoretical frameworks provide little insight as to why, in the present programme of research, behavioural responses to fall-related anxiety were largely consistent; yet, behavioural consequences varied across populations. For example, while both low- and high-risk older adults displayed reduced proactive feedforward movement planning when anxious about falling during Chapter 7, negative consequences (increased stepping errors) were only observed for high-risk individuals. Consequently, there is a need to develop a conceptual framework that accounts for: (a) individual differences in attentional responses to heightened fall-related anxiety; (b) why certain individuals experience decreased performance following heightened conscious movement processing (and associated reductions in feedforward planning); (c) the situations in which conscious movement processing will likely reduce safety, and; (d) the mechanisms through which specific attentional and behavioural responses can reduce safety during posture and gait tasks. Such conceptual framework will help identify the potentially maladaptive attentional and behavioural responses to fall-related anxiety. This represents a necessary first step in designing interventions aimed at reducing anxiety-related fall risk in older adults.

9.5 Developing a New Conceptual Framework

The previous sections have outlined the limitations associated with attempting to apply existing theoretical frameworks to the control of posture and gait during situations where anxiety about falling is heightened. In this section, we present the Gait-Specific Model of Threat Perception: a conceptual framework that aims to consolidate both previous experimental findings, and the body of work described herein.

When explaining how attentional responses influence behaviour and performance during conditions of heightened fall-related anxiety, we draw upon psychological theories previously described – namely, ACT/ACTS. However, we also use Blascovich's (2008) Biopyschosocial Model of Challenge and Threat (BPSM) to account for individual differences in attentional responses to anxiety. This theory was developed to explain how distinct reactions and responses often occur in pressurised situations where motivation to succeed is high. Blascovich built upon Lazarus and Folkman's (1984) Cognitive Appraisal Theory, which described how humans constantly evaluate the situations with which they engage; evaluating stressors as either harmful, threatening or challenging. The BPSM purports that stress-related evaluations occur as a two-stage appraisal process. Firstly, the individual evaluates the demands of the situation, followed by an evaluation of the coping resources available. If the coping resources meet or exceed situational demands, then a *challenge* state is suggested to occur. However, if the demands exceed resources, then the individual is more likely to evaluate the situation as a *threat*. Blascovich (2008) proposed that these evaluations occur in a predominantly unconscious and automatic manner, and trigger distinct psychophysiological reactions.

9.5.1 The Gait-Specific Model of Threat Perception

Based on the limited scope of existing theoretical frameworks, we propose the Gait-Specific Model of Threat Perception to provide an evidence-based explanation of how fall-related anxiety can influence the control of posture and gait (Figure 9.2). The factors that influence whether a situation will initially trigger fall-related anxiety are complex, but relate primarily to the perceived risk posed by the potential threat – typically[9] in relation to an

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[9] An individual will *typically* appraise the potential risk of a situation in respect to her/his perceived balance ability. However, once the task becomes complex enough, or the consequences associated with losing one's balance increase, scenarios are likely to invoke anxiety and motivation to succeed, irrespective of one's perception of ability. For example, walking along an icy sidewalk or attempting to climb down a steep, narrow staircase without a handrail for support will likely be appraised as a potential threat to balance, regardless of how one might perceive her/his balance ability.

individual's appraisal of their balance ability (Hadjistavropoulos et al., 2011). If the situation is perceived as having little or no potential to threaten one's balance, then anxiety will remain unchanged. Accordingly, motivation to succeed will be unaffected, as will attention and behaviour. In contrast, when the situation is perceived as having the potential to threaten one's balance, an anxiety response will be triggered; leading to an increase in motivation to succeed, and subsequent alterations in both attention and behaviour. We argue that these attentional and behavioural responses are, however, dependent upon whether the anxious individual evaluates the situation as a challenge or a threat.

Consistent with the BPSM, the Gait-Specific Model of Threat Perception contends that individuals anxious about falling will evaluate both the demands of the situation (i.e., the challenge posed by the postural threat), and whether they possess the resources necessary to cope with these demands (i.e., perceived balance ability). Individuals who deem their coping resources as sufficient will evaluate the situation as challenging, thus entering into a challenge state, whereas those who evaluate their resources as insufficient for the meeting the situational demands will enter into a threat state. These divergent evaluations then produce distinct attentional and behavioural responses to the anxiety-inducing situation; with threat state responses likely to lead to further fall-related anxiety.

It is worth noting that Vine, Moore and Wilson (2016) have recently applied the BPSM to visuomotor performance during stressful situations. This framework provides important insight into how stress-related evaluations can influence attention, visuomotor control and subsequent performance. Nonetheless, it largely remains an extension of ACT/ACTS, using the BPSM model to describe how different evaluative states alter the balance between the goal-directed and stimulus-driven attentional systems. For example, threat evaluations are purported to increase anxiety, leading to both the dominance of the stimulus-driven system, and subsequent disruptions in attentional control and visuomotor performance (as per ACT/ACTS). In contrast, it is suggested that challenge evaluations do not trigger an anxiety response and thus allow for the continued balance between the two attentional systems, resulting in optimal attentional and visuomotor control. This framework provides a detailed account of why certain individuals become anxious and display disrupted visuomotor performance during stressful situations (e.g., competitive sports). However, this framework is less applicable to the domain of posture and gait, wherein the threat posed by a “stressful” situation (i.e., a situation appraised as potentially threatening one’s balance) relates directly to an individual’s own survival. In other words, any “stressful” situation within the context of posture and gait will be likely to trigger both anxiety and protective mechanisms (e.g., altered attention and behaviour) aimed at preventing a fall from occurring, irrespective of whether evaluated as a threat or a challenge. Therefore, while Vine et al.’s (2016) framework shares some similarities to our conceptual model, these frameworks differ on a number of key assumptions.

The central caveat of the present framework rests on key assumptions presented in both ACT and the BPSM:

1) Anxiety leads to preferential attention being directed towards threatening stimuli – in this case, immediate/proximal external threats to balance (as purported in ACT/ACTS);
2) In accord with the BPSM, anxious individuals will then evaluate either their coping resources as meeting (or exceeding) the demands posed by this postural threat (*challenge evaluation*), or the situational demands as exceeding the available coping resources (*threat evaluation*);
3) These evaluations dictate the subsequent anxiety-related attentional and behavioural responses.

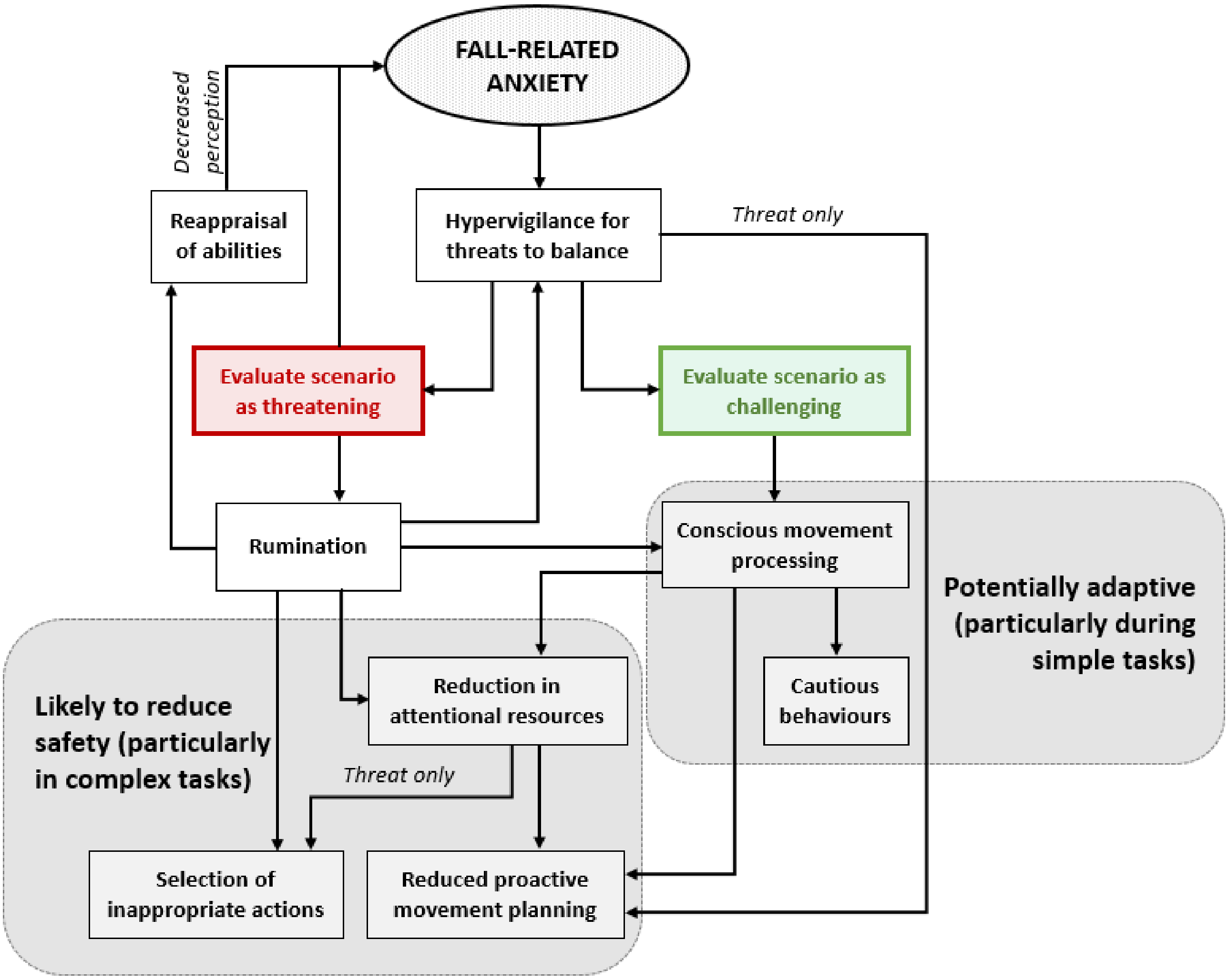

Figure 9.2. The Gait-Specific Model of Threat Perception.

9.5.2 Anxiety-Related Hypervigilance

The Gait-Specific Model of Threat Perception posits that fall-related anxiety leads to a hypervigilance towards threats to balance. While previous research has similarly proposed that individuals anxious about falling exhibit a gaze bias towards potential threats (e.g., Staab, 2014), we suggest a temporal relationship between anxiety and these gaze behaviours. Once a situation has been appraised as posing a potential risk to one's balance, and an anxiety response triggered, preferential attention will be allocated towards detecting the most salient threat. This assumption supports predictions made previously by Eysenck and colleagues

(Eysenck et al., 2007; Eysenck & Wilson, 2016), who purport that anxiety leads to the increased dominance of the stimulus-driven attentional system. This system is responsible for "… the detection of behaviourally relevant sensory events, particularly when they [are] salient and unattended" (Corbetta & Shulman, 2002, pp. 201–202).

We argue that in a complex environment containing multiple threats to balance, the most salient threatening stimulus will typically be the constraint that the walker has to negotiate the soonest. This hypervigilance will invariably occur at the expense of proactive visual scanning behaviours typically observed during non-anxious locomotion, resulting in the reduced perception of any visual stimuli other than the salient threat. However, as noted previously in Section 9.4.3, we propose that rapid visual fixations towards the salient, threatening areas of the walking path will likely reflect a primarily adaptive mechanism, ensuring that the walker has sufficient time to prepare and initiate the appropriate behavioural response to safely negotiate the environmental constraint.

Following the direction of gaze towards the most salient threat, anxious individuals then evaluate the degree to which they possess the resources required to meet the demands posed by this particular constraint (i.e., threat or challenge evaluation; see below). Once the anxious individual perceives that the current threat has been successfully negotiated, preferential attention will again be directed towards identifying the next most salient threat. Based on the salience of the subsequent threat, we suggest that such hypervigilance may encourage individuals to prematurely transfer attention from the current goal (e.g., transferring gaze away from the constraint they are currently negotiating), in order to fixate the next most salient threat sooner. We suggest that such an assumption can account for the premature transfers of gaze previously reported in individuals anxious about falling (Chapter 5; Young & Hollands, 2012b; Young et al., 2012), and also supports claims presented previously by Staab (2014). As a premature transfer of gaze away from a current stepping goal is causally associated with increased stepping errors in older adults (Young & Hollands, 2010), we highlight this as one instance whereby an anxiety-related hypervigilance may represent a maladaptive, rather than fundamentally adaptive, process.

9.5.3 Challenge Evaluation

If an individual evaluates their resources as meeting or exceeding the demands posed by the situation, they will evaluate this as a challenge. The Gait-Specific Model of Threat Perception proposes heightened conscious processing of movement as the primary attentional response associated with a challenge evaluation. Such an assumption is based on the findings presented herein, whereby reliable increases in conscious movement processing were reported when high functioning individuals (e.g., young adults) performed comparatively simple balance tasks in the presence of fall-related anxiety. Comparable findings have also been reported in previous research (Huffman et al., 2009; Johnson et al., 2019b; Zaback et al., 2016). For example, we deem it highly unlikely that the young adults studied by Huffman et al. (2009) would have evaluated performing a quiet standing task (i.e., standing still) while on a raised platform as exceeding their resources (e.g., their balance abilities). Regardless, these anxious individuals reported consciously processing their movement. Most anxiety-inducing gait and posture tasks carry a significant negative behavioural consequence if performance is unsuccessful (e.g., a potentially injurious or life-threatening fall). We therefore suggest that, despite being confident in their abilities to meet the demands posed by the postural threat, individuals adopting a challenge state will nonetheless direct conscious attention towards monitoring and/or controlling movement to ensure that a fall does not occur.

Key assumption: Conscious movement processing is likely to serve some degree of adaptive purpose during challenge states. The findings presented throughout this thesis strongly suggest that conscious movement processing during locomotion manifests as cautious behavioural adaptations (e.g., shorter steps, slower gait, prolonged stance durations, etc.), with individuals modifying gaze behaviour to accommodate such conservative movement patterns. For example, conscious movement processing was associated with prioritising the visual information needed to plan and control individual stepping actions, at the expense of previewing future environmental constraints. Such conscious on-line processing of discrete movements might have reduced the probability of producing a misplaced step. Indeed, research has highlighted that heightened on-line processing when anxious about falling can lead to a reduction in stepping errors, by virtue of an improvement in the walker's ability to adapt, modify and correct ongoing steps (Brown et al., 2006). Relatedly, studies exploring the effect of fall-related anxiety on static postural control have also reported associations between conscious movement processing and behaviours likely to aid stability and reduce the likelihood of a fall occurring (Huffman et al., 2009; Zaback et al., 2015). For example, when standing at the edge of a raised platform, a higher propensity to consciously process one's movements was associated with greater reductions in sway amplitude, as well as leaning further away from the platform edge (Zaback et al., 2015).

We have thus far argued that the conscious movement processing associated with a challenge state is likely to serve some level of adaptive function. However, we also acknowledge that there are certain situations whereby such conscious processing might reduce safety. This programme of research has highlighted that conscious movement strategies are attentionally demanding, thus limiting the cognitive resources available for conducting other processes necessary for safety during locomotion, such as effectively planning and preparing adaptive locomotor movements (Clark, 2015; Clark, Rose, Ring, & Porges, 2014). During simple, cognitively undemanding tasks, this is likely to have little impact on safety. However, when the demands of the task increase – thereby creating competition for shared executive resources – this could lead to the execution of inefficient or incorrect movement patterns. Indeed, consciously processing movement was associated with poorer stepping performance during trials with increased cognitive load in Chapter 4. Relatedly, Chapter 3 described greater dual-task-related decrements in visual search effectiveness in individuals reporting higher levels of trait-conscious movement processing.

Throughout this programme of research we have reported that conscious movement strategies during adaptive locomotion result in the conscious processing of a short-term action (e.g., individual steps), at the expense of planning future adaptive movements. This appeared to constitute an increase in both short-term planning (e.g., planning individual steps) and on-line control (e.g., guiding the trajectory of the step itself). However, when navigating a complex, cluttered environment, such behaviours may limit safety by reducing the walker's ability to identify – and subsequently plan the adaptive movements required to negotiate – upcoming environmental hazards. While the present programme of research suggests that individuals can compensate for such reductions in feedforward planning, this occurred at the expense of movement efficiency (e.g., increased stance durations prior to negotiating an un-previewed constraint). However, complex situations, such as those requiring the rapid initiation of an avoidance step, will not always allow individuals to momentarily pause before initiating movement. In these situations, inefficient movements will likely reduce safety. Clark (2015) has similarly suggested that conscious movement strategies reduce the walker's ability to rapidly calibrate and initiate movement during locomotion.

This section has argued that the conscious movement processing associated with a challenge state will likely to aid both stability and safety during simple, cognitively undemanding tasks. However, this form of motor control is also attentionally demanding, requires increased time to calibrate and initiate movement, and limits a walker's ability to carry out proactive visual scanning of their walking environment. Consequently, during complex tasks, such conscious movement processing may, nonetheless, be counterproductive to safety.

9.5.4 Threat Evaluation

In contrast to a challenge evaluation, an individual evaluating their resources as insufficient for coping with the demands posed will instead adopt a threat state. This framework proposes that ruminations related to falling are the primary attentional response associated with a threat evaluation. This assumption is supported by the many studies that have reported heightened cognitive anxiety (i.e., worries/concerns about failure) in individuals experimentally manipulated into a threat state (Moore, Vine, Wilson, & Freeman, 2012; Moore, Wilson, Vine, Coussens, & Freeman, 2013; Williams, Cumming, & Balanos, 2010; Vine et al., 2016). Based on the findings from Chapter 6, we posit that these ruminations manifest largely as worrisome/disturbing thoughts related to both previous falling episodes, and the consequence of future falls. The Gait-Specific Model of Threat Perception proposes a compounding closed feedback-loop whereby ruminations serve to further exacerbate anxiety; with ruminations about falling purported to trigger a subsequent (negative) reappraisal of an individual’s balance abilities. This in turn leads to increased anxiety, further threat evaluations and stronger, more prevalent ruminations.

One central assumption of ACT/ACTS is that anxious individuals are both less able to inhibit preferential attention from being allocated towards threatening stimuli, and less effective at diverting attention back towards non-threatening cues. While we largely view the previously described anxiety-related hypervigilance to be an adaptive response during posture and gait, we propose that threat evaluations may cause anxious individuals to be less able to disengage from threatening stimuli following these initial hypervigilant responses. Doing so may reduce safety within the context of adaptive locomotion, by reducing an individual’s ability to plan future stepping actions. Such an assumption might account for the results presented previously by Young et al. (2012). In this research, a group of high-risk anxious adults (the large majority of whom had recently experienced a fall and were thus likely to be ruminating) fixed their gaze primarily towards the immediate stepping constraint, previewing future areas of their walking path to a significantly lesser degree. These behaviours were associated with increased stepping errors.

This framework proposes three key assumptions relating to threat evaluations:

Assumption 1: Threat state ruminations impair processing efficiency (Fig. 9.3). This assumption is derived primarily from predictions presented within PET/ACT. These theories argue that processing ruminative thoughts compromises the capacity of working memory thus reducing the cognitive resources available for performing other processes necessary for successful task performance. Anxious individuals can employ additional resources (compensatory self-regulatory strategies) to overcome these distractions. Nonetheless, doing so requires increased mental effort, and further reduces the cognitive resources available for processing the primary task. Supporting this assumption is research that has described reduced processing efficiency in older adults concerned about falling, leading to impaired stepping reactions (Uemura et al., 2012). Vine et al. (2016) have similarly argued that individuals adopting threat states will likely display impaired processing efficiency. A sufficient supply of cognitive resources is required for the planning, preparation and execution of adaptive locomotor movements (Clark, 2015; Clark et al., 2014). Conscious attentional input is also required for the regulation of postural stability – particularly in older adults and/or during complex tasks (Boisgontier et al., 2013). Consequently, we argue that processing ruminative thoughts related to falling will increase the likelihood of movement failure during posture and gait tasks, by virtue of diverting cognitive resources from processes necessary for ensuring safety.

The present body of work also highlights that a sufficient supply of cognitive resources are required to consciously process walking movements. For example, visual search was impaired to a greater extent during dual-task conditions in individuals reporting higher trait conscious movement processing (Chapter 3), and increased cognitive and motor dual-task costs were also reported during experimentally-induced conditions of conscious movement processing (Chapter 4). Consequently, processing ruminations/worries about falling will reduce the resources available for consciously processing stepping movements during conditions of heightened fall-related anxiety, likely impairing the effectiveness of this motor control strategy.

Assumption 2: Conscious movement processing as a compensatory mechanism. A central caveat of PET/ACT is that anxious individuals will often employ compensatory or alternative processing strategies in an attempt to overcome task-irrelevant distractions (e.g., worrisome thoughts), and maintain effective task performance. During posture and gait, we propose that compensatory/alternative processing strategies will likely take the form of conscious movement processing. This aligns with claims presented previously by Eysenck and Wilson (2016) in ACTS. As with challenge states, these movement strategies may be adaptive during simple tasks; thereby overcoming, to some degree, the negative impact of task-irrelevant ruminations. However, given that processing efficiency will be reduced to a greater extent following threat evaluations (due to the additional processing of worries), we propose that threat evaluations will be associated with greater disruptions in performance effectiveness when task complexity increases. Consequently, as task complexity increases, disrupted performance is proposed to occur sooner – and to a greater extent – during threat rather than challenge states (Figure 9.4).

Conscious movement processing within the context of posture and gait is also purported to impair (i.e., slow down) the processing and subsequent integration of perceptual information into the motor pattern (Clark, 2015). These inefficiencies are likely to be further exacerbated by the simultaneous processing of distracting ruminations. In these circumstances, working memory has to not only consciously process and integrate the acquired perceptual information, but also inhibit – or concurrently process – task-irrelevant distracters.

Assumption 3. Threat evaluations lead to the selection of inappropriate behaviours. We propose two potential routes through which threat evaluations, and subsequent fall-related ruminations, can lead to the selection of inappropriate behaviours likely to reduce safety during posture and gait tasks. The first route describes a direct link between threat evaluations and the selection of inappropriate behaviours – specifically excessively cautious behavioural modifications. For example, despite experiencing comparable levels of fall-related anxiety, older adults reporting lower falls-efficacy/balance confidence[10] displayed "excessive" gait modifications during conditions of postural threat (Delbaere et al., 2009). Specifically, these individuals exhibited large reductions in gait speed – a typical hallmark of "cautious" gait (Hadjistavropoulos et al., 2012; Young & Williams, 2015). Excessive reductions in gait speed are, however, associated with both impaired stability and safety (Espy, Yang, Bhatt, & Pai, 2010). As Espy et al. (2010) describe, "…a one-standard-deviation decrease in gait speed increases the odds of fall by four-fold" (p. 378).

These overly cautious behavioural modifications are likely to be regulated via conscious on-line processes (see Chapter 7 and 8; also, Uiga et al., 2018). We therefore highlight this as one key distinction between the conscious movement processing exhibited during threat and challenge states: While these strategies might serve some degree of functional purpose during challenge states (particularly during simple tasks), consciously

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[10] Low self-efficacy is hypothesised to be a key determinant of a threat state (see Section 9.5.5).

processed movement patterns could conversely reduce stability and safety during even simple tasks performed while in a threat state. In other words, while both evaluations are associated with heightened conscious movement processing, the forms that such movement strategies take are likely to differ between states. We propose that the conscious movement strategies associated with a challenge evaluation might be primarily monitoring in nature; that is, individuals in a challenge state will consciously *monitor* their stepping movements, only intervening to consciously modify (or control) the ongoing action in instances where the walker deems the motor pattern as unsatisfactory. In contrast, we suggest that the conscious movement strategies associated with a threat evaluation are likely to be related primarily to *control*; that is, individuals in a threat state will direct conscious attention towards controlling the ongoing action in all instances. Further research is, however, required to confirm such assumption.

This framework proposes that threat evaluations can also lead to the selection of inappropriate behaviours via an indirect route resulting from processing inefficiencies. Locomotion, particularly during complex environments necessitating efficient movement planning and preparation, requires a sufficient supply of cognitive resources (Clark, 2015; Clark et al. 2014). Indeed, a reduction in available cognitive resources (cognitive dual-task conditions) is associated with the selection of “risky”, inappropriate behaviours during locomotion likely to lead to serious injury, e.g., selecting an unsafe period to cross a busy street (Janouch et al., 2018; Nagamatsu et al., 2011). We suggest that processing attentionally demanding ruminations may similarly impair older adults’ abilities to select, plan and prepare appropriate behaviours to meet the situational demands. In the present programme of research, anxious high-risk older adults (who also reported lower falls-efficacy/balance confidence[11]) failed to effectively adapt their behaviour when negotiating a series a stepping constraints (Chapter 7). Specifically, despite failing to acquire appropriate perceptual information pertaining to future stepping constraints, these individuals appeared unable to adapt their behaviour to compensate (e.g., increasing stance durations preceding the step towards the un-previewed constraint). These individuals also reported significantly greater worries/disturbing thoughts about falling during these trials. Therefore, we suggest that processing ruminative thoughts reduced the cognitive resources needed to either identify that a gait-related modification was required, or to prepare and initiate the necessary behavioural adaptations. Such assumption is supported by recent research presented by Caetano et al. (2018), who found that lower falls-efficacy – a key predicted determinant of threat evaluations in the present framework – was associated with less effective compensatory gait adaptations.

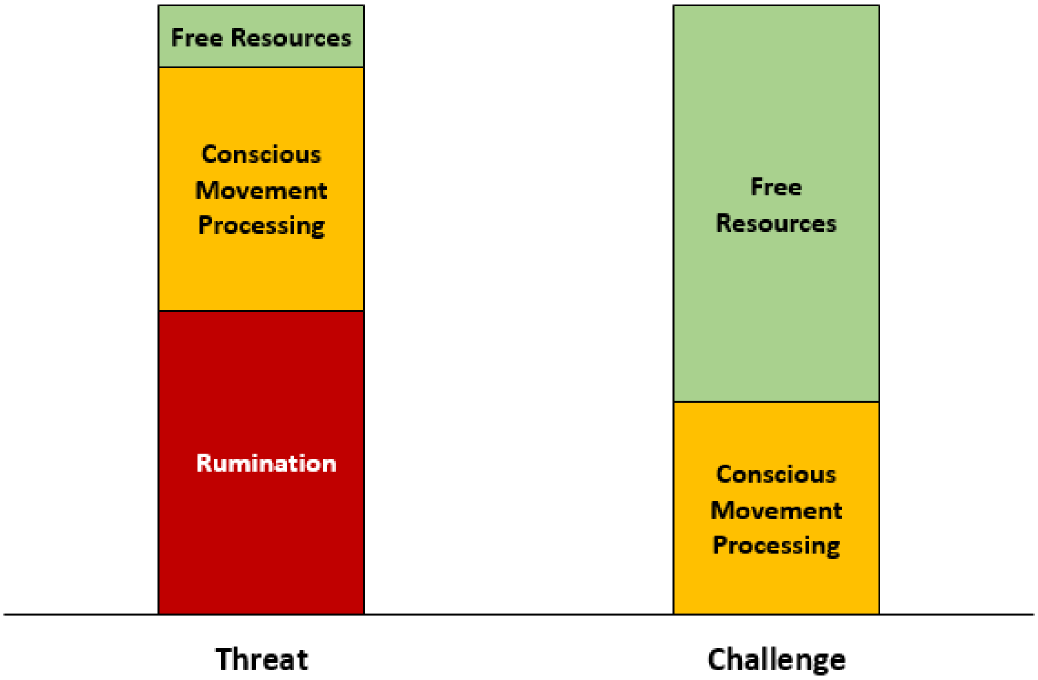

Figure 9.3. A schematic representation of the attentionally demanding nature of ruminations and conscious movement processing; both of which limit the resources available for directing towards other processes necessary for safety during posture and gait.

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[11] Once again, low self-efficacy is hypothesised to be a key determinant for an individual adopting a threat state (see Section 9.5.5).

9.5.5 Determinants of Challenge and Threat States

Consistent with assumptions presented by Vine et al. (2016), we propose previous performance outcomes as a key determinant of challenge and threat states. Specifically, we suggest that individuals who have recently fallen are more likely to evaluate a situation which subsequently induces fall-related anxiety as exceeding their coping resources (e.g., threat evaluation). This assumption accounts for the attentional responses consistent with threat evaluations observed in the older adult fallers studied in Chapter 6. Given that threat states are associated with attentional and behavioural responses likely to reduce safety, we view threat evaluations as having the potential to increase the likelihood of future falls – thus also increasing the probability of future threat evaluations, and even further fall-risk. This suggests that an individual may become trapped in a vicious cycle of inappropriate anxiety-related attentional and behavioural responses following a fall, with these responses increasing the likelihood of subsequent future falls.

In their application of the BPSM to athletic performance, Jones, Meijen, McCarthy, and Sheffield (2009) also describe self-efficacy as another key determinant of challenge and threat states. While experiencing a fall will frequently lead to reduced self-efficacy in relation to balance (e.g., falls efficacy or balance confidence; Scheffer, Schuurmans, van Dijk, van der Hooft, & de Rooij, 2008), there are many other independent risk factors associated with low falls-efficacy/balance confidence, such as age, being female, health status and problems with balance or gait (Scheffer et al., 2008). It is, therefore, possible for an individual to have low falls efficacy/balance confidence, and thus evaluate an anxiety-inducing situation as exceeding their coping resources, without having experienced a recent fall. We suggest that such an assumption might account for the attentional and behavioural responses consistent with threat states observed in the high-risk older adults studied in Chapter 7. While only

12/20 of these participants had recently fallen, this group reported significantly lower levels of falls-efficacy/balance confidence.

In addition to being a determinant of a threat state, research also highlights that evaluating a situation as threatening can lead to decreased self-efficacy (Williams et al., 2010). Consequently, we propose a feedback loop whereby threat evaluations lead to a negative reappraisal of one's balance abilities (i.e., decreased self-efficacy/balance confidence), serving to further increase fall-related anxiety and bias the anxious individual to further evaluate the situation as exceeding their coping resources; thus triggering a stronger, more pervasive threat state.

Based on the findings presented within this section, we suggest that individuals who have recently fallen and/or those with low falls-efficacy/balance confidence are more likely to evaluate a situation that induces fall-related anxiety as exceeding their available coping resources. Consequently, these individuals are more likely to enter a threat state, and display the potentially maladaptive attentional and behavioural responses associated with such evaluation.

9.5.6 Key Assumptions of the Model

Hypothesis 1: Appraisal of the anxiety-inducing situation, rather than anxiety itself, determines the behavioural response. This assumption is supported by research which describes that, despite experiencing comparable levels of fall-related anxiety, anxious individuals with lower falls-efficacy/balance confidence will exhibit markedly different behavioural responses to postural threats (e.g., Davis, Campbell, Adkin, & Carpenter, 2009; Delbaere et al., 2009).

Hypothesis 2: Low-self efficacy leads to less adaptive responses to fall-related anxiety. Not only will low self-efficacy lead to an individual experiencing more frequent fall-related anxiety (i.e., situations rated more frequently as potentially threatening one's balance;

Hadjistavropoulos et al., 2011), but low self-efficacy will also encourage the individual to respond to the subsequent anxiety in a manner likely to reduce balance performance and impair safety during all but the most simplest of balance tasks. This model proposes that these potentially maladaptive behaviours are underpinned primarily by fall-related ruminations. It is worth noting that during very simple balance tasks, such as walking along a flat path, an excessively cautious/conservative pattern of movement may have little negative consequence. However, the central caveat of this framework rests on the proposal that balance safety following the adoption of a threat state will be impaired during any task requiring rapid, adaptive stepping movements.

Hypothesis 3: Threat-related ruminations further exacerbate anxiety. Ruminations or worries about falling trigger a subsequent (negative) reappraisal of an individual's balance abilities, which serves to further exacerbate anxiety. Consequently, threat evaluations results in a maladaptive closed-loop, whereby ruminations exacerbate anxiety, leading to further threat evaluations, stronger ruminations, more anxiety, and so on.

Hypothesis 4: Processing efficiency is impaired for both evaluations; but to a greater extent during threat states. Both evaluative states lead to attentional responses, which can reduce processing efficiency (challenge = conscious movement processing; threat = ruminations and conscious movement processing; Figure 9.3). However, given that adopting a threat state is proposed to result in both fall-related ruminations and conscious movement processing, a key hypothesis of this framework is that processing efficiency will be impaired to a greater extent following threat evaluations.

Hypothesis 5: Challenge state will outperform threat state on even simple balance tasks. Threat states are associated with greater reductions in both processing and movement efficiency, and more frequent selection of inappropriate behaviours. We thus propose that threat evaluations will negatively impact balance performance during even simple tasks when anxious about falling. Indeed, work presented by Davis et al. (2009) described that young adults who reported lower balance confidence (i.e., self-efficacy) when standing on an elevated platform exhibited postural responses likely to reduce stability (e.g., increased COP displacements). In contrast, individuals with higher levels of balance confidence, yet comparable levels of state anxiety, displayed a reduction in COP displacements.

Hypothesis 6: Negative effects of anxiety on performance become greater as overall task demands increase. As both states are associated with reductions in processing efficiency (see Hypothesis No. 3), the negative consequences of these evaluations are hypothesised to increase in line with the complexity of the task (i.e., when increased attentional resources are required to maintain successful performance). However, given that threat states are associated with the greatest reductions in processing efficiency, these negative consequences will be more pronounced, and occur at a lower level of task complexity, following threat evaluations (Figure 9.4).

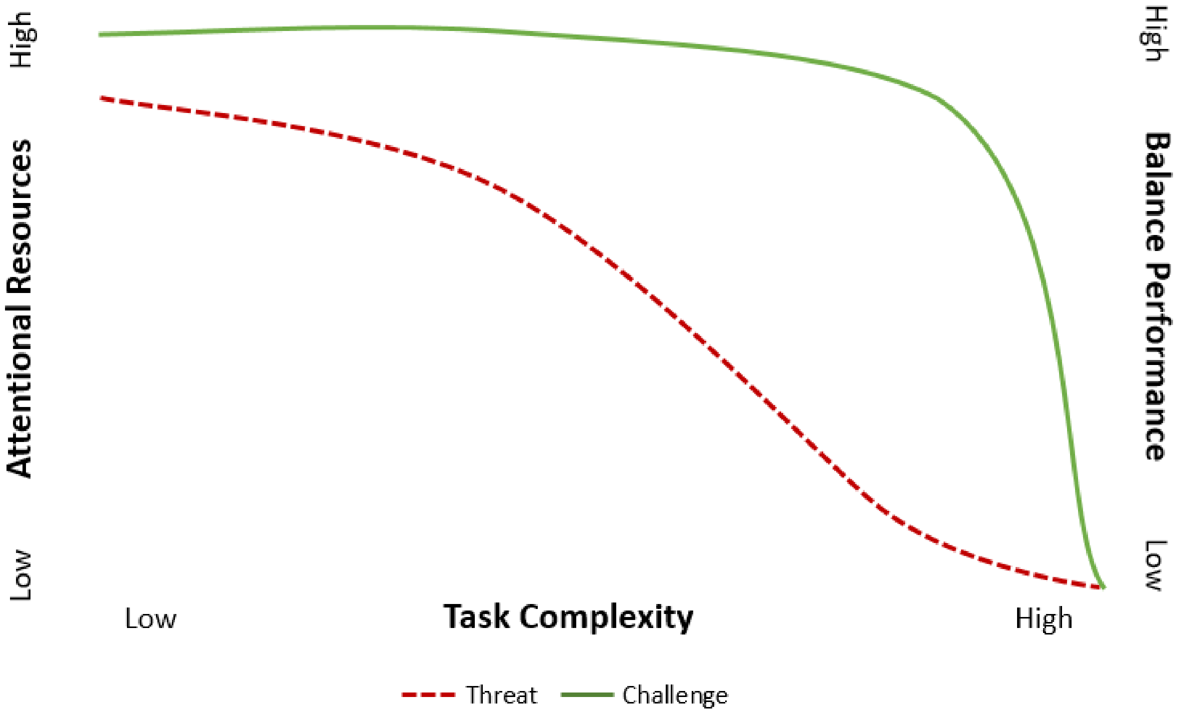

Figure 9.4. A schematic representation of the interaction between attentional resources, task complexity and balance performance, when an individual adopts either a threat or challenge state.

9.5.7 Limitations of the Framework

While this framework provides a detailed account of how attentional responses to fall-related anxiety may influence an individual’s performance on posture and gait tasks, there are numerous other factors that will ultimately determine an individual’s overall balance performance (see Figure 9.5). Consequently, an individual may adopt a “suboptimal” threat evaluation and still outperform an individual who adopts a more “optimal” challenge state. The aim of the present framework was not, however, to provide an exhaustive account of the factors that might potentially interact with either challenge or threat states to influence balance performance. Rather, we sought to describe how different attentional states may influence balance performance if other factors are comparable; thus accounting for why certain individuals, irrespective of their physiological fall-risk, display potentially maladaptive behavioural responses to fall-related anxiety (e.g., Davis et al., 2009; Delbaere et al., 2009). We nonetheless acknowledge that the present framework describes just one factor that might contribute to overall balance performance and fall-risk. Furthermore, as a number of the assumptions presented in the framework are speculative in nature, further research are needed to confirm some of the hypotheses presented herein.

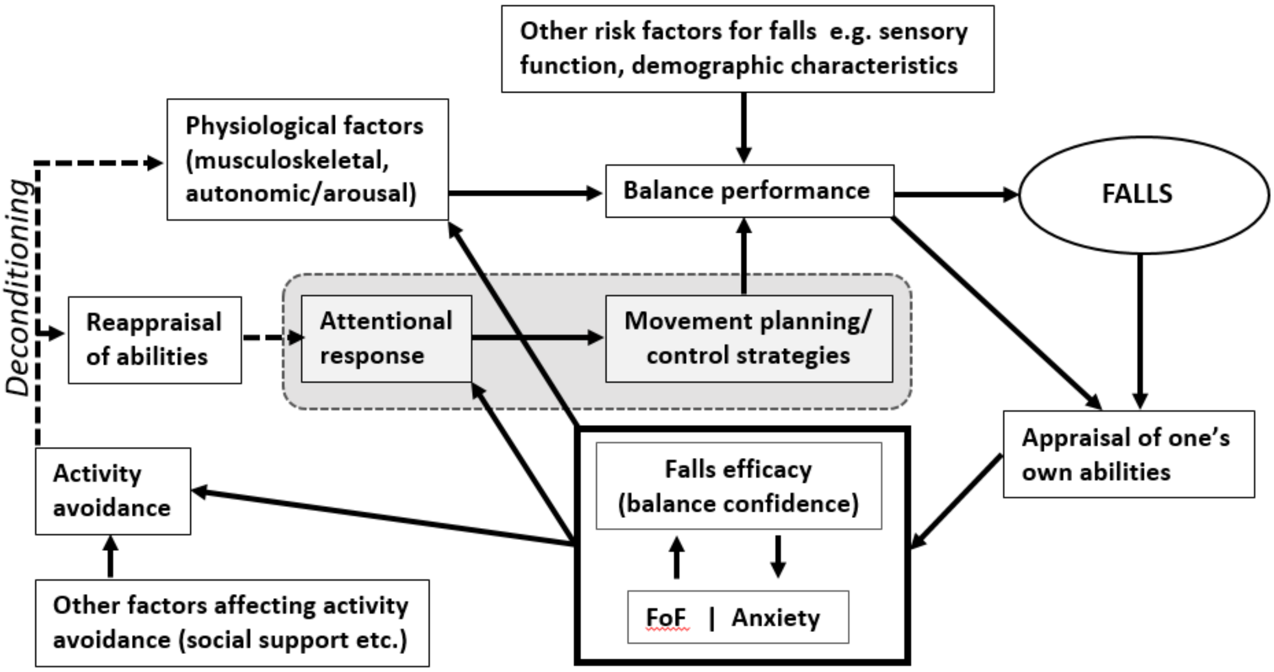

Figure 9.5. Reconceptualisation of Hadjistavropoulos et al.'s (2011) model of fear of falling, balance performance, and fall risk. The grey box provides a visual representation of how the attentional factors described in the present framework influence balance performance.

9.6 Applied Implications

The findings from this body of work also have important implications for applied practice. Fear of falling, and its negative impact on physical functioning and fall-risk, has received much focus within public health organisations (e.g., National Institute of Clinical Excellence, 2013). This has led to the common view that high levels of fear/anxiety related to falling is maladaptive and should be reduced through interventions. However, fall-related anxiety may not always be associated with an increased risk of falling; particularly if this anxiety represents an accurate appraisal of the risk of a fall occurring (Litwin, Erlich, & Dunsky, 2017). In such cases, heightened feelings of anxiety may discourage individuals from exposing themselves to unnecessary risk (e.g., stepping around a patch of ice rather than walking over it or holding onto a handrail when walking along an uneven path). Therefore, designing interventions to indiscriminately reduce anxiety about falling may paradoxically have a detrimental effect on actual falls for certain individuals for whom heightened anxiety, and subsequent behavioural adaptations, represent an adaptive response to a realistic threat to balance (Litwin et al., 2017).

Research does, however, demonstrate that not all attentional and behavioural responses to postural threats are likely to be adaptive. For example, Delbaere et al. (2009) reported that despite displaying anxiety responses appropriate for the level of risk posed by a postural threat, some individuals will nonetheless exhibit “excessive” behavioural adaptations likely to decrease stability (e.g., excessively slow gait). Therefore, rather than attempting to indiscriminately target fall-related anxiety in all individuals, it may instead be more appropriate to design interventions aimed at modifying maladaptive anxiety-related attentional and/or behavioural responses associated with reduced safety.

The findings presented in this body of work highlight a number of seemingly maladaptive anxiety-related responses which could inform the development of such interventions. The results from Chapter 6 illustrate the lasting negative impact that falling can have on older adults’ psychological functioning. Specifically, these results indicated that when their balance is threatened and their anxiety is high, fallers – unlike their non-faller counterparts – will direct attention towards ruminative/worrisome thoughts related to falling. As described in the previous sections, processing such ruminations will likely reduce the cognitive resources available for directing towards the primary task, e.g., maintaining postural stability and safety while walking (Eysenck et al., 2007; Young & Williams, 2015). Thus, processing such ruminative thoughts when anxious about falling may decrease older adults’ safety, by virtue of reducing the already limited cognitive resources available ensuring postural stability and carrying out other tasks necessary for safety. We therefore highlight such ruminative/worrisome thoughts as one potential anxiety-related response that interventions could target.

Recent research highlights the effectiveness of traditional cognitive behavioural therapy (CBT) in targeting generalised concerns about falling in older adults (Parry et al., 2016). Indeed, public health organisations highlight traditional CBT as an effective treatment for reducing anxiety about falling (e.g., the National Institute of Health Research, 2016). While CBT often targets “catastrophic” and “unhelpful” cognitions (Hawton, Salkovskis, Kirk, & Clark, 1989), clinical psychologists have also developed a ruminative-focused version of CBT designed to specifically target ruminative symptoms (e.g., Watkins et al., 2007). The findings from this thesis highlight the potential effectiveness of tailoring CBT interventions for high-risk older adults to specifically target ruminative/worrisome thoughts about falling; perhaps through the adoption of ruminative-focused CBT as described by Watkins et al. (2007). By targeting ruminations, as well as the proposed subsequent negative reappraisals of balance abilities (suggested to further exacerbate anxiety), it may be possible to break the maladaptive feedback loop that ruminations are purported to serve. Cognitive training which encourages anxious individuals to reappraise anxiety-inducing situations as challenging, rather than threatening, may also be effective in reducing ruminations proposed to follow threat evaluations (Moore, Vine, Wilson, & Freeman, 2015).

The results from Chapter 5, 7 and 8 also highlight numerous anxiety-related gaze behaviours which are likely to jeopardise safety in older adults deemed to be at a high-risk of falling. Firstly, Chapter 5 described a causal relationship between heightened anxiety and premature transfers of gaze away from a stepping constraint (i.e., before the constraint has been safely navigated) in young adults. Older adults, particularly those at a high-risk of falling, require visual feedback to accurately guide stepping movements (Hollands et al., 2017). Therefore, premature transfers of gaze away from a stepping constraint prior to successful negotiation, in order to fixate future threats to balance, will likely reduce safety in this population. Indeed, this visual search behaviour is causally associated with increased stepping errors in older adults (Young & Hollands, 2010). The present work also highlighted a causal relationship between fall-related anxiety and a reduction in planning future stepping actions. This causal relationship was observed in both young (Chapter 5) and older adults (Chapter 7). Chapter 7 demonstrated that these visual search behaviours are associated with increased stepping errors in high-risk older adults.

Given that this research describes numerous anxiety-related gaze behaviours which we propose will likely impair safety in older adults deemed to be at a high-risk of falling, it might seem logical to propose interventions which attempt to directly modify visual search. However, we argue against the implementation of such interventions – on the basis that any attempts to explicitly modify gaze behaviours during walking will likely disrupt the automatic visuomotor visual processes that typically underpin goal-directed locomotor movements (Hollands et al., 2017). Rather, we propose it more appropriate to identify, and subsequently target, the underlying causes of these behaviours; instead using the anxiety-related gaze behaviours reported herein to develop diagnostic and monitoring tools for working with patients presenting fall-related anxiety, or those deemed to be at a high risk of falling.

Chapter 5, 7 and 8 provide strong evidence that the observed reductions in long-term movement planning are likely underpinned by anxiety-related increases in conscious movement processing. These findings described that anxious individuals visually prioritised the areas of the walkway needed for the conscious processing of short-term goals (e.g., individual steps). On the one hand, we could interpret these findings to suggest that attempts to consciously process walking movements should be discouraged. However, as we observed increased conscious movement processing when both young adults (Chapters 4 and 5) and highly functioning low-risk older adults (Chapters 6 and 7) were anxious about falling, we suggest that anxiety-related increases in conscious on-line movement processing may not necessarily reflect a maladaptive behavioural response (as described in greater detail in the previous section). Indeed, research indicates that heightened on-line processing when anxious about falling may even enhance safety, by allowing the walker to adapt, modify and correct individual steps when negotiating environmental constraints (Brown et al., 2006). Additionally, for certain individuals, such as those with deficits in proprioception or balance control (Kal et al., 2019), conscious movement processing is likely to be necessary for ensuring effective control and regulation of locomotion.

We therefore propose that any attempts to indiscriminately discourage such conscious movement strategies might possibly serve to reduce safety during conditions of heightened anxiety. Instead, we suggest that interventions should target the seemingly maladaptive behavioural outcomes associated with this mode of motor control. As described in the previous section, we hypothesise that the negative aspects of conscious movement processing relates primarily to the resource-draining nature of this movement strategy, which during complex, cognitively demanding scenarios may lead to reduced safety. Therefore, cognitive dual-task training could be implemented to negate the reductions in processing efficiency observed during this mode of motor control (e.g., Chapter 3 and 4). Indeed, preliminary research highlights the effective of dual-task training in enhancing the gait performance of older adults anxious about falling (Wollesen, Schulz, Seydell, & Delbaere, 2017). Relatedly, cognitive dual-task training might also be successful in reducing the proposed negative effects of fall-related ruminations on processing efficiency. We have previously proposed that consciously processed cautious gait modifications are likely to serve a functional benefit, until they become “excessive” (Section 9.5.3). However, as excessive modifications are proposed to occur primarily during threat evaluations, this further highlights the potential benefits of interventions designed to encourage older adults to reappraise threatening situations instead as challenges (as described previously in this section).

Finally, this present body of work also highlighted numerous areas of psychological and attentional functioning relevant to fall-risk. Traditionally, healthcare providers have limited any falls-related psychological assessment to a generalised metric of fear of falling (National Institute of Clinical Excellence, 2013). However, the results presented herein suggest that, in addition to generalised fall-related anxiety, it may also be useful for healthcare providers to assess and monitor additional areas of psychological and attentional functioning, such as: Processing (in)efficiency (as highlighted in Chapters 3 and 4); ruminations about falling (as highlighted in Chapter 6), and; conscious processing of walking movements (as highlighted in Chapters 5, 6, 7 and 8). Such detailed psychological assessment could be used in a rehabilitation setting to allow for both the long-term monitoring of patients deemed to be at an increased risk of falling, as well as gauging the psychological impact/s following the occurrence of a fall. Researchers should, therefore, look to design a time-efficient measurement capable of assessing each of these constructs. The development of such tool could have considerable utility in both a research and clinical setting.

9.7 Limitations of the Thesis

While limitations specific to individual experiments are described in the relevant experimental chapter, there are a number of overarching limitations relating to this body of work as a whole. These namely relate to: (a) the experimental protocol (i.e., the walking task); (b) the experimental manipulations, and; (c) the variables assessed. This section will describe each of these limitations in detail.

9.7.1 The Experimental Protocol

The experimental task used in Chapters 4, 5, 7 and 8 consisted of participants walking along a wooden walkway (width = 40 cm, length = 3.3/3.4 m), and stepping into two raised foam targets. While this protocol was derived from previous research (e.g., Chapman & Hollands, 2006a, 2006b; Young & Hollands, 2012b; Young et al., 2012), there are a number of limitations which need to be highlighted. While the protocol was designed to mimic tasks which commonly occur during adaptive locomotion (e.g., stepping accurately onto a stable paving stone), the ecological validity can nonetheless be questioned. For example, the simplicity of the task, wherein participants had to walk along a relatively short walkway at a comfortable pace and negotiate two clearly identifiable, stable constraints located in a fixed position, is unlikely to translate to more complex scenarios common during daily locomotion (e.g., walking through a busy environment while avoiding unpredictable postural threats, such as oncoming walker). However, we deemed it first necessary to isolate the influence of fall-related anxiety on visuomotor behaviours during a simple, controlled environment, before exploring these behaviours during complex environments representative of daily locomotion.

Another potential limitation of this experimental protocol relates to the behavioural outcomes used to define performance effectiveness (i.e., AP and ML stepping error). The magnitudes of the between-condition/participant differences in stepping errors observed in the present body of work are largely comparable to previous research (Curzon-Jones & Hollands, 2018; Reynolds & Day, 2005; Young & Hollands, 2010). Nonetheless, these differences in stepping errors were small. However, even small deviations in stepping accuracy could have reduced safety during this experimental protocol; whereby participants would have had approximately only 3 cm deviation in either the medial or lateral direction before contacting the edges of the target.

Finally, while the stepping targets used in the present work had raised edges, these were made of compliant foam which would have been unlikely to significantly perturb participants in any instances of a misplaced step (in contrast to negotiating, for example, a raised paving stone in a real-world setting). Consequently, there would have been a low behavioural consequence of a misplaced step. We do not, however, deem this a major limitation, as anxious participants nonetheless appeared to view these threats as a potential threat to their balance (e.g., verbal reports results from Chapter 5). Relatedly, both young adults (Chapter 5) and low-risk older adults (Chapter 7 and 8) displayed proactive feedforward movement planning during ground level walks, effectively previewing future stepping constraints. Furthermore, anxious low-risk older adults also adapted their movements (e.g., increased stance durations), presumably to avoid producing a misplaced step resulting from anxiety-related reductions in feedforward planning. Taken together, these results indicate that participants did, in fact, place importance on successfully negotiating these stepping constraints. Regardless, future work should look to replicate these findings in a precision stepping task which carries a greater behavioural consequence of an inaccurate step (e.g., stepping onto a raised curb or over a solid obstacle).

Relatedly, while the current protocols were sufficient to evaluate movement inefficiencies and infer “unsafe” behaviours (e.g., increased likelihood of tripping on a target), this was achieved without creating a scenario in which the individual would actually fall; given that the targets were made of pliable foam and were unlikely to significantly perturb participants in any instances of foot contact. Consequently, this represents another limitation of the protocol, as we are unable to directly infer fall-risk with the experimental data.

9.7.2 The Experimental Manipulations

The fall-related anxiety manipulation used throughout this body of work (Chapters 4, 5, 7 and 8) involved participants traversing an elevated walkway (1.1 m for young adults; 0.6 m for older adults). The large majority of literature which explores how fall-related anxiety influences walking behaviour has similarly induced anxiety via an elevated walkway paradigm (e.g., Brown et al., 2002; Delbaere et al., 2009; Gage et al., 2003; Hadjistavropoulos et al., 2012; McKenzie & Brown, 2004; Tersteeg et al., 2012). Nonetheless, is possible that inducing fall-related anxiety through elevation might alter behaviour as a direct consequence of height exposure, rather than anxiety itself. For example, elevating participants above ground level would have altered the visual environment, increasing the distance between the walker and the ground. This is a potential issue, as doing may induce postural instability by way of changes in optic flow (Bles et al., 1980). Despite this, we deem it unlikely that the results presented in this body of work – and those reported by other researchers using identical paradigms – can be attributed solely (if at all) to alterations in the visual environment. For example, research presented by Tersteeg et al. (2012) demonstrates that anxiety-related behavioural adaptations induced through elevation persist even in the absence of visual exposure to height; thus ensuring that the visual environment was consistent between low- and high-anxiety conditions. Consequently, we suggest that the anxiety-related behavioural adaptations observed in the present body of work are likely to be driven by threat-related interpretations of the environment, rather than being a direct consequence of the altered visual environment itself.

Chapters 4, 5 and 8 also included an experimental manipulation designed to induce heightened conscious movement processing. This involved informing participants that they would be asked “internal focus” questions relating to their movements after certain trials in this condition (e.g., “which foot did you step onto the walkway with?”). This manipulation was based on research which described that older adults who report heightened conscious movement processing will provide more accurate answers to questions pertaining to their movements (Uiga, Capio et al., 2015; Wong et al., 2009; Young et al., 2016). However, it is possible that such awareness of movement may be a consequence of conscious attempts to *control* individual stepping actions, rather than being the conscious movement strategy itself.

In other words, while the experimental manipulation used herein significantly increased the level of attention individuals directed towards their movements, these changes may not necessarily reflect the conscious movement strategies individuals use in naturalistic settings.

Previous researchers have instead used "conscious control" instructions to induce conscious movement processing during locomotor tasks (e.g., Mak et al., 2019). These manipulations involve participants receiving instructions to focus on controlling a certain aspect of their movement. However, we decided against using conscious control instructions, as we deemed that such manipulation would also be unlikely to capture the complex, multifaceted nature of such conscious movement strategies. Future research should, nonetheless, seek to compare visual search behaviours during a range of different conscious movement processing manipulations. One method could involve asking participants to report their individual strategies used to control/monitor gait during naturally-induced conscious movement processing (e.g., during conditions of postural threat/anxiety). These strategies could be then relayed to participants as a personally meaningful instruction with which they could use to consciously process movement during conditions of low-threat/anxiety.

9.7.3 The Variables Assessed

Throughout this body of work, fall-related anxiety was assessed via self-reported fear of falling and balance confidence – with physiological responses to anxiety ignored (e.g., heartrate, galvanic skin conductance, etc.). The decision to restrict anxiety assessments to a self-rated measure of cognitive anxiety/confidence was made on the basis that previous research has highlighted a clear relationship between self-reported anxiety and altered locomotion (Hadjistavropoulos et al., 2012). In contrast, the relationship between physiological anxiety responses and gait-related behaviours remains comparatively unclear (Hadjistavropoulos et al., 2012). This therefore suggests that it is the cognitive response to heightened anxiety, rather than the physiological anxiety response itself, which underpins the subsequent gait-related adaptations. Thus, while we did not directly assess physiological anxiety, we do not view this as a major limitation.

The lack of comprehensive gait analysis could potentially be viewed as another limitation. Throughout this body of work, the primary gait variables assessed related to stepping error, walking times (i.e., time to complete the walking task), and indices of movement efficiency (e.g., stance durations preceding stepping targets). These gait variables were selected to provide a behavioural index of movement planning, thus allowing for inferences to be made about the effectiveness of certain gaze behaviours. However, a more detailed analysis of gait kinematics would have allowed for the additional assessment of a range of other behavioural outcomes important for the maintenance of safety while walking (e.g., movement variability, gait stability, postural sway, etc.). Future research should, therefore, explore the influence of fall-related anxiety, and associated changes in attentional focus, while collecting a more comprehensive assessment of gait behaviour.

9.8 Key Directions for Future Research

While it is not without its limitations, the present work establishes various potential routes for future research. We speculate that the anxiety-related visual search behaviours reported in Chapters 5, 7 and 8 are likely to reduce safety, by virtue of individuals having a reduced ability to perceive environmental hazards, and thus being less efficient at adapting behaviour to meet these demands. Indeed, Chapter 7 highlights that such reductions in feedforward planning are associated with increased stepping errors in high-risk older adults. However, the question remains as to whether increased stepping errors observed in the laboratory translate to reduced safety in real-world environments. Therefore, longitudinal research needs to be conducted to determine whether these visual search behaviours are indeed associated with an increased risk of falling. Relatedly, longitudinal research could also be conducted to explore the extent to which specific attentional responses to postural threat predict incidences of falls. For example, while we suggest that the increased attention directed towards ruminative/worrisome thoughts will likely reduce safety, future research is needed to confirm such assumption.

Future research should also look to replicate the experimental paradigms featured in this body of work during more complex locomotion tasks. While the low-risk older adults studied in Chapter 7 were able to adapt their stepping movements to "overcome" the anxiety-related restricted feedforward planning, such behavioural adaptations came at cost to both movement and processing efficiency. However, given the relative simplicity of the experimental task used in this chapter – and the thesis overall – participants were able to adapt their behaviour without experiencing any negative consequences (i.e., they had both the cognitive resources, and time, available for making such behavioural adaptations). Thus, future research should explore the potential risk factors associated with adopting such restricted visual search during experimental tasks more representative of the complex, anxiety-inducing scenarios encountered frequently in the real-world (e.g., walking across an uneven pavement in a crowded environment, while talking to a friend).

While recreating such complex, ecologically valid scenarios in a laboratory setting presents numerous challenges, recent technical advancements have allowed researchers to explore visuomotor behaviour while walking in natural, real-world settings (e.g., Feld & Plummer, 2019; Matthis et al., 2018). It is, however, worth noting that this research has restricted such explorations to young adult participants; individuals for whom traversing such environments is unlikely to represent a significant risk to safety. Conversely, the question can be raised as to the suitability of such experimental paradigms for older adults – particularly those with deficits in balance control. Instead, it may be more appropriate for future research to explore older adults' visuomotor control during virtual reality (VR) scenarios designed to mimic complex, real-world postural threats – given that participants would be able to complete such tasks in a laboratory setting, while wearing a protective harness. Indeed, VR has been used effectively to induce heightened fall-related anxiety in both young adults (Cleworth, Horslen, & Carpenter, 2012) and clinical populations (Ehgoetz Martens, Ellard, & Almeida, 2014), highlighting this technology as an encouraging avenue for further study.

Finally, researchers should look to also explore the potential efficacy of using cognitive training to modify these potentially disruptive anxiety-related responses. For example, recent work published by Ducrocq, Wilson, Vine, and Derakshan (2016) has implied that training attentional control (specifically inhibitive control) may positively influence the effectiveness of visual search behaviours and performance effectiveness during high-pressure sporting situations. In this research, while both the intervention and control group reported comparable levels of state anxiety during pressure conditions, the attentional control training group appeared insulated from any negative behavioural effects of anxiety. Ducrocq et al. (2016) proposed that these positive outcomes were a result of the attentional control training enhancing participants' ability to inhibit task-irrelevant distracters (e.g., ruminations/worries). Consequently, future research should examine whether such training could be effective in similarly inhibiting ruminations/worries in older adults deemed to be at a high risk of falling.

9.9 Concluding Remarks

The present body of work aimed to investigate the relationship between fall-related anxiety, changes in attentional focus, and altered patterns of locomotion. The findings presented highlight that when anxious about falling, younger and older adults alike will consciously process stepping movements, in an attempt to avoid a fall occurring. This appeared to result in slower, more cautious movements (e.g., increased stance phases preceding a precision step, heightened control of individual stepping movements). Our results also strongly imply that such conscious movement strategies will manifest as the visual prioritisation of walkway areas needed to do so (e.g., looking 1–2 steps ahead to ensure accurate placement of individual steps). This appears to constitute an increase in both short-term planning (e.g., planning individual steps rather than planning future adaptive stepping movements over an obstacle, etc.), and on-line control (e.g., guiding the trajectory of the step itself) – at the expense of planning more long-term movements (e.g., future stepping actions). While both younger adults and low-risk older adults appeared able to adapt their walking behaviours to accommodate such altered patterns of visuomotor control, reduced feedforward planning was associated with increased stepping errors in older adults deemed to be at a high-risk of falling.

In an attempt to account for these differences – as well as owing to the difficulties of translating existing psychological theories to the domain of posture and gait – we presented a new conceptual framework: The Gait-Specific Model of Threat Perception (see Figure 9.2). This model contends that individuals who deem their coping resources as sufficient will evaluate the anxiety-inducing situation as challenging, thus entering into a challenge state, whereas those who evaluate their resources as insufficient for the meeting the situational demands will enter into a threat state. While challenge evaluations are suggested to be largely adaptive in nature (with heightened conscious movement processing purported to be the primary attentional and behavioural response associated with this state), threat evaluations are conversely proposed to be largely maladaptive, leading to ruminations/worries about falling – in addition to conscious movement strategies. This framework contends that processing ruminations will reduce the effectiveness of any conscious movement strategies, impairing the walker’s ability to adapt their gait patterns to accommodate the visuomotor control associated with conscious movement processing.

Taken holistically, the present body of work highlights a clear link between fall-related anxiety, subsequent changes in attention, and altered control of adaptive locomotion.

While the relationship between fear of falling and increased fall risk is well documented (Friedman et al., 2002; Hadjistavropoulos et al., 2011; Young & Williams, 2015), the present body of work describes a direct link between heightened fall-related anxiety and behaviours likely to reduce stepping safety in high-risk older adults. The findings presented herein also support the importance of considering attentional mechanisms when inferring how anxiety about falling may influence an individual's risk of falling. It is hoped that future research will look to directly test the hypothesised links presented in the Gait-Specific Model of Threat Perception (see Figure 9.2).

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Appendices

Appendix A

Scenario 1 (*Note, this is the 'Low-Threat scenario***):**

> *Think about a moment during walking when you are completely relaxed and there is a low chance of tripping or falling. For example, you could be walking on a flat, even surface or walking in a familiar, safe environment.*

When you are completely relaxed, <u>what do you think about and focus your attention to</u>?

When you are completely relaxed, <u>what do you do to ensure that you do not trip or fall</u>?

Scenario 2: (*Note, this is the ‘High-Threat scenario***)**

> *Think about an important moment during walking, when your anxiety is very high and there is a very strong chance of tripping or falling if you do not execute the next step well. For example, you could be walking through a busy crowd, stepping off a high curb, or walking on a slippery (wet or icy) or uneven surface.*

When your anxiety is at its peak, <u>what do you think about and focus your attention to</u>?

When your anxiety is at its peak, <u>what do you do to ensure that you do not trip or fall</u>?

Appendix B

Gait-Specific Attentional Measure

While completing the walking task, you may have directed your attention toward different information. Please indicate the extent to which you thought about or paid attention to:

Movement processes
Attempts to consciously control or monitor movement, e.g., focusing on picking up your feet, or controlling either step length or walking speed

1 / 2 / 3 / 4 / 5 / 6 / 7 / 8 / 9 / 10 / 11

Never Always

Threats to your balance
Focusing on anything in the environment which may cause you to trip up or lose your balance

1 / 2 / 3 / 4 / 5 / 6 / 7 / 8 / 9 / 10 / 11

Never Always

Worries or disturbing thoughts
E.g., Thoughts relating to falling and the potential negative consequences of this

1 / 2 / 3 / 4 / 5 / 6 / 7 / 8 / 9 / 10 / 11

Never Always

Self-regulatory strategies
Any coping strategy that helps you feel, think and behave in the way you want, e.g., focusing on controlling your breathing or telling yourself "you can do it!"

1 / 2 / 3 / 4 / 5 / 6 / 7 / 8 / 9 / 10 / 11

Never Always

Task-irrelevant information
Thoughts unrelated to the walking task, e.g., thinking about what you are having for dinner or letting one's mind wander

1 / 2 / 3 / 4 / 5 / 6 / 7 / 8 / 9 / 10 / 11

Never Always

Appendix C

Mean, standard error of the mean (*SEM*) and *p* values for comparisons between Threat (Chapter 8) and Control-Threat (Chapter 7) trials for all state measures, motor performance measures and gaze variables.

	Threat		**Control-Threat**		
	Mean	*SEM*	Mean	*SEM*	*p*
Balance confidence (%)	77.22	4.97	66.11	5.67	.005ǂ
Fear of falling (%)	9.44	3.66	17.22	4.70	.061ǂ
Mental effort (0-150)	36.11	5.14	36.67	6.10	.916
Attention directed towards…					
…Movement processes (1-11)	7.00	0.69	6.72	0.81	.586
…Threats to balance (1-11)	1.89	0.49	3.22	0.71	.041ǂ
…Worries or disturbing thoughts (1-11)	1.72	0.42	1.83	0.46	.414
…Self-regulatory strategies (1-11)	3.17	0.47	3.11	0.59	.953
…Task-irrelevant information (1-11)	1.06	0.06	1.56	0.31	.102
Time to complete the task (s)	6.51	0.39	6.74	0.41	.070
Stance duration (s), first target	0.95	0.05	0.87	0.03	.192
Stance duration (s), second target	1.04	0.06	1.09	0.07	.187
First target, AP stepping error (mm)	24.41	2.63	27.58	3.37	.390
First target, ML stepping error (mm)	18.69	1.65	18.24	1.73	.956
Second target, AP stepping error (mm)	35.23	3.42	30.42	3.03	.193
Second target, ML stepping error (mm)	16.45	1.80	15.98	1.41	.758
First fixation location on (1-4)	1.60[a]	0.60[b]	1.40[a]	0.70[b]	.253
(1) Immediate walkway					
(2) First target					
(3) Second walkway					
(4) Second target					
Immediate walkway fixation duration (%)	18.75	2.45	22.61	2.51	.113
First target fixation duration (%)	58.90	4.31	62.24	4.11	.073
Second walkway fixation duration (%)	8.49	1.91	8.50	1.65	.438
Second target fixation duration (%)	10.13	3.34	6.64	1.93	.345
No. previewing fixations (avg. per trial)	0.46	0.13	0.39	0.09	.323

Note: ǂ = We suggest that these differences are a likely consequence of participants having previous experience with the threat-manipulation, and thus being more confident in their abilities to complete the task without falling.

[a] = median (rather than mean), [b] = interquartile range (rather than *SEM*)