The Effects of Trait and State Anxiety on Gait in Healthy Young Adults

by

Pershia Norouzian

A thesis
presented to the University of Waterloo
in fulfillment of the
thesis requirement for the degree of
Master of Science
in
Kinesiology

Waterloo, Ontario, Canada, 2023

Author’s Declaration

I hereby declare that I am the sole author of this thesis. This is a true copy of the thesis, including any required final revisions, as accepted by my examiners.

I understand that my thesis may be made electronically available to the public.

Abstract

Having an anxious state of mind, often elicited using a height-induced threat, has been consistently shown to alter static and dynamic postural stability in both young and older adults; however, the effects on walking have been less studied. Interestingly, even more stable characteristics such as trait anxiety, in the absence of threat, have been shown to impact gait in clinical populations, although little work has been conducted on young, healthy adults. Attentional processes have also been suggested to play a role in posture and gait control, and anxiety (both state and trait) is known to consume attentional resources and reduce functional cognitive capacity. However, the interaction between trait and state anxiety, and attention on gait has not yet been investigated formally. Therefore, the current study examined the role of trait anxiety as a predictor in gait behaviour during both single- and dual-task walking at the ground and elevated levels, stimulated within a virtual reality (VR) environment.

Using a repeated measures design, 30 young, neurotypical adults aged 19-28 completed five walking trials on the Zeno pressure sensor walkway during four different VR-stimulated condition blocks. Conditions were completed in the fixed order of: (i) low threat – walking across a plank on the ground, (ii) low threat + dual-task – walking across a grounded plank while simultaneously monitoring numbers on an audio track, (iii) high threat – walking across a plank elevated above a deep pit, (iv) high threat + dual-task – walking across an elevated plank while simultaneously monitoring numbers on an audio track. At baseline, trait anxiety levels were determined by the State Trait Anxiety Inventory (STAI) and baseline cognitive task performance was recorded while seated. After every trial, state anxiety levels were reported using self-assessment manikins.

In general, self-reported anxiety levels increased when walking during the elevated conditions compared to the ground. Trait anxiety was a significant predictor of reductions in gait velocity and increased time spent in double support when at elevated conditions during compared to the ground, as well as when dual task walking compared to single task walking at elevation. In addition to reductions in gait velocity and increased time spent in double support, trait anxiety also predicted increased step length variability while dual tasking at elevated conditions compared to dual task walking on the ground. However, the study did not find that trait anxiety was a significant predictor of any spatiotemporal aspects of gait during ground level single task walking, nor when considering dual task walking compared to single task walking at the ground level. The results of this study suggest that trait anxiety does not predict gait behaviour when walking on the ground both with and without attentional tasks. Rather, trait anxiety can predict a slower, more cautious gait pattern under elevated stress (threat) conditions and when performing a dual task during threat.

Acknowledgements

I would like to start by expressing my gratitude and thanks for my supervisor and mentor, Dr Kaylena Ehgoetz Martens, for her immense support and guidance throughout the duration of this degree. I would also like to thank my committee members, Dr Laura Middleton and Dr Brian Horslen, for their feedback and guidance each step of this research journey. I am highly grateful to have been able to learn from your expertise and look forward to working further with you all in the future.

Additionally, I wish to extend my appreciation to the Neurocognition and Mobility Lab members, my fellow colleagues, peers, and friends who have guided me towards success with encouragement and feedback. I am very thankful to have met each and every one of you during this time. I am truly humbled to be surrounded with an incredible group of mentors and peers who motivate me to push boundaries in our work.

Finally, I would like to thank and acknowledge my family, who have always provided me with unconditional love and support. You inspire me each day to continue working hard and it is due to you that I am where I am today.

Table of Contents

List of Figures

List of Tables

List of Abbreviations

HAM-A – Hamilton Anxiety Rating Scale

STAI – State Trait Anxiety Inventory

PD – Parkinson’s Disease

VR – Virtual Reality

VE – Virtual Environment

DT – Dual Task

ST – Single Task

SAM – Self Assessment Manikin

SAS – Sport Anxiety Scale

MSRS – Movement Specific Reinvestment Scale

GSAP – Gait Specific Attention Profile

DTC – Dual Task Cost

MSC – Movement Self Conscious

CMP – Conscious Movement Processing

ACT – Attentional Control Theory

EDA – Electrodermal Activity

GSR – Galvanic Skin Conductance

PPV – Phobic Postural Vertigo

1.0 Introduction

Gait refers to the pattern or manner in which someone walks. Although gait was once thought of as an automatic movement, it is now recognized to interact with cognition and emotion (Azevedo et al., 2007; Sanders & Gillig, 2010). In fact, recent work suggests that gait may be a biometric modality that could identify an individual's emotional state, individual traits, brain health or even their identity through subtle variations in their walking patterns (Connor & Ross, 2018). However, much research is still needed to determine precisely how much information is embedded in our walking.

State anxiety is defined as a specific situation that is perceived to be dangerous or threatening. It has been well-established in the literature that emotions, such as a state of fear or anxiety, can have a direct impact on both static and dynamic postural control (Zaback et al., 2015, 2016, 2019). The most common method to manipulate threat to examine the effect of threat on balance control has been by elevating a surface height of a platform on which individuals stand. This was first employed by Brown and Frank (1997) but has been extensively used to investigate the effects on standing balance in young and older adults, and within clinical populations. The elevated paradigm has also been used to probe and interpret the effects of anxiety on different types of postural tasks such as anticipatory postural control, reactive postural control, and functional balance tasks. Overall, research has found that when individuals are placed in high threat on an elevated platform, they demonstrate an increase in centre of pressure frequency and decreased amplitude of centre of pressure displacements (Adkin & Carpenter, 2018; Zaback et al., 2015). Researchers have suggested that changes in attention may mediate anxiety-related postural changes (Zaback et al., 2016). However, significantly less work has been undertaken to examine the effects of state anxiety on normal gait in healthy young adults (Gage et al., 2003), where there remains a gap in the current literature.

Trait anxiety is defined as a stable aspect of one's personality that tends to experience fear, worry, or negative emotions. It has been suggested that trait anxiety depletes the capacity of the central executive and impairs performance on tasks requiring high attentional demand (Calvo & Eysenck, 1992). While there are some preliminary studies that have investigated the effects of trait anxiety on gait, this has been predominately in clinical populations (Ehgoetz Martens et al., 2015b, 2018). Moreover, few studies have investigated the effects of individuals experiencing clinical anxiety symptoms during walking and found lower gait velocity, step length, and cadence in individuals with anxiety versus healthy individuals without anxiety symptoms (Feldman et al., 2019). Whilst research has proposed that having an anxious personality can consume attentional resources similarly to the cognitive load experienced from performing two tasks simultaneously (Bishop, 2009), there have been no studies to date that have examined this hypothesis in healthy young adults.

This study aimed to address these gaps by examining the effects of both state and trait anxiety on gait using the well-established height-induced threat paradigm, which was induced in virtual reality (VR) setting. By pairing this paradigm with a dual task aimed at dividing attention, the study evaluated whether changes in attention mediate the effect of state and trait anxiety on gait, respectively.

2.0 Literature Review

2.1 Gait control

Gait refers to the pattern of movement exhibited during walking (Alexander, 1984); it is much more complex than static postural control. During the gait cycle, the body must maintain balance during periods of instability while locomoting and bearing body weight (Pirker & Katzenschlager, 2017). To maintain postural balance during unstable instances of single limb support, muscles, joints, and limbs follow a characterized pattern regarding muscle timing and activation. To achieve this, there is high coordination involving all levels of the nervous system and requires coordination with the musculoskeletal system and cardiorespiratory system as well (Pirker & Katzenschlager, 2017).

Originally, scientists believed that gait was an automatic process which required no contributions from higher order processes and utilized minimal executive control (Bernstein, 1966; Clark, 2015; Wu et al., 2004; Wu & Hallett, 2005). However, since the early 2000s, it has been identified that while some elements of gait may remain automatically controlled, gait requires the involvement of the cortex, and further that emotion and cognition contribute to motor control of gait (Woollacott & Shumway-Cook, 2002; Yogev-Seligmann et al., 2008).

Gait can be characterised in several ways, most commonly by describing spatiotemporal features (e.g. cadence, velocity, step length, step width, step time, etc). Moreover, spatiotemporal aspects of walking have been suggested to vary based on an individual’s traits and internal states, and across different environmental contexts. For example, an emotional state such as sadness can evoke reductions in walking speed, and arm swing compared to joyful walking which is associated with increased gait velocity, and a wide range of limb motion (Deligianni et al., 2019;

Michalak et al., 2009). As seen in **Figure 1** below, the neural control of gait spans the entire brain showing how emotions and gait may interact through cortical and subcortical inputs. Interplay of these structures may be seen through neural pathway connectivity between the amygdala and the prefrontal cortex, basal ganglia and supplementary motor area (Avanzino et al., 2018).

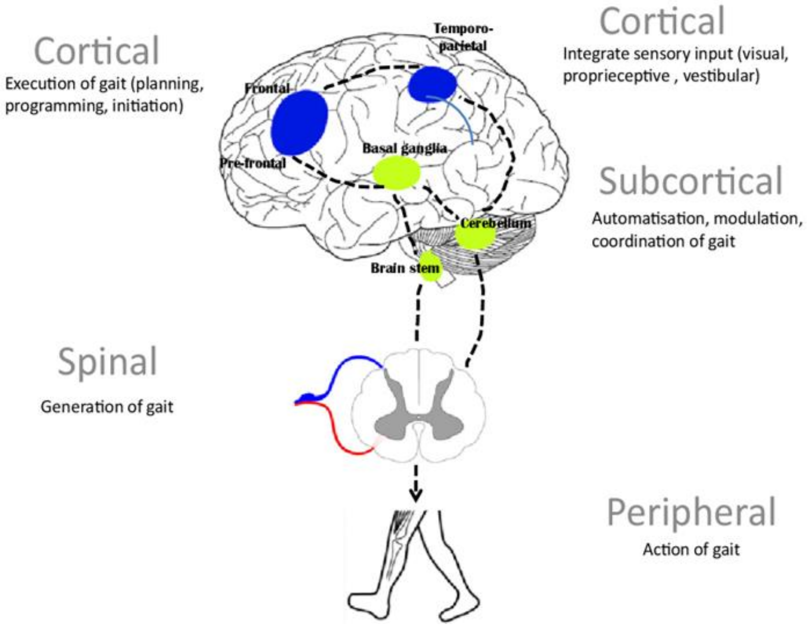


Figure 1. Different levels of the neural control of gait (Zhang et al., 2019).

2.2 Emotional Influences on Gait

Emotions can play a role during human locomotion, and they have been investigated in relation to gait behaviours in healthy adults. One study found that different emotions elicited different walking speeds and stride lengths during happy, sad, angry, or proud emotional states (Montepare et al., 1987). Specifically, negative emotions such as anger, elicited longer stride lengths and heavier footsteps while positive emotions like happiness evoked a faster pace

(Montepare et al., 1987). However, other work has found that both happiness (joy) and anger elicited longer strides and faster speeds compared to sadness, but anger had a faster cadence than happiness (Halovic & Kroos, 2018; Kang & Gross, 2016). Additionally, fear was expressed with short and fast strides that were resemblant of scurrying (Halovic & Kroos, 2018). While many studies to date have focused on the "discrete" emotions (happy, sad, angry), fewer studies have investigated the impact of states of fear or anxiety which are commonly experienced during daily life. These states are critical to investigate further as they have been linked to falls and other gait impairments in older adults and clinical populations.

2.2.1 Influence of State Anxiety on Gait

State anxiety can be defined as an emotion or behaviour which is experienced based on situational influence that can be perceived as threatening or dangerous; it is classified by feelings of apprehension or nervousness as well as increased heart and breathing rate (Spielberger, 1971). It has been well-established that state anxiety from postural threat (i.e., elevated heights) can influence postural control (Adkin et al., 2000; Adkin & Carpenter, 2018; Carpenter et al., 2001; Lelard et al., 2019). However, there is far less literature on gait in healthy young adults as most of the literature has focused on older adults and clinical populations (Delbaere et al., 2009; Ehgoetz Martens et al., 2015a).

In early postural control work, young healthy adults were asked to stand on elevated platforms to determine whether postural control modifications would follow a graded response with varying heights from low, to medium, and high (Adkin et al., 2000). The postural response to manipulations of height were recorded via force plates on the platform during quiet standing.

Findings revealed tighter control of posture with higher threat conditions as seen by a linear decrease in centre of pressure displacement amplitude and a linear increase in centre of pressure displacement frequency when going from low to high elevations (Adkin et al., 2000). Thus, giving primitive insight into how the central nervous system controls body movements under postural threat. Other work expanded on these findings in healthy young adult populations, quietly standing during low, medium and high postural threat conditions at slightly different heights from Adkin et al.'s work (Carpenter et al., 2001). The main difference between this work and previous studies was the addition of visual feedback and vestibular information as exposures of interest; however, it was found again that centre of pressure displacements and frequency were influenced by degree of postural threat. Both studies found increased frequency and decreased amplitude of individual's centre of pressure displacements when standing quietly at high elevations that evoke increased postural threat compared to low (Adkin et al., 2000; Carpenter et al., 2001). Moreover, a recent review noted common findings that regardless of age, postural control becomes less stable and stiffer (reduced postural sway) when individuals were anxious about falling such as when faced with postural threat from elevated surfaces (Lelard et al., 2019). It can therefore be argued that postural control may be mediated by arousal states as healthy, young individuals exhibit postural stiffening/tightening during situations that evoke state anxiety, specifically from elevations perturbing postural threat.

As noted, height-induced threat paradigms have been used across the majority of studies evaluating static postural control, with less work examining the gait of healthy young adults. For instance, Delbaere et al., found that the elevated platform paradigm effectively induced physiological arousal in participants by evoking postural threat from the platform elevation (2009). When walking at elevation, participants experienced reduced walking speed, step length, cadence and spent more time in double support as compared to the ground (Delbaere et al., 2009). However, this study was done on community-dwelling elderly individuals, who were concerned about fall risk and thus may exhibit exacerbated changes to gait at heights when compared to younger adults.

Other work has examined whether anxiety affects gait similarly in younger individuals as older adults. Studies compared the gait patterns of both young and older adults when walking under conditions of postural threat from elevated walkways. By manipulating the width of the same elevated height platform to induce postural threat Brown et al., found reduced velocity, longer phases of double limb support and shorter stride lengths in both young and old healthy adults in the elevated conditions overall (2002). Therefore, Brown et al. concluded that environments conducive to postural threat are sufficient to demand gait pattern alterations in both young and elder adults. This work on elevated and constricted platforms has been extended past straight-line walking as well, with other studies investigating obstacle interference tasks during these conditions in both young and healthy adults (McKenzie & Brown, 2004). In these studies, the lowest velocities of the whole body and leading/trailing limbs were experienced when crossing obstacles that were placed on constrained and elevated walkways (McKenzie & Brown, 2004). The low velocity seen was resemblant of conservative gait and postural control aiming to reduce fall risk, and this gait pattern was more drastic for older adults compared to younger adults (McKenzie & Brown, 2004). It can therefore be noted that the anxiety linked to fear of falling may be a protective strategy against falling, specifically in older adults, as other work indicated less obstacle contact frequency at these elevated and constrained conditions when the same conservative gait patterns (i.e., reduced velocity, longer double limb support phase) were observed (Brown et al., 2006). Thus, whether performing straight-line walking, or obstacle negotiation tasks, both older and younger adults exhibit altered (more conservate/restrictive) gait when under conditions of state anxiety induced from postural threat.

While evidence suggests that elevated threat conditions evoke different postural and gait responses when compared to ground-level walking, it remains unclear exactly why this occurs and what mechanisms may modulate this outcome. One suggestion is that attentional demands may be allocated differently during situations of high state anxiety. Building on the findings of Brown et al.'s study from 2002, Gage et al., conducted another study in 2003 aiming to address whether anxiety from fear of falling would alter attentional demands on gait in both young and older healthy adults. Gage et al.'s study had these individuals walk under the same postural threat and width manipulations, while also completing a dual task condition (walking while also performing another cognitively taxing task simultaneously) on some trials. It was found that during elevated situations that combined both anxiety (from postural threat) and cognitive interference (from dual tasking by responding to auditory cues during walking), all individuals experienced reduced velocity, longer phases of double limb support and increased reaction times in responding to the auditory probe (Gage et al., 2003). These results demonstrate that state anxiety (i.e., from postural threat) may influence the attentional demands required by locomotion. Notably, no studies have investigated whether individual traits such as trait anxiety may interact with this effect to alter gait characteristics further during walking under anxiety-inducing conditions that evoke state anxiety from postural threat in healthy young adults, or the role of attention in the relationship which may be impacted by trait anxiety. To sum, there still remains a large gap in the literature concerning how individuals with anxious traits alter gait under situations of state anxiety from postural threat, and whether attention may modulate this relationship as well.

2.2.2 Influence of Trait Anxiety on Gait

It is important to note that the influence of stable aspects of one's personality, such as trait anxiety, without any external influences of stress/threat has not yet been studied in detail. Few studies have investigated the impact of trait anxiety on gait, of which most have focused on clinical populations, or with solely clinical markers of anxiety (Ehgoetz Martens et al., 2018; Feldman et al., 2019). One study examined 93 adults aged 18-65 from outpatient clinics, 48 of which had high levels of anxiety (> 14 on the Hamilton Anxiety Rating Scale; HAM-A), and 45 healthy controls (≤5 on HAM-A). From their work, individuals with trait anxiety had slower walking speeds, shortened step length, inability to balance and impaired mobility compared to healthy controls when performing a 10-metre walk test (Feldman et al., 2019). However, these participants were recruited from outpatient clinics and may have been faced with environmental (situational) anxiety from the clinic, on top of being under medical treatments from underlying conditions. Additionally, this study used observational analysis to quantify gait patterns (through timing how long it took participants to walk a 10-metre distance) where observational bias and human reaction times should be considered, as opposed to using a quantitative pressure sensor carpet to quantify spatiotemporal aspects of gait without human error biases as was used in our current study. Another study compared both single and dual task gait in individuals with Parkinson's disease (PD) who had high compared to low trait anxiety (measured using the Spielberger State and Trait Anxiety Inventory; STAI). The results from this study showed that PD patients with high anxiety had slower gait during single task as seen by reduced step length and increased time at baseline when compared to healthy controls and PD patients with low anxiety (Ehgoetz Martens et al., 2018). This study also investigated whether cognitive load impacted gait in a similar way as trait anxiety by comparing dual task walking (i.e., walking while simultaneously performing an auditory digit monitoring task of counting the frequency of 2 numbers heard from an audio track) to single task walking. It was found that the gait performance (as seen from increased step time and length variability) of highly anxious PD patients during single task gait resembled the gait performance of low anxious PD and healthy control patients during dual task, suggesting an interference between attention and anxiety on gait. However, to date, there have been no studies that examine the relationship between attention and trait anxiety on the gait of healthy young controls.

There have also been prior studies that have investigated the impacts of trait anxiety solely on postural control, and not on gait (Hainaut et al., 2011; Zaback et al., 2015). A study by Hainaut and colleagues (2011), examined the interaction between state and trait anxiety for balance control in healthy young adults. Using the Stroop Color Word Test with interference to evoke moderate levels of state anxiety during quiet standing, they found larger and faster sway area and paths during the periods of state anxiety regardless of trait anxiety level but did not find differences between intermediate (STAI score of 40-62) or very low (STAI score of 23-35) levels of trait anxiety (Hainaut et al., 2011). They suggest that future studies should aim at investigating higher levels of trait anxiety, with a state anxiety measure that will evoke higher levels of arousal (such as from postural threat paradigms) as this may have been why the differences between the trait anxious groups during state anxiety measures were not statistically different. Currently, there is no study that has addressed the gait differences in healthy young adults with varying levels of anxiety when walking under various posture threatening conditions.

On the other hand, a study on healthy young adults examined the interaction between trait and state anxiety on postural control during both quiet standing and when asked to rise to their toes while on platforms of high and low elevations (Zaback et al., 2015). In addition to trait anxiety (measured by STAI), Zaback et al.’s study also assessed movement reinvestment traits, which refers to the degree in which individuals direct attention to their movements while ambulating. Movement reinvestment can be classified by conscious motor processing (the degree in which they will consciously control their movements) and movement self conscious (the degree in which they are concerned about their movement appearance) as given by the Movement Specific Reinvestment Scale. Movement reinvestment is important to consider during studies of gait as it is thought that individuals with high movement reinvestment will have poorer motor performance during anxiety-inducing conditions (especially in height-induced threat) because the process of consciously controlling movements will disrupt movement automaticity (Masters & Maxwell, 2008). While this study found did not find that trait anxiety significantly impacted quiet standing postural control, it did find that individuals with more elements of trait movement reinvestment experienced an increase in frequency of postural adjustments and decreased amplitude variability of the adjustments in attempt to limit chances of falling (Zaback et al., 2015). The investigators noted that future work should consider making low threat conditions at the ground level as opposed to the slight elevation (0.8m) they had induced for their study at baseline. It is also important to note that Zaback et al.'s study provided the Movement Specific Reinvestment Scale prior to walking trials, which may have primed subjects to consciously control their movements whether already predisposed or not.

In sum, while there is some work done that has examined the influence of trait anxiety on postural control, much less work has been done on gait, and moreover, no study to date has investigated the influence of trait anxiety on gait in young healthy adults, nor whether high levels of trait anxiety might interact with state anxiety to exacerbate gait changes, which were the first and second objectives of this thesis. To inform the hypotheses of this study, the work done on postural threat from standing balance in healthy individuals can be used to understand expected changes seen during gait control in healthy young adults. As gait is much more complex than static balance, it is reasonable to expect that based on these results, there will be more pronounced effects of gait variability, speed, and step width or length (amongst other parameters) in individuals who experience trait anxiety. Based on the results from the postural control studies, it is also reasonable to hypothesize that locomotion during situations of high anxiety (from elevations inducing postural threat) will exacerbate any difference seen between trait anxiety levels when simply walking at ground level. While behavioural effects are observed under these conditions, and some earlier work may point to attention as a mediator for impacts of postural threat and anxiety on gait, further work is needed. As noted, there has been some previous literature that suggests attention may mediate the relationship between trait and state anxiety on gait, but this has not been extended to healthy, young individuals. Therefore, understanding the relationship between anxiety and attention during the gait of healthy young individuals was the final objective of this study.

2.3 Attention may mediate the influence of anxiety on gait

Recent literature has identified that gait largely requires cortical control, and it has been suggested that there is involvement from attention. Attention has been defined by researchers as the information processing capacity of an individual (Woollacott & Shumway-Cook, 2002). Attention operates during and after sensory information processing to filter out irrelevant information while selecting relevant information to the task at hand (Awh et al., 2006). Operating under the assumption that information processing capacity is limited, each task being carried out will occupy varying amounts of capacity or attentional resources and thus may not occur automatically. Although there have been no studies done in healthy individuals examining the attentional allocation of individuals with high trait anxiety during regular walking, nor during situations of state anxiety, studies that have assessed cognitive functioning suggest that individuals who have high levels of trait anxiety experience impoverished prefrontal control of attention (Bishop, 2009). These individuals are more susceptible to worry and become very distractable, thus demanding further information processing resources to complete tasks (Bishop, 2009). Other researchers suggest that trait anxiety can also influence functional cognitive capacity by impacting attentional resources and executive functions, as seen through the functional network model (Sylvester et al., 2012). This model suggests that trait anxiety reduces the fronto-parietal network functioning which results in decreased top-down attention as seen during conscious control of movement (Sylvester et al., 2012). Top-down attentional control refers to the voluntary allocation of attention towards movement, and it is seen during reinvestment which refers to the way in which individuals intentionally focus attention on aspects of their movement (Masters & Maxwell, 2008). Much of the work carried out to date has examined the role of attention in mediating anxiety-related changes to postural control during simple standing rather than walking, with only one study examining trait influences, including reinvestment, and even fewer studies have investigated whether the influence of trait anxiety on gait is mediated by attention. As there is no direct work done on trait anxiety and attention during gait in healthy individuals, the current literature on state anxiety and attention and few studies on trait anxiety and gait performed on clinical and elder populations were used to inform the current study.

2.3.1 Dual-task effects on posture and gait in healthy young adults

In order to examine the influence of attention on gait, many studies have effectively utilized a dual-task paradigm where individuals perform two tasks simultaneously and outcome performances are compared against baseline (performing each task on its own). It has been argued that simultaneously performing another task (i.e., a cognitive task such as responding to cues) should not impact the performance of one or either task, since the task at hand (i.e., walking) is fully automatic (Yogev-Seligmann et al., 2008). However, this is not the case, as gait is not purely automatic and dual tasking has been shown to increase gait variability when walking, as well as worsen performance on cognitive tasks during static balance control (Al-Yahya et al., 2011; Kerr et al., 1985).

In early dual task research on the balance control of healthy young adults, Kerr et al. (1985) aimed to understand the link between postural control and cognition by testing both a visuospatial memory task (Brooks spatial matrix) and a non-spatial verbal memory task while either seated or standing. They found that when attention was challenged by performing both the visuospatial memory task and balance task together, there were more errors made when compared to only doing the memory task seated, but no significant differences on posture were found between the two different memory tasks. These findings were significant in determining how attention may impact postural control, which was then further investigated during gait. More recent studies on healthy adults with intact cognitive and motor functions have demonstrated slower gait speed, and increased stride and swing time variability (worsened) under dual task conditions when compared to single task (Al-Yahya et al., 2011; Hausdorff et al., 2008). Specific studies have commonly used non-spatial cognitive tasks such as serial subtractions (i.e., counting backwards by 3 or 7) and phoneme monitoring while walking to increase demand of cognitive processing streams during walking (Hausdorff et al., 2008). In general, when cognitive tasks are performed in combination with gait tasks, cadence and speed decreases, while stride time and variability increase as compared to the gait task alone (Al-Yahya et al., 2011; Hausdorff et al., 2008). These results suggest that attentional load may impact gait but have not discussed its role on the relationship between anxiety and gait. It is therefore important to further investigate how attention may mediate any anxiety-dependent outcomes on gait. By combining the dual task paradigm with height-induced state anxiety, this thesis aimed to understand the role of attention under various gait outcomes during walking.

2.3.2 Conscious Control of Movement

Masters & Maxwell put forward a theory of reinvestment in 2004, suggesting internal and external focuses of attention during locomotion can impact human movement outcomes. An internal focus of attention, or conscious movement processing, requires an individual's attention to be internalized on movement regulation, or self-control of the thoughts or emotions regarding attaining personal goal-directed movement outcomes (Masters & Maxwell, 2008; Panayiotou & Vrana, 2004). As gait tasks increase in difficulty (for example, during high postural threat), it is suggested that there is also increase in internal focus of attention causing gait to become less efficient as individuals compromise automaticity in their movements by attending to the movement execution processes (de Melker Worms et al., 2017; Wulf et al., 2001). For instance, recent work has shown that when subjects were told to consciously process their movements, they found slower gait and increased stance durations during single tasks involving conscious movement processing (Ellmers et al., 2020). Therefore, consciously attending to movements not only have been shown to reduce movement automaticity but also reduces the attentional resources available for completing additional tasks during gait, causing variance from normal uninterrupted gait behaviour (Ellmers et al., 2020; Eysenck et al., 2007).

Additionally, based on work by Eysenck et al. in 2007 on Attentional Control Theory (and Processing Efficiency Theory), it has been noted that worry, a stable aspect of trait anxiety which can predict bodily responses to state anxiety, has been shown to reduce performance effectiveness and efficiency in stressful situations. It has been argued that individuals with high trait anxiety will experience elevated levels of worrying in general, which can be exacerbated during situations of high stress as worrisome thoughts (from anxiety) may consume the limited attentional resources of working memory and reduce the amount necessary for cognitive task processing (Eysenck et al., 2007).

Zaback et al., considered various traits as predictors of postural control when standing at low vs high threat conditions, as well as when rising to toes on an elevated platform. Some of the predictors that were considered in their model were trait anxiety, as well as aspects of trait reinvestment measured by conscious movement processing and movement self-conscious. It was found that higher movement self-consciousness scores were associated with a likeliness to sway at smaller amplitudes, whereas higher conscious movement processing was associated with larger sway amplitudes during high postural threat (Zaback et al., 2015). This may be because having an internal focus of attention may lead to altered balance control (more variability) as automatically controlled movement behaviours may become disrupted if consciously controlled.

Further studies utilized the postural threat paradigms to understand the impacts of movement specific reinvestment during locomotion (conscious movement control) (Ellmers & Young, 2018; Young et al., 2016). In Young et al.'s work, conscious movement processing was assessed by determining whether participants would stop walking while talking about aspects of their movement (i.e., by being asked probing questions about their movements while walking) (Young et al., 2016). When compared to no threat conditions, internal awareness (via conscious movement control) was present during postural threat trials, demonstrating another example of attentional changes concurrent with fall-related anxiety (Young et al., 2016). Thus, when individuals shift their focus more on ensuring they do not fall, they may experience a cognitive overload that results in variance from normal gait. These results support the idea that there must be a cognitive correlate to gait control, which may be an explanation of the possible impacts of trait anxiety on gait.

In contrast to having an internal focus of attention from reinvestment, an external focus of attention relates to an individual’s attention being attuned to something in the external environment and is either relevant to the movement task, mitigating interference, or distracting to the task and cognition (Masters & Maxwell, 2008; Wulf et al., 2001). The relationship between external focus of attention and gait has been seen when healthy young individuals performed a dual task (backwards serial subtractions) while walking (Ellmers et al., 2016). This study found that those who had higher movement self consciousness traits had more external focuses of attention (i.e., fixations on task-irrelevant cues) outside of the walking task at hand, as well as slower walking task completion rates (Ellmers et al., 2016). The findings suggest that both internal and external focuses of attention will occupy attentional processing capacity; however, internally focused movements from reinvestment may increase external task-irrelevant fixations which will further exacerbate gait impairments (Ellmers et al., 2016). Therefore, movement reinvestment is critical to understanding how both internal and external focuses of attention may vary based on traits related to the cognitive control of gait and respective gait outcomes. Overall, there is still poor understanding of the role of attention with respect to trait anxiety during situations of state anxiety, which is the final objective of this thesis.

2.4 Summary

While there is much research examining the effects of state anxiety from postural threat on balance and stability, there is less literature understanding the effects on walking. Particularly, there is a paucity of literature regarding possible gait changes of trait anxious individuals under situations that evoke state anxiety. Additionally, although there have been recent studies understanding the impact of trait anxiety in the absence of threat, there is much less literature examining this relationship in healthy young adults which is a large focus of this thesis. The work that has investigated the effect of trait anxiety on gait focused only on individuals with clinical anxiety or in clinical populations, neither of which generalize the healthy young adult population. This thesis was the first study to our knowledge to examine whether levels of trait anxiety predict gait behaviour.

Intriguingly, there is no current literature that examines how trait anxiety impacts attention during locomotion in healthy adults, which is where this thesis aimed to fill gaps on emotional-cognitive interference during gait. There is accumulating evidence that attention may mediate the relationship between state and trait anxiety, yet a gap remains with respect to gait. Most of this research to date has been done during standing postural control rather than in gait. Commonly used methods that have been shown to be reliable and valid for both healthy and clinical populations in evoking state anxiety include inducing postural threat (from elevated platforms). However, it is more feasible to employ height-induced threat to manipulate state anxiety using fully immersive virtual reality (VR) to stimulate these situations safely within this thesis. Therefore, this thesis used VR to induce height-induced postural threat and manipulating dual task conditions on trials that will challenge attentional allocation during gait.

Insight into emotional-cognitive interference on gait, specifically the role of attention, will be beneficial for holistic care and long-term rehabilitation in a variety of clinical, psychiatric and neurological populations. For instance, the findings of this work can be further extended to elderly populations, particularly those at risk of falling or freezing of gait, whereby we may manage symptoms of anxiety and prevent falls from occurring. By understanding how trait anxiety may exacerbate situational factors and alter gait control, it can also open avenues for future research on neurodegenerative disease populations. For instance, we may be able to categorize distinct gait signatures derived from anxiety to predict disease progression in elderly or neurodegenerative populations. Ultimately, aiming for more holistic treatments of these conditions by considering how trait anxiety may impact gait and increase risk of falling in these populations.

3.0 Objectives

I. Evaluate the influence of *trait* anxiety on gait in neurotypical adults aged 18-35 during virtual reality (VR) single task walking at the ground level.

H_{A1}: Individuals with higher trait anxiety will experience increased step length variability, slower gait, and spend more time in double limb support (DLS) phases during walking.

II. Evaluate the influence of *trait* anxiety on gait during situations that provoke *state* anxiety (VR-stimulated) in neurotypical adults aged 18-35.

H_{A2}: All individuals will experience increased step length variability, slower gait, and spend more time in double limb support during the state anxiety-provoking situations; this effect will be further pronounced based on trait anxiety levels.

III. Examine the role of attention on the relationship between trait and state anxiety on gait by contrasting dual task (DT) and single task (ST) performance.

H_{A3}: Gait variability will be greater, more time in double support will be spent, and gait will be slower in the DT (high attention) compared to ST (low attention) conditions, independent of and in addition to effects of state to trait anxiety levels. The most pronounced effects will be seen when examining the high threat/dual task condition.

4.0 Methods

4.1 Study Participants

Thirty participants (13 male, 17 female) aged 19-28 (mean age 23 ± 2.3 years) were recruited from the University of Waterloo community by word of mouth and recruitment posters (see Appendix A). Participants were all able to walk freely/unassisted, communicate in English, and had normal to corrected normal vision. They were also free of pre-existing physical conditions (i.e., major surgery and trauma within last 12 months, cardiovascular disease, vestibular issues or any other physical conditions impacting locomotion) and mental health problems (such as depression, anxiety, mania) as diagnosed by a healthcare professional, and not on medications for these mental health conditions. In addition, participants were also non-smokers, and were not recreational drug users, as these variables have been shown to influence the relationship between attention and anxiety (Hanson et al., 2011; Ishigami et al., 2016).

4.2 Study Design

This study used a repeated measures design and consisted of a baseline questionnaire collection period, and 4 blocked conditions for VR walking trials in increasing order of difficulty as follows: 1) single task walking at the ground level; 2) dual task walking at the ground level; 3) single task walking at the elevated level; 4) dual task walking at the elevated level. The fixed order of trial blocks was selected to minimize effects of potential higher anxiety provoking trials carrying over to the following trials and to maximize the observable effects of subsequently more challenging conditions (Cleworth et al., 2012; Adkin et al., 2000). Trait anxiety levels were measured at the baseline questionnaire collection period, following which gait was collected during the blocked VR walking conditions. Each condition block consisted of 5 trials. Only one session per participant was required to collect data, with the study taking place exclusively in the Faculty of Health Expansion building (EXP) laboratory room 2692. The study was reviewed and received ethics clearance through the University of Waterloo Research Ethics Committee (REB #43418).

4.2.1 Baseline Questionnaire Collections

All participants provided written (signed) informed consent prior to participating in the study. After consent, participants completed the Simulator Sickness Questionnaire (SSQ) (see Appendix A) indicating levels of nausea and general discomfort symptoms prior to VR immersion (Kennedy et al., 1993). The SSQ has 16 items scored on a 0-3 scale where 0=no symptoms, 1=slight, 2=moderate, and 3=severe symptoms of nausea, oculomotor or disorientation (Kennedy et al., 1993). It is scored by summing each category and then applying a multiplier of 3.74 to get a total score (Kennedy et al., 1993) (see Appendix A for scoring).

A series of questionnaires were used to assess baseline trait anxiety, state anxiety, depression, and fear of heights. Attention and attentional set shifting were also assessed to ensure healthy cognitive functioning within the sample by comparing against established normative values. Baseline balance confidence and cognitive task performance were also assessed during this time, in addition to the collection of anthropometric measures (height, weight, leg length). The difference between left and right leg lengths were below 2cm for all participants.

To obtain trait and state anxiety levels, which were obtained at baseline, participants completed the State and Trait Anxiety Inventory (STAI). To assess trait anxiety, STAI form Part Y-2 (Self Evaluation Questionnaire) was used, which has good test-retest reliability (r=0.73-0.86) and internal consistency (alpha=0.91-0.92) in college-aged individuals (Spielberger, 2010, Spielberger et al., 1983). This test has 20 questions relating to feelings of anxiousness, each assessed on a 4-point Likert scale with responses ranging from “almost never” to “almost always”. Questions assess how often in general participants experience feelings relating to anxiety, with total scores ranging from 20-80; higher scores reflect higher levels of trait anxiety. To assess state anxiety levels, STAI form Part Y-1 was used with the same 4-point Likert scale as Part Y-2; however, these questions assess the anxiousness of the participant at the current moment with total scores between 20-80 where higher scores reflect higher levels of state anxiety. Both STAI Part Y-1 and Y-2 are included in Appendix A, including the scoring methods.

To assess depression levels in the sample, the Hospital Anxiety and Depression Scale (HADS)-D was used. The HADS-D has 7 questions that can be allotted 0-3 points per response; a 0 would indicate little to no impact of depressive symptoms and 3 would indicate more severe impacts of depressive symptoms on the participants. The HADS-D has been validated for use in young and elderly adult populations with good test-retest reliability (r=0.86) and internal consistency (alpha=0.79) across age groups (Spinhoven et al., 1997). Scores can range from 0-21 with scores of 0-7 indicating normal levels, 8-10 borderline abnormal, and 11-21 indicating abnormal levels of depression (see Appendix A).

Fear of heights was assessed using responses from a single 10-point Likert scale where participants were asked to “rate [their] fear of heights from 1-10 with 1 being not scared at all to 10 being extremely scared” at baseline, prior to commencing walking trials. A higher score on this question would indicate higher fear of heights.

The confidence to maintain balance and avoid a fall was recorded at baseline on a scale ranging from 0% (not confident at all) to 100% (completely confident), as used in prior work on postural control (Zaback et al., 2015; Huffman et al., 2009; Cleworth et al., 2012; Cleworth et al., 2016) (this scale can be viewed in Appendix A).

The Trail Making Test parts A (TMT-A) and B (TMT-B) were used to assess and ensure normative cognitive functioning at baseline, specifically attention (part A) and attentional set shifting (executive functioning) (part B), based on the normative values for completing each part of the test (Tombaugh, 2004). This task requires participants to connect circles containing numbers from 1-25 (Part A) as fast as possible; in Part B, participants connect both numbers (1-13) and letters (A-L) while alternating between them each time. The normative reference values for individuals aged 18-34 to complete the tasks were a maximum of 57 seconds for Part A, and 95 seconds for Part B; mean (S.D.) normative values for this age group ranged from 22.93 (6.87)-24.40 (8.71) for Part A, and 48.97 (12.69)-50.68 (12.36) for Part B (Tombaugh, 2004).

Anthropometric measures were taken at baseline including height (cm), weight (lbs), and leg length (cm) within the lab by the student researcher (Pershia Norouzian) and other trained research staff.

4.2.2 VR Walking Trial Collection

Following collection of baseline information, participants remained seated and performed an auditory digit monitoring task where they were required to listen to an audio track and count the frequency of two numbers heard. Seated performance served as a baseline measure of single task performance to compare dual-task performance against during the walking trials (Ehgoetz Martens et al., 2018). The 25-second-long audio track consisted of a randomized presentation order of numbers ranging from 1-9 with interstimulus intervals (i.e., the time between hearing one digit and hearing the next) which were randomly varied from 100ms to 1000ms (Pieruccini-Faria et al., 2014). All trials with the auditory monitoring task (including baseline measure, and walking trials) would randomly play one of two versions of the track with different randomizations of the number presentation orders and interstimulus intervals.

Participants were then fitted with the wireless, VR head mounted display (HMD) (HTC VIVE Pro Eye HMD). The VR-HMD weighs 550g in total and features gyro sensors, a 110-degree field of view, 1440x1600 pixel resolution per eye featuring stereoscopic vision, and a refresh rate of 90Hz to fully immerse individuals in the virtual environment. Field of view focus and eye width was adjusted for each participant. Once fitted, the participants walked around the virtual environment (VE) both on and off the gait carpet to familiarize themselves with the environment until comfortable. The VE displayed in the HMD was a modification of the WorldViz Pit Demo, which was coded using Python and run through Vizard 7 software (WorldViz Inc, CA). The WorldViz Pit Demo was altered such that the plank length was calibrated to the length of the Zeno Walkway, (see **Figures 2, 3** below). The Vizard software was used to connect live tracking of the exact location of VIVE HMD through 2 base stations located along the edges of the laboratory room.

Participants were required to perform 5 walking trials in 4 different VR-stimulated conditions (i.e., 20 trials total), in a blocked order with increasing difficulty (Cleworth et al., 2012). The condition blocks were in the following order: (i) Ground + Single Task (G-ST): participants walked across a plank placed on flat ground; (ii) Ground + Dual-task (G-DT): participants walked across the plank that is located on the ground while simultaneously performing the auditory digit monitoring task, (iii) Elevated + Single Task (E-ST): participants walked across an elevated plank above a deep pit, (iv) Elevated + Dual-task (E-DT): participants walked across an elevated plank while simultaneously performing the auditory digit monitoring task. During the dual-task trials, the participants were asked to equally prioritize both the digit monitoring task as well as the walking task. All trials took place across a 6m Zeno^{TM} Pressure walkway (ProtoKinetics) where participant gait parameters were only recorded between positions A to B (see **figure 2** below). Participants started and ended each trial approximately 1m behind/in front of these points in order to maximize step count while on the carpet. One pass was marked when the participant walked from point A to B and stepped off the carpet by approximately 1m; a single trial was complete when 2 passes were completed (i.e., participant walked from point A to point B and stepped off carpet [1 pass], then turned back and walked until they are 1m off the carpet from point A [2nd pass]). Participants had a standing rest period of at least 30-seconds between trials in order to minimize any carry-over effects between trials. All trials were done in the virtual environment (VE) to keep observed walking patterns consistent.

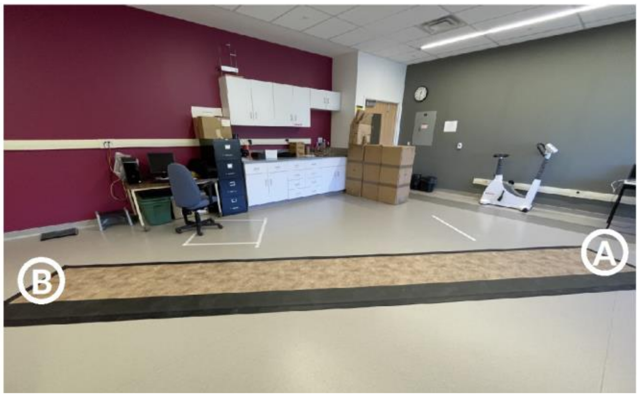
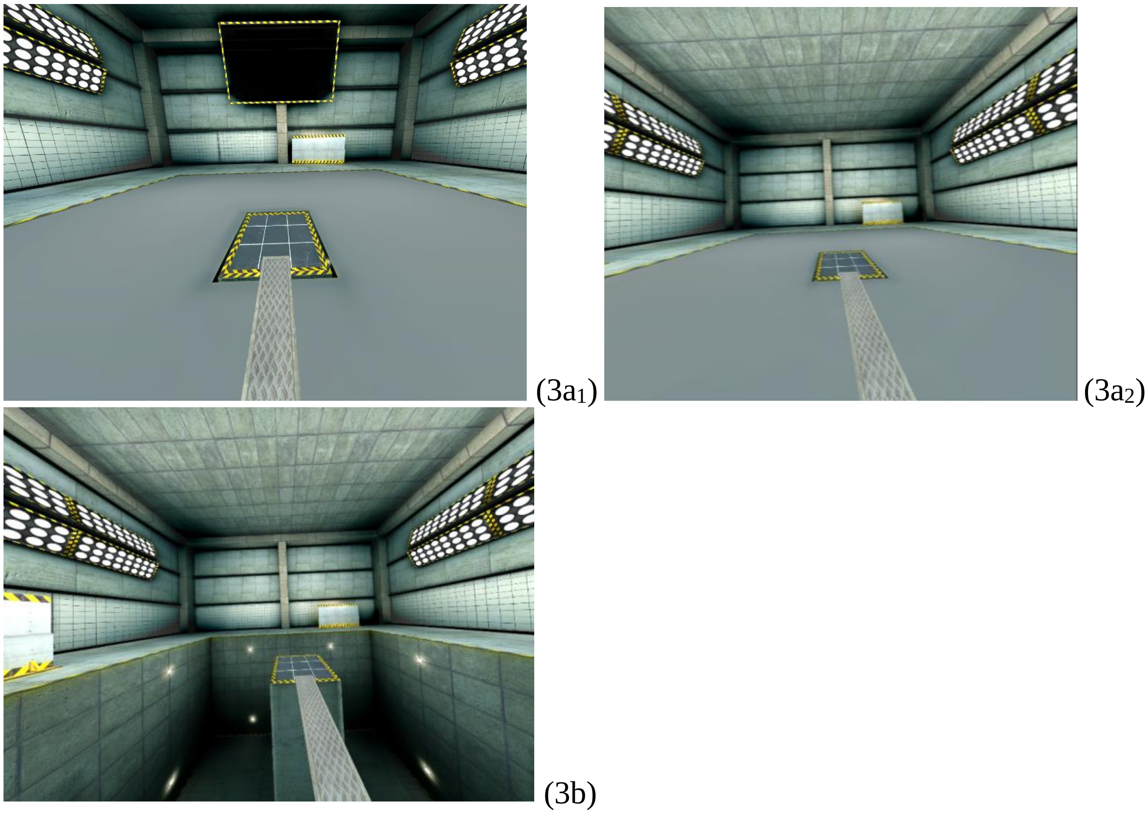


Figure 2. The laboratory setup of AHS room 2692 in the University of Waterloo.


(3a$_1$) (3a$_2$)

(3b)

Figure 3. The virtual environment (VE) viewed from various angles.

(3a$_{1\ \&\ 2}$) show the ground level condition, while (3b) shows the elevated (pit) condition that will be used to evoke state anxiety. (3a$_1$) shows the actual participant's viewing angle while (3a$_2$) and (3b) demonstrate the various elevations/pit level from the exact same viewpoint. The silver metallic ends of the plank are aligned with the real-world location of points A and B from figure 2. As participants step off the metal portion of the plank and onto the square platform marked by hazard lines, they step off the gait carpet in the real-world as well. The length of the square platforms in VE accommodate the real-world 1m distance needed to walk off the carpet that marks the end of 1 pass.

After each individual trial within each condition block, Self Assessment Manikins (SAM) appeared on the screen within the HMD where participants verbally stated their feeling of anxiousness on a scale of 1-9 (see **Figure 4** below) (Bradley & Lang, 1994). After each block of trials (i.e., after all 5 trials within the condition were complete), participants removed the VR headset and completed questionnaires assessing feelings of stability, fear of falling, and task-related anxiety. The participants recorded how stable they felt during the walking task on a scale ranging from 0% (not confident at all) to 100% (completely confident). Fear of falling during the walking task was also reported on a scale ranging from 0% (not fearful at all) to 100% (completely fearful) (see Appendix G for stability and fear of falling scales). Task-related anxiety was reported on a modified Sport Anxiety Scale (SAS) which featured a 16-item questionnaire assessing worry, somatic, and concentration elements of anxiety on 9-point Likert scales (see Appendix A for modified SAS) (Zaback et al., 2015, Huffman et al., 2009; Cleworth et al., 2016). After all four blocks of walking trials were completed, participants completed the Movement Specific Reinvestment Scale (MSRS) and the Gait Specific Attention Profile (GSAP) to examine whether they allocate attention towards or away from their movements during walking (see Appendix A for questionnaires and scoring). Participants also completed the Simulator Sickness Questionnaire (SSQ) again to determine change from pre to post levels of general discomfort and nausea following VR immersion.

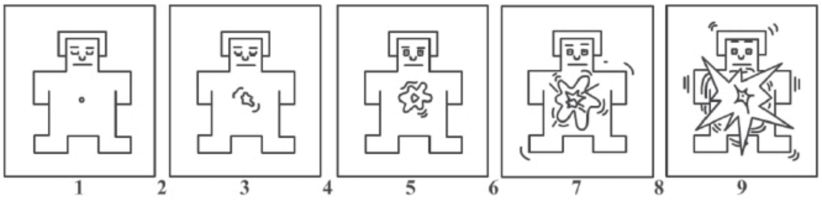


Figure 4. The Self-Assessment Manikin: Nine-point scale assessing arousal (Bradley & Lang, 1994).

Each walking trial took approximately 30 seconds to complete, and collections took approximately 75 minutes to complete from baseline assessments to VR walking trials completion. See figure 5 for schematic of study procedures.

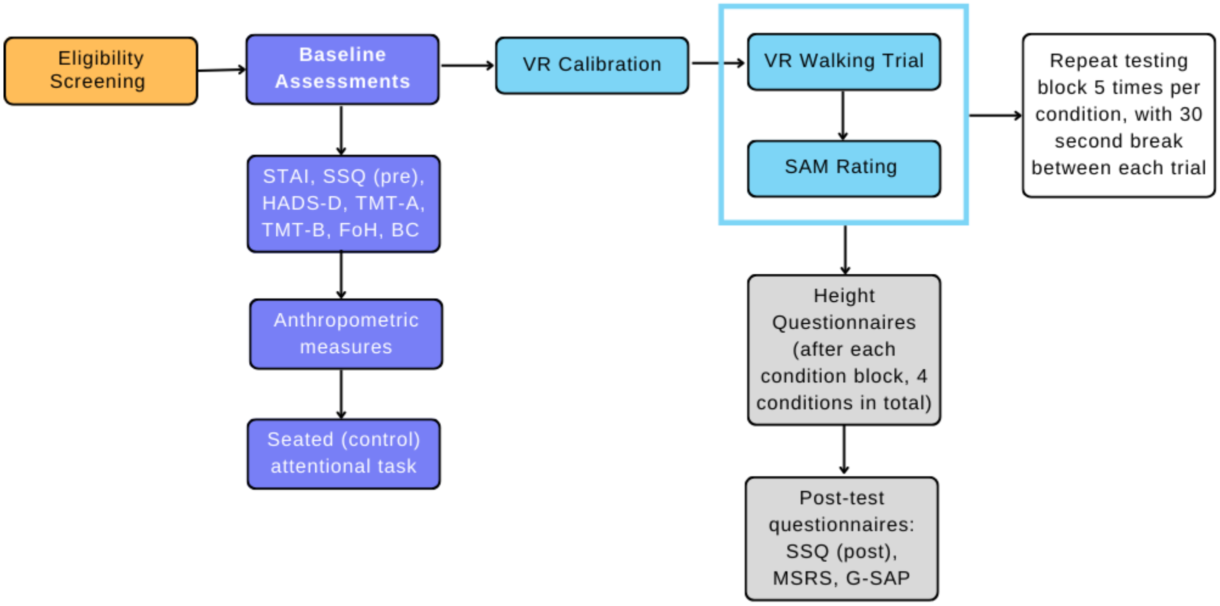


Figure 5. The schematic representation of the experimental procedure.

4.3 Dependent Measures

4.3.1 Gait Behaviour

Key gait variables included in this study were time spent in double support (%) as a percentage of overall gait cycle phase, step length variability (%CV) representing standard deviation of step length over the mean step length, and velocity (distance traveled in cm/time to travel said distance in sec). These variables were measured while participants walked across the ZENO^{TM} Walkway pressure sensor carpet during each experimental trial. The data were then processed and exported to .csv files based on the following a priori considerations using the ProtoKinetics software:

I. Participant video of the footsteps aligned with the correct left and right steps that have been picked up by the PKMAS software.
II. Partial footfalls that were not fully captured on the long or short edges of the gait carpet were removed (including partial footsteps that the PKMAS software had considered full steps) so that the only steps remaining are full steps from heel to toe off.

A total of 600 trials were processed and exported, containing all 20 trials from each of the 30 participants.

4.3.2 Psychological State

To determine whether the threat manipulation adequately induced anxiety across the participants, self-reported anxiety levels were measured using 9-point Self-Assessment Manikin (SAM) following each trial. The SAM has been used in many previous VR studies to verify anxiety rating from stimulated virtual environments (Ehgoetz Martens et al., 2014, 2015a; Xie et al., 2020). Additionally, the 16-item modified SAS questionnaire responses for perceived anxiety after each condition block was used to investigate whether overall anxiety differed from condition to condition; the 16-item modified SAS total scores were summed and compared between the 4 conditions to rationalize this (Adkin et al., 2002). Finally, perceived stability and fear of falling were compared across conditions to confirm whether the postural threat felt realistic enough to evoke these fearful and unstable feelings as though responding to real, perceived threat. These measures have been validated and show good test-retest reliability under testing with postural threat and instability conditions (Hauck et al., 2008).

4.3.3 Dual Task Interference

During the dual task conditions, (G-DT and E-DT) participants were required to equally prioritize gait and the digit monitoring (cognitive) tasks to determine the cost of dual task (DTC) as well as the errors made during each trial. The number of errors made by the participant when asked to count the number of times the participant heard 2 pre-established digits ("i.e., how many 4s and 5s did you hear?") were recorded (Pieruccini-Faria et al., 2014). For instance, if the true number of times "4" appeared was 3 and the true number of times "5" appeared was 4 times, then any guesses more or less than 3/3 and 4/4 would be the number of errors made (i.e., reporting hearing 4/3 "4s" and 3/4 "5s" would result in 2 errors made). The single task score was determined from baseline, seated performance prior to engaging in the walking trials.

The following equation was used to determine DTC for the motor behaviour (velocity), as it has been most commonly reported, based on the work of Doumas et al., (2008):

$$\text{DTC (velocity)} = 100 * [(\text{dual task performance} - \text{single task performance})/(\text{single-task performance})]$$

4.4 Statistical Analyses

The statistical software's RStudio 2022 IDE (RStudio, PBC) and SPSS 27 (IBM Statistics) were used to analyze and graph the results of this experiment with significance level, alpha = 0.05. Demographic and descriptive factors including sex, weight, height, leg length, trait MSC, trait CMP, HADS-D, GSAP, fear of heights, baseline balance confidence, motion sickness, and TMT-A and B times were summarized, and minimum and maximal values were recorded (Table 1). Distributions of the gait outcomes of interest were assessed for normality using Shapiro-Wilk test; the relationship between trait anxiety and the dependent gait and descriptive variables were examined using scatterplots. As the distribution of trait anxiety scores were clustered towards the centre (mean) of data and less towards either extremes, a median split of data (i.e., creating 2 groups of high vs low trait anxiety based on a median score) was not justified. Trait anxiety was treated as a continuous variable in all of the following analyses.

Objective 1. Evaluate the influence of trait anxiety on gait in neurotypical adults aged 18-35 during virtual reality (VR) single task walking at the ground level.

Linear regression models were used to examine the relationship between trait anxiety and the primary gait outcomes of interest (step length variability CV%, velocity (cm/s), mean double support time (%)) during single task walking in VR. Univariate, unadjusted linear regression models were to be used to examine the relationship between trait anxiety and the primary gait outcomes during only the ground level single task walking condition block. The best fitting model for each gait outcome was decided by examining scatterplots, and statistically based on the model which explained the most variance with a significant increase in the R-square change between a less and more complex model, and the lowest standard error of estimate for the model. Trials were averaged across the ground-single task condition, and trait anxiety was mean centered to reduce multicollinearity in the additive transformations for hierarchal (polynomial → quadratic, cubic) regression models. In all cases, the linear models were the best-fitting, least complex models.

To examine whether changes seen in gait were attributed to potential motion sickness from the VR immersion, a paired samples t-test was done to determine the significance of Simulator Sickness Questionnaire totals from pre to post intervention.

Objective 2. Evaluate the influence of ***trait*** anxiety on gait during situations that provoke (VR-stimulated) ***state*** anxiety in neurotypical adults aged 18-35.

Linear regression models were used to examine the relationship between trait anxiety and the primary gait outcomes of interest (step length variability CV%, velocity (cm/s), mean double support time (%)) during elevated single task walking (trials averaged across this condition). Additionally, difference scores were calculated for each of the primary gait outcomes of interest (step length variability, velocity, mean double support time) by subtracting single task performance at ground level from the single task performance at the elevated level to obtain the magnitude effect of single task walking at the elevation. Another set of linear regressions were then completed to obtain the relationship between trait anxiety and the magnitude of change from single task walking at the ground level to the elevated level (i.e., the impact of trait anxiety on the magnitude of the threat effect on walking).

To confirm whether the threat manipulation increased anxiousness 2x2 repeated measures MANOVAs were conducted to examine the effect of the threat condition (high-elevated vs low-ground) and task condition (single task vs dual task) based on psychological state (i.e., arousal – SAM rating, perceived anxiety, fear of falling, stability score). It was expected that self-reported anxiety levels (perceived anxiety, SAM rating, fear of falling) would be highest and that perceived stability would be the lowest in elevated conditions compared to the ground for all participants. Follow-up ANOVAs were completed to understand which measures were significantly different between the ground vs elevated conditions (Table 3).

Objective 3. Examine the role of attention on the interaction between trait and state anxiety on gait by contrasting dual task (DT) and single task (ST) performance.

Difference scores were calculated for each of the primary gait outcomes of interest (step length variability, velocity, mean double support time) by subtracting single task performance from dual task performance at i) the ground level, subtracting single task performance from dual task performance at ii) the elevated level, and finally by iii) subtracting dual task values between high vs low threat dual task conditions in order to get the magnitude of the impact of dual task on the high threat condition. Using these difference scores, 3 separate univariate, linear regression models were then used to examine the relationship between trait anxiety and the primary gait outcomes of interest.

With regards to errors made during dual tasks, a one-way within-participants repeated measures ANOVA was conducted comparing the mean dual task errors between baseline, ground, and elevated conditions.

5.0 Results

5.1 Descriptive Characteristics of the Cohort

All thirty participants who were recruited for the study had full data sets for all walking trials and completed all baseline measurements. Participant characteristics are further detailed in Table 1. When examining central tendencies of trait anxiety within the sample, the average levels were 34.63 (s.d.=8.38) with scores ranging from 20-54; the median was 35 indicating a centrally clustered distribution across participants (skewness = 0.237, kurtosis = -0.398); 9 individuals had scores of ≥40, 11 individuals had scores of ≤30, and 10 individuals had scores between 40 and 30. The mean and standard deviation of trait anxiety of STAI-Y2 scores for this population were similar to the normative values for working adults aged 19-39 of 35.85 (9.64) averaged between males and females, which is slightly lower than that of college students (mean of 39.35 (9.67) averaged between males and female college students) (Spielberger, 1983). Therefore, the sample of participants is well representative of the expected trait anxiety distributions for neurotypical young adults in the general population.

To determine whether participants felt worsening symptoms of discomfort following VR immersion, a paired samples t-test was run. The SSQ scores from pre to post were significantly different (t(29)= -2.045, p=0.010), with a mean pre-SSQ total score of 4.74 (5.97) and mean post-SSQ total score of 9.10 (8.93). As participant scores did not go over a 2 (moderate), with the majority indicating either no or slight levels of discomfort, these scores both still resemble only slight levels of discomfort.

Table 1. Demographics and descriptive statistics for individual characteristics (n=30)

Individual Characteristics	Mean	Standard Deviation	Minimum	Maximum
Age	23.07	2.32	19	28
T-ANX	34.63	8.38	20	54
S-ANX	26.83	6.62	20	46
Height	169.22	11.33	130.0	187.0
Leg Length	89.12	5.81	80.0	100.5
T-CMP	14.50	5.24	5	28
T-MSC	14.10	6.27	5	30
HADS-D	2.37	2.53	0	9
GSAP-A	4.77	1.99	3	10
GSAP-CMP	7.40	3.05	3	12
GSAP-T	5.37	2.31	3	12
GSAP-E	3.83	1.56	2	8
FoH	4.40	2.42	1	10
BBC	89.50	13.02	50	100
∆Motion Sickness	4.36	8.59	-7.48	29.92
TMT-A	18.54	6.45	11.50	39.46
TMT-B Time	38.07	11.73	13.31	68.78
Sex		13M, 17F		

Note: T-ANX = Trait anxiety (STAI-Y2, scale range: 20-80); S-ANX = State anxiety (STAI-Y1, scale range: 20-80); T-CMP =Trait conscious movement processing (MSRS CMP section, scale range: 5-30); T-MSC = Trait movement self-conscious (MSRS MSC section, scale range: 5-30); HADS-D = Depression column of Hospital Anxiety and Depression Scale (scale range 0-21); GSAP-A = Anxiety score of GSAP (scale range: 3-15); GSAP-CMP = Conscious movement processing score of GSAP (scale range: 3-15); GSAP-T = Focus on task irrelevant thoughts from GSAP (scale range: 3-15); GSAP-E = Processing efficiency from GSAP (scale range: 3-15); FoH= Fear of heights (scale range: 1-10); BBC= Baseline balance confidence (scale range: 1-100%); ∆Motion Sickness = the change in SSQ total score post-pre (scale range: 0-2437.88 for either pre or post); TMT-A = Time to complete Trail Making Test Part A in seconds; TMT-B = Time to complete Trail Making Test Part B in seconds.

5.2 Descriptive Characteristics of Trial Conditions

Characteristics of the four conditions are presented in Table 2. Participants averaged 16.04 (2.66) steps per trial with a minimum of 11 and maximum of 32 footfalls recorded across all the trials. All 5 trials within each condition block were included.

The MANOVA for gait outcomes (double support time (%), velocity (cm/sec), step length variability (%CV)) revealed significant main effects of threat conditions (F(3,594)=7.631, p<0.001, n^2=0.037) and task conditions (F(3,549)=18.516, p<0.001, n^2=0.085) for dependent gait variables, the threat by task interaction was not significant (F(3,594)=0.551, p=0.648, n^2=0.003). Follow-up 2x2 (threat x task) within-participants ANOVAs were examined to determine which gait outcomes were significantly different. A main effect of threat was found, which showed that step length variability increased (F(1,29)=9.818 p<0.001, n_p^2=0.052), velocity decreased (F(1,29)=7.721, p<0.001, n_p^2=0.040), and double support time increased (F(1,29)=7.716, p<0.001, n_p^2=0.047) during elevated compared to ground conditions. A main effect of task was found, which showed that step length variability decreased (F(1,29)=5.002 p<0.001, n_p^2=0.010), velocity decreased (F(1,29)=69.18, p<0.001, n_p^2=0.124), and double support time increased (F(1,29)=41.86, p<0.001, n_p^2=0.079) during dual task walking compared to the single task condition (see results summarized in Table 2). Corresponding figure **6** below shows main effects of task and threat for each of the gait variables.

The MANOVA for dependent psychological state variables revealed significant main effects of threat conditions (F(4,593)=40.885, p<0.001, n^2=0.216), and task conditions (F(4,593)=16.614, p<0.001, n^2=0.101). As revealed by 2x2 (threat by task) within-participants ANOVAs, a main effect of threat was found when walking in the elevated as compared to the ground condition, perceived stability decreased (F(1,29)=27.247, p<0.001, n_p^2=0.201), fear of falling increased (F(1,29)=21.421, p<0.001, n_p^2=0.141), perceived anxiety (SAS total score) increased (F(1,29)=25.549, p<0.001, n_p^2=0.147), and self-reported anxiety (SAM) scores increased (F(1,29)=30.915, p<0.001, n_p^2=0.156). When walking at dual task compared to single task, there was no significant main effect of task for stability, fear of falling, and SAM rating; however, perceived anxiety (SAS total score) increased during the dual task when compared to single task (F(1,29)=7.762, p=0.009, n_p^2=0.020).

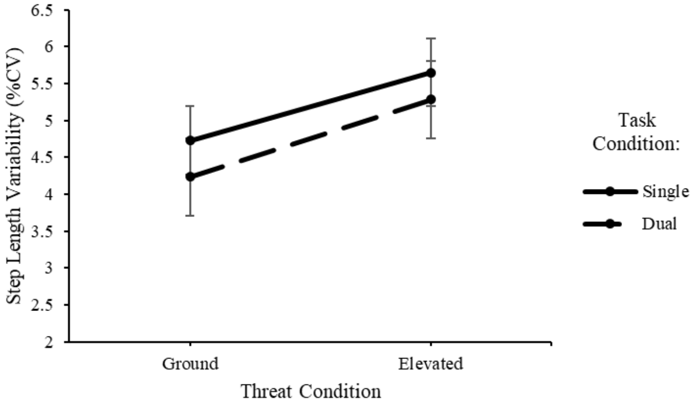
For the errors on the auditory digit monitoring task, one-way within subjects repeated measures ANOVA revealed no significant differences between baseline (seated), low and high threat conditions (F(2,58)=0.189, p=0.828) with baseline errors averaging 1.63 (1.35), low threat (ground-level) errors averaging 1.63 (1.37), and high threat (elevated-level) errors averaging 1.52 (1.29). Further information about trial by condition effects for arousal and each gait outcome variable is included in the supplementary data within the appendices.

Table 2. Mean and standard deviation values for gait and psychological and cognitive state measures

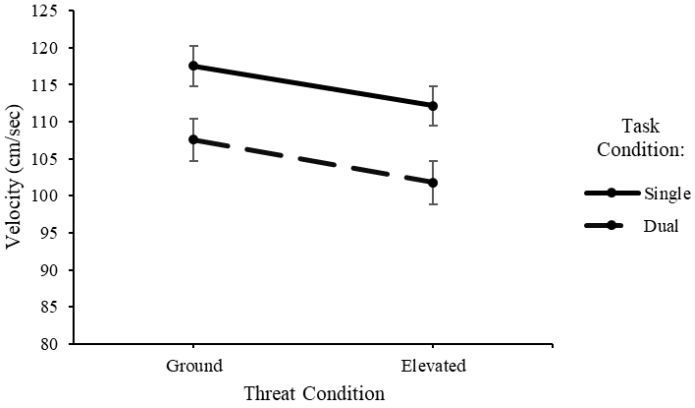
Dependent Measure	Low Threat (Ground)	High Threat (Elevated)	Single-Task	Dual-Task	Threat Main Effect	Task Main Effect	Interaction Effect
Step length variability (%CV)	4.48 (3.04)	5.46 (3.03)	5.19 (3.61)	4.75 (2.41)	***	***	ns
Velocity (cm/sec)	112.54 (12.93)	106.96 (17.10)	114.83 (14.35)	104.68 (14.75)	***	***	ns
Double support time (%)	25.62 (2.11)	26.73 (3.26)	25.44 (2.50)	26.90 (2.90)	***	***	ns
Stability score (%)	91.52 (9.99)	74.12 (22.52)	82.62 (19.73)	83.02 (19.22)	***	ns	ns
Fear of falling score (%)	5.72 (16.05)	23.05 (25.97)	17.07 (25.77)	11.70 (20.10)	***	ns	ns
Perceived Anxiety (sum)	28.53 (11.29)	41.67 (19.64)	32.83 (16.86)	37.37 (17.47)	***	**	ns
SAM Rating (1-9)	1.77 (1.14)	4.07 (1.92)	2.32 (1.74)	2.52 (1.67)	***	ns	* (not interpreted as there was non-significant MANOVA interaction)

*p<0.001 '***', p<0.01 '**', p<0.05 '*', non-significant 'ns'.*

(A) Step Length Variability (%CV)



(B) Velocity (cm/sec)



(C) Double Support Time (%)

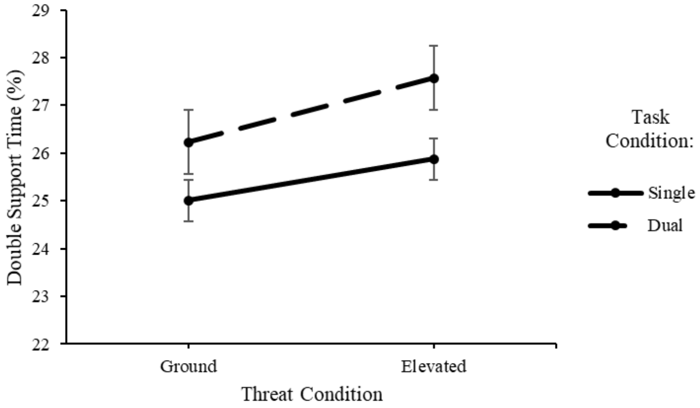


Figure 6. Main effects of threat (ground, elevated) and task (single, dual) conditions for (a) step length variability (%CV); (b) velocity in cm/sec, and (c) time spent in double support phase (%).

5.3 Trait Anxiety and Gait During Single-Task Walking

The influence of trait anxiety on gait behavior during ground level single task walking was examined. Increases in trait anxiety levels were not significantly associated with changes in step length variability ($\boldsymbol{\beta}$=0.228, p=0.226), velocity ($\boldsymbol{\beta}$= -0.034, p=0.860), or double support time ($\boldsymbol{\beta}$= -0.192, p=0.310) (figure 7). Further results are displayed below in table 3.

Extended regression tables detailing polynomial regression models can be found in the Supplemental Data within the Appendices.

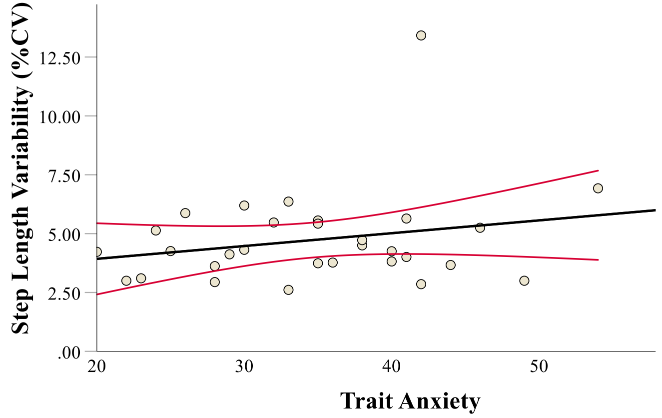
Table 3. Univariate regression model results for gait outcomes (A) step length variability, (B) velocity, (C) mean double support time as dependent on baseline trait anxiety levels during single task walking at the ground level.

Model	**Outcome measure**	**Exposure**	$\boldsymbol{\beta}$	**B (SE)**	R^2	**(95% CI)**	**p-value (regression)**
Linear 1A	Step length CV%	T-anx.mc	0.228	0.054 (0.044)	0.052	(-0.036, 0.114)	0.226
Linear 2B	Velocity (cm/s)	T-anx.mc	-0.034	-0.044 (0.244)	0.001	(-0.544, 0.457)	0.860
Linear 3C	DLS (mean %)	T-anx.mc	-0.192	-0.043 (0.042)	0.037	(-0.128, 0.042)	0.310

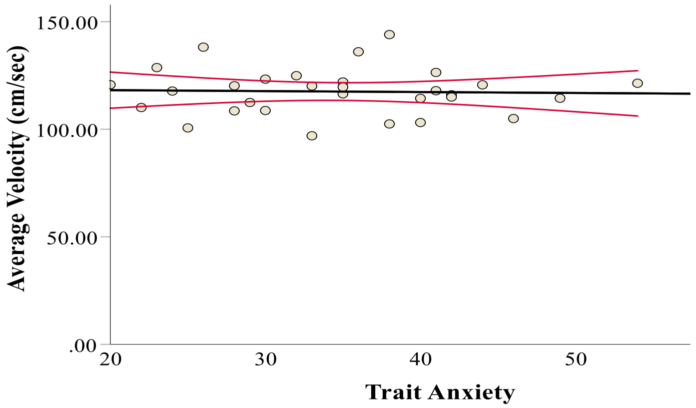
Exposure is the inputted predictor variable: trait anxiety, mean-centered (T-anx.mc).

Figure 7. Regression Plots

7. (A) Step Length Variability (%CV)



7. (B) Average Velocity (cm/sec)



7. (C) Mean Double Support Time (%)

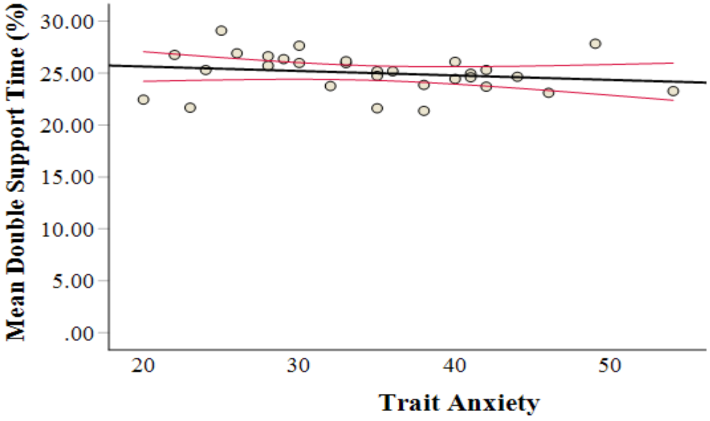


Figure 7. Regression plots for trait anxiety predicting ground-level, single task walking behavior. *These plots show the regression models of trait anxiety levels (on the x axis) in relation to a) step length variability (CV%), b) velocity (in centimetres per second), and c) mean double support time % (on respective y axes) as based on respective linear models. The curved lines around the trend lines show the 95% confidence interval for the fit of the linear regression model. The regression equation of each plot is fit to the linear regression model.*

5.4 Trait Anxiety and Gait During Threat (Elevation)

The influence of trait anxiety on gait in the elevated, single task condition was examined. Higher trait anxiety levels were significantly associated with lower velocity ($\boldsymbol{\beta} = -0.390$, p=0.033). Increases in trait anxiety levels were not significantly associated with changes in step length variability ($\boldsymbol{\beta} = 0.344$, p=0.063), or double support time ($\boldsymbol{\beta} = 0.191$, p=0.312) (figure 8). Further results are displayed below in table 4.

Extended regression tables detailing polynomial regression models can be found in the Supplemental Data within the Appendices.

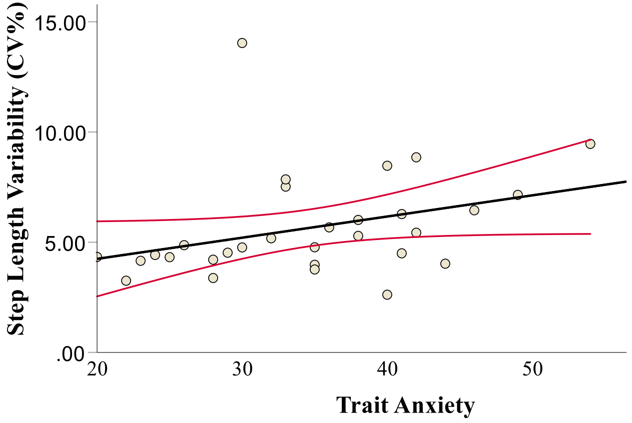
Table 4. Univariate regression model results for gait outcomes (A) step length variability, (B) velocity, (C) mean double support time as dependent on baseline trait anxiety levels during single task walking at the elevated level.

Model	**Outcome measure**	**Exposure**	$\boldsymbol{\beta}$	**B (SE)**	$\boldsymbol{R^2}$	**(95% CI)**	**p-value (regression)**
Linear 4A	Step length CV%	T-anx.mc	0.344	0.096 (0.050)	0.118	(-0.005, 0.197)	0.063
Linear 5B	Velocity (cm/s)	T-anx.mc **	-0.390	-0.716 (0.320)	**0.152***	(-1.371, -0.061)	**0.033**
Linear 6C	DLS (mean %)	T-anx.mc	0.191	0.060 (0.059)	0.037	(-0.060, 0.181)	0.312

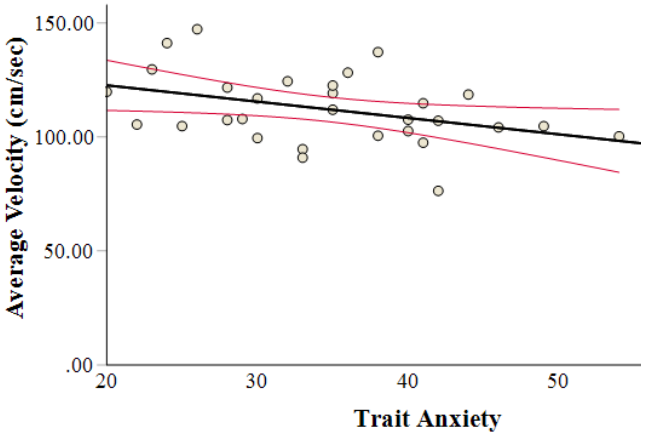
(*) in R^2 column indicates this model had the best fit for the variable based on change in r-squared between each of the models resulting in significance and being the least complex, significant model. (**) in (exposure) column indicates variable is a significant predictor, $p<0.05$. Exposure is the inputted predictor variable: trait anxiety, mean-centered (T-anx.mc).

Figure 8. Regression Plots

8. (A) Step Length Variability (%CV)



8. (B) Average Velocity (cm/sec)



8. (C) Mean Double Support Time (%)

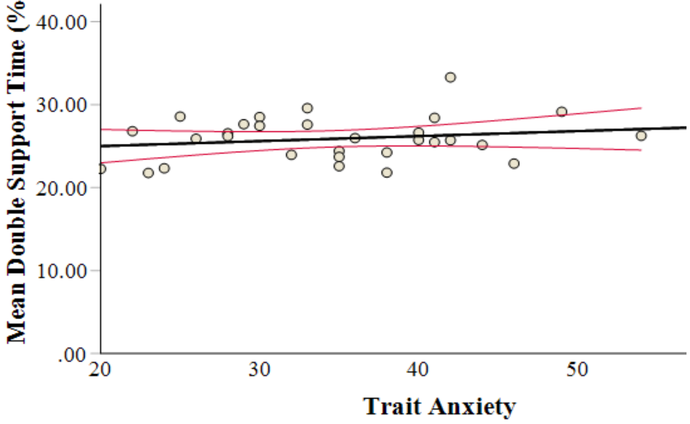


Figure 8. Regression plots for trait anxiety predicting single task walking behavior during elevated (threat) condition. *These plots show the regression models of trait anxiety levels (on the x axis) in relation to A) step length variability (CV%), B) velocity (in centimetres per second), and C) mean double support time % (on respective y axes) as based on respective linear models. The curved lines around the trend lines show the 95% confidence interval for the fit of the linear regression model.*

To further understand the impact of high threat (elevated) condition on single task walking, another set of regression models were examined using the difference scores from the elevated single task and ground single task conditions, resulting in the magnitude of change due to the elevated condition. Higher trait anxiety levels were significantly associated with decreases in velocity ($\boldsymbol{\beta}=$ -0.481, p=0.007) and increased time spent in the double support phase of the gait cycle ($\boldsymbol{\beta}=0.445$, p=0.014) (figure 9). Increases in trait anxiety levels were not significantly associated with changes in step length variability ($\boldsymbol{\beta}=0.153$, p=0.421). Further results are displayed below in table 5.

Extended regression tables detailing polynomial regression models can be found in the Supplemental Data within the Appendices.

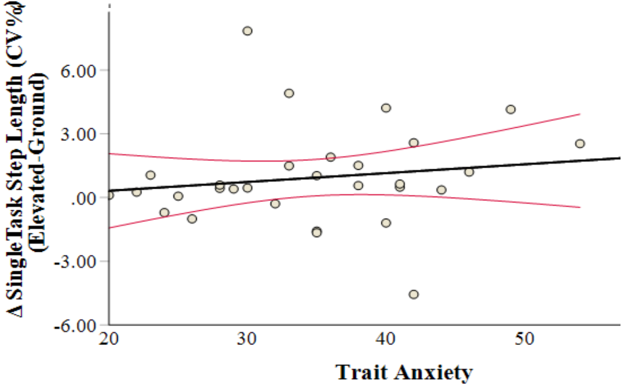
Table 5. Univariate regression model results for gait outcomes (A) step length variability, (B) velocity, (C) mean double support time as dependent on baseline trait anxiety levels when comparing single task walking (difference scores) between elevated and ground single task conditions [magnitude effect of single task walking at elevation based on ground-level single task walking].

Model	**Outcome measure**	**Exposure**	$\boldsymbol{\beta}$	**B (SE)**	R^2	**(95% CI)**	**p-value (regression)**
Linear 7A	Step length CV%	T-anx.mc	0.153	0.042 (0.051)	0.023	(-0.063, 0.146)	0.421
Linear 8B	Velocity (cm/s)	T-anx.mc **	-0.481	-0.673 (0.232)	**0.231***	(-1.148, -0.197)	**0.007**
Linear 9C	DLS (mean %)	T-anx.mc **	0.445	0.103 (0.039)	**0.198***	(0.023, 0.184)	**0.014**

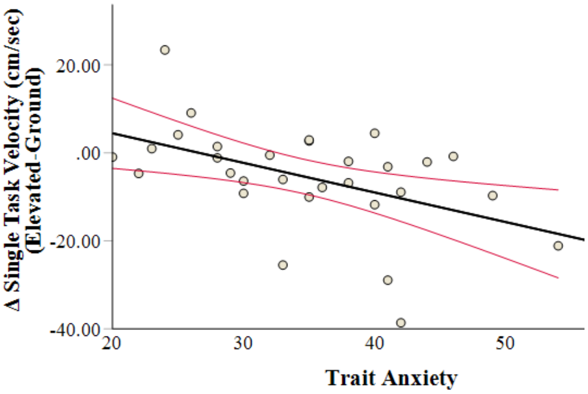
(*) in R^2 column indicates this model had the best fit for the variable based on change in r-squared between each of the models resulting in significance and being the least complex, significant model. (**) in (exposure) column indicates variable is a significant predictor, p<0.05. Exposure is the inputted predictor variable: trait anxiety, mean-centered (T-anx.mc).

Figure 9. Regression Plots

9. ***(A) Δ Step Length Variability***



9. (B) Δ Velocity



9. (C) Δ Double Support Time

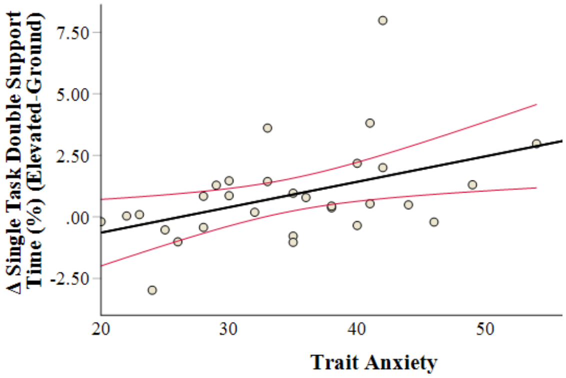


Figure 9. Regression plots for trait anxiety predicting single task walking behavior based on the change from low to high threat. *These plots show the regression models of trait anxiety levels (on the x axis) in relation to A) Δstep length variability, B) Δvelocity (in centimetres per second), and C) Δmean double support time % (on respective y axes) as based on respective linear models. The curved lines around the trend lines show the 95% confidence interval for the fit of the linear regression model. The regression equation of each plot is fit to the linear regression model.*

5.5 The role of attention in the relationship between trait anxiety on gait

To understand the role of attention during walking, the gait outcomes from performing dual task walking on the ground were subtracted from the ground-level single task condition, resulting in the magnitude of change due to dual task. Increases in trait anxiety levels were not significantly associated with changes in step length variability ($\boldsymbol{\beta}$=-0.193, p=0.308), velocity ($\boldsymbol{\beta}$= -0.234, p=0.214), or double support time ($\boldsymbol{\beta}$= 0.125, p=0.511) (figure 10). Further results are displayed below in table 6.

Extended regression tables detailing polynomial regression models can be found in the Supplemental Data within the Appendices.

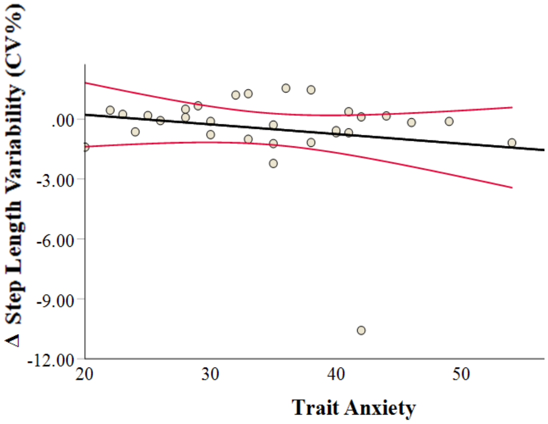
Table 6. Univariate regression model results for gait outcomes (A) step length variability, (B) velocity, (C) mean double support time as dependent on baseline trait anxiety levels when comparing single vs dual task walking (difference scores) at the ground level.

Model	**Outcome measure**	**Exposure**	$\boldsymbol{\beta}$	**B (SE)**	R^2	**(95% CI)**	**p-value (regression)**
Linear 10A	Step length CV%	T-anx.mc	-0.193	-0.048 (0.047)	0.037	(-0.144, 0.047)	0.308
Linear 11B	Velocity (cm/s)	T-anx.mc	-0.234	-0.199 (0.157)	0.055	(-0.520, 0.122)	0.214
Linear 12C	DLS (mean %)	T-anx.mc	0.125	0.014 (0.021)	0.016	(-0.029, 0.056)	0.511

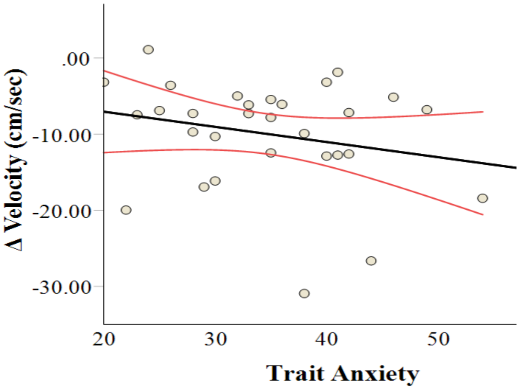
Exposure is the inputted predictor variable: trait anxiety, mean-centered (T-anx.mc).

Figure 10. Regression Plots

10. (A) Δ Step Length Variability (ground)



10. (B) Δ Velocity (ground)



10. (C) Δ Double Support Time (ground)

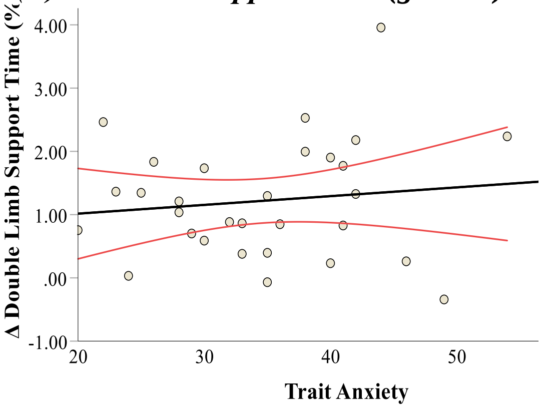


Figure 10. Regression plots for trait anxiety predicting changes gait changes from <u>single to dual task</u> during <u>ground level</u> walking. *These plots show the regression models of trait anxiety levels (on the x axis) in relation to A) Δstep length variability, B) Δvelocity (in centimetres per second), and C) Δmean double support time % (on respective y axes) as based on respective linear models. The curved lines around the trend lines show the 95% confidence interval for the fit of the linear regression model. The regression equation of each plot is fit to the linear regression model.*

Further, the difference scores between single and dual task gait outcomes from walking under threat conditions (elevation) were analyzed. Higher trait anxiety levels were significantly associated with decreases in velocity ($\boldsymbol{\beta} = -0.401$, p=0.028) and increased time spent in the double support phase of the gait cycle ($\boldsymbol{\beta} = 0.404$, p=0.027) (figure 11). Increases in trait anxiety levels were not significantly associated with changes in step length variability ($\boldsymbol{\beta} = 0.172$, p=0.363). Further results are displayed below in table 7.

Extended regression tables detailing polynomial regression models can be found in the Supplemental Data within the Appendices.

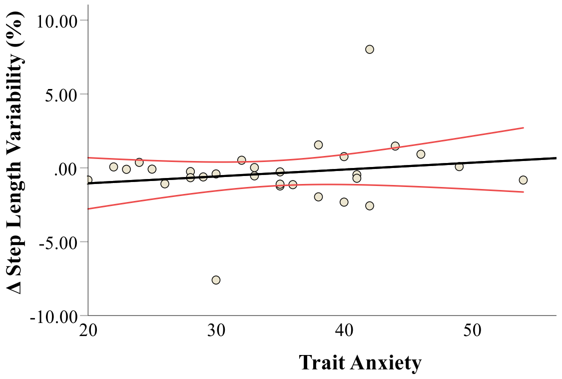
Table 7. Univariate regression model results for gait outcomes (A) step length variability, (B) velocity, (C) mean double support time as dependent on baseline trait anxiety levels when comparing single vs dual task walking (difference scores) at the elevated level.

Model	**Outcome measure**	**Exposure**	$\boldsymbol{\beta}$	**B (SE)**	$\boldsymbol{R^2}$	**(95% CI)**	**p-value (regression)**
Linear 13A	Step length CV%	T-anx.mc	0.172	0.047 (0.050)	0.030	(-0.057, 0.150)	0.363
Linear 14B	Velocity (cm/s)	T-anx.mc**	-0.401	-0.406 (0.175)	**0.161***	(-0.765, -0.047)	**0.028**
Linear 15C	DLS (mean %)	T-anx.mc**	0.404	0.087 (0.037)	**0.163***	(0.011, 0.163)	**0.027**

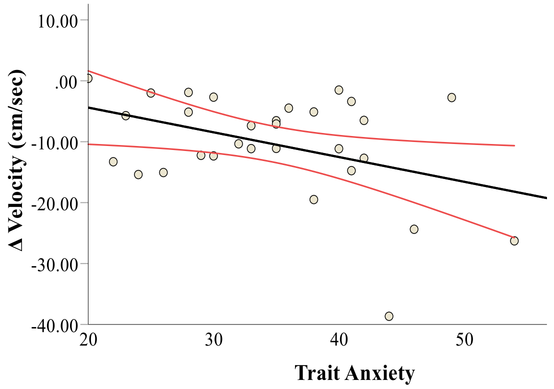
(*) in R^2 column indicates this model had the best fit for the variable based on change in r-squared between each of the models resulting in significance and being the least complex, significant model. (**) in (exposure) column indicates p<0.05. Exposure is the inputted predictor variable: trait anxiety, mean-centered (T-anx.mc).

Figure 11. Regression Plots

11. (A) Δ Step Length Variability (elevated)



11. (B) Δ Velocity (elevated)



11. (C) Δ Double Support Time (elevated)

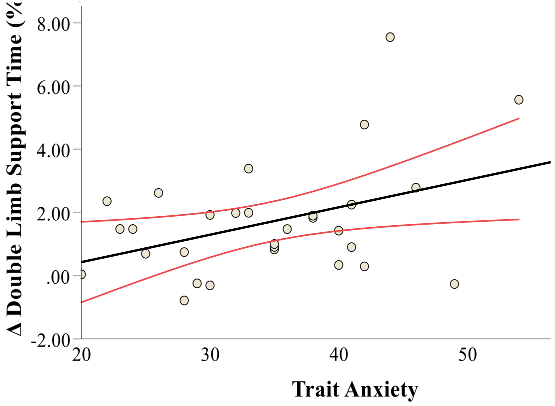


Figure 11. Regression plots for trait anxiety predicting gait changes from single to dual task during elevated level walking (threat). *These plots show the regression models of trait anxiety levels (on the x axis) in relation to A) Δstep length variability, B) Δvelocity (in centimetres per second), and C) Δmean double support time % (on respective y axes) as based on respective linear models. The curved lines around the trend lines show the 95% confidence interval for the fit of the linear regression model. The regression equation of each plot is fit to the linear regression model.*

Finally, difference scores between high and low threat dual task conditions were subtracted in order to get the magnitude of the impact of dual task on the high threat condition. Higher trait anxiety levels were significantly associated with an increase in step length variability ($\boldsymbol{\beta}=0.402$, p=0.028), decreases in velocity ($\boldsymbol{\beta}= -0.626$, p<0.001) and increased time spent in the double support phase of the gait cycle ($\boldsymbol{\beta}=0.565$, p=0.001) (figure 12). Further results are displayed below in table 8.

Extended regression tables detailing polynomial regression models can be found in the Supplemental Data within the Appendices.

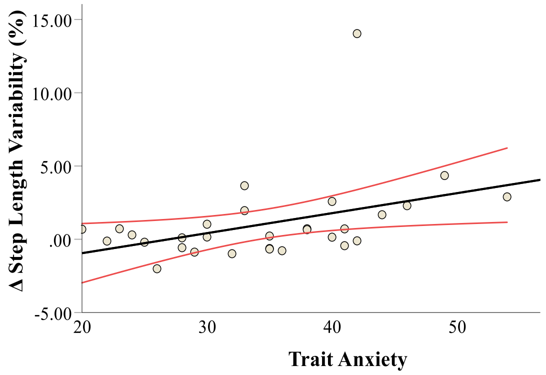
Table 8. Univariate regression model results for gait outcomes (A) step length variability, (B) velocity, (C) mean double support time as dependent on baseline trait anxiety levels when comparing dual task walking (difference scores) between elevated and single task conditions [effect of dual task walking in elevated condition based on dual task walking on ground].

Model	**Outcome measure**	**Exposure**	$\boldsymbol{\beta}$	**B (SE)**	***R*^{2}**	**(95% CI)**	**p-value (regression)**
Linear 16A	Step length CV%	T-anx.mc**	0.402	0.136 (0.059)	**0.162***	(0.016, 0.257)	**0.028**
Linear 17B	Velocity (cm/s)	T-anx.mc **	-0.626	-0.879 (0.207)	**0.391***	(-1.304, -0.455)	**<0.001**
Linear 18C	DLS (mean %)	T-anx.mc **	0.565	0.176 (0.049)	**0.319***	(0.077, 0.276)	**0.001**

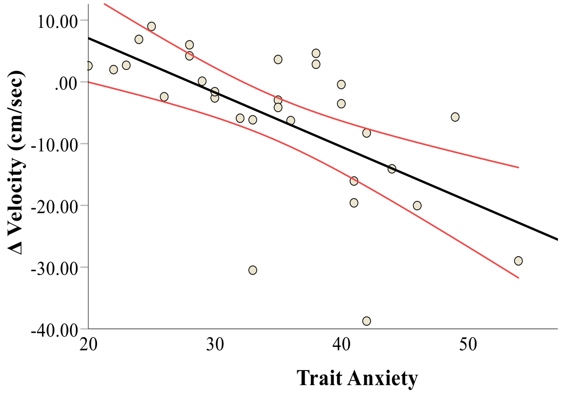
(*) in R^2 column indicates this model had the best fit for the variable based on change in r-squared between each of the models resulting in significance and being the least complex, significant model. (**) in (exposure) column indicates p<0.05. Exposure is the inputted predictor variable: trait anxiety, mean-centered (T-anx.mc).

Figure 12. Regression Plots

12. (A) Δ Step Length Variability (E-DT – G-DT)



12. (B) Δ Velocity (E-DT – G-DT)



12. (A) Δ Double Limb Support Time (%) (E-DT – G-DT)

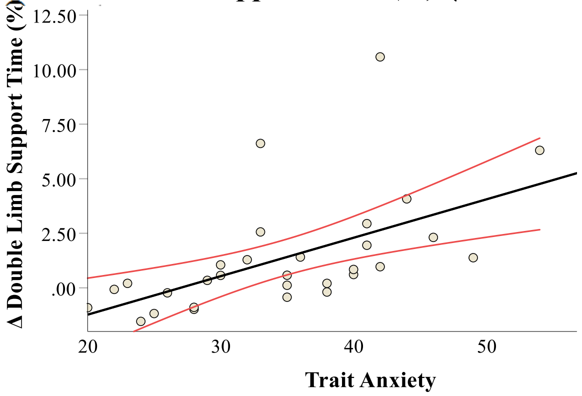


Figure 12. Regression plots for trait anxiety predicting gait changes from <u>ground-level dual task</u> to <u>elevated-level</u> dual task walking. *These plots show the regression models of trait anxiety levels (on the x axis) in relation to A) Δstep length variability, B) Δvelocity (in centimetres per second), and C) Δmean double support time % (on respective y axes) as based on respective linear models. The curved lines around the trend lines show the 95% confidence interval for the fit of the linear regression model. The regression equation of each plot is fit to the linear regression model.*

6.0 Discussion

Executive Summary

To summarize, the threat manipulation was effective at increasing feelings of self-perceived anxiousness since the ratings of anxiety (SAM, SAS) were increased during the elevated conditoins compared to the ground. Additionally, feelings of instability, and fear of falling were also increased during the elevated conditions as compared to the ground. Likewise, the DT was effective at dividing attention, since gait speed was reduced, double support time increased, and steps became more variable, despite the cognitive task errors remaining unchanged from baseline. This might suggest that participants adequately paid attention to the secondary task such that their performance was not compormised, however, their walking behaviours were impacted. To note, first-trial effects were not seen in any gait outcomes, and therefore averaging the trial blocks (i.e., taking the average of all 5 trials per condition) was justified.

The primary and secondary objectives of this study were to first examine the influence of trait anxiety on gait when walking on the ground, and secondly when under postural threat at elevation. It was hypothesized that individuals with higher levels of trait anxiety would walk slower and have more variability in their steps on the ground, which would be further exacerbated when at elevation. Results showed that trait anxiety levels did not impact gait behaviour on the ground level, however, when evoking state anxiety through postural threat at elevation, individuals with higher levels of trait anxiety walked slower and spent more time in double support compared to walking on the ground. As well, an increase in self-percieved anxiousness confirmed that anxiety levels seen in this condition differed from regular ground-level walking conditions, and the impact of this increased situational (state) anxiety on gait was further exacerbated based on trait anxiety levels. These findings suggest that participants with higher levels of trait anxiety may have adopted cautious patterns of gait as seen by reductions in speed and more time spent with a stable base of support (with both feet on the ground).

The third objective of this study was to examine how attentional load may impact the relationship between trait anxiety and gait. It was hypothesized that gait would be altered when dual tasking compared to single task walking, and that this would be more exacerbated when at elevation, as trait anxiety itself may impose increased processing demands in addition to computing both an attentional and threat response. The results did not show an impact of attentional load based on trait anxiety at the ground level; however, performing the dual task at elevation resulted in slower gait and more time in double support as compared to the single task walking at elevation. Further, when comparing the dual task at elevation to the dual task on the ground, individuals with higher trait anxiety levels also experienced more step length variability in addition to slow gait speeds/more time in double support. Both findings show that trait anxiety can impact the way that individuals consume processing resources when challenged with responding to threatening stimuli as well as an attentional task, which results in slower and more variable gait performance.

6.1 Trait anxiety does not impact single task gait in young healthy adults

The primary goal of this thesis was to investigate how trait anxiety can impact the way that indivuals walk. Overall, it was found that trait anxiety did not have an impact on single task walking under conditions of low threat, as would be experienced when walking normally. Specifically, it was found that there was no impact of trait anxiety on gait velocity, double support time, or step length variability. These findings are dissimilar from past work in clinical populations, where people who had anxiety symptoms walked slower than those who did not (Feldman et al., 2019; Ehgoetz Martens et al., 2018). As the young adult population was neurotypical and not faced with cognitive impairments or age-related cognitive changes, gait differences during normal walking may not be apparent. Therefore, it is possible that due to the large/older age range and neurologically impaired population of the samples in previous work, the effects of trait anxiety on gait may have been attributed to cognitive and neural impairments not solely linked to trait anxiety. On the other hand, we can compare the results of our study to previous literature regarding trait anxiety and standing balance in healthy young adults with demographics more similar to our own (Zaback et al., 2015; Hainaut et al., 2011). In these studies, there was no difference in sway area or sway path length between individuals with differing trait anxiety levels when quietly standing without exposure to threats. Efficient postural control was denoted by low sway path length and sway area, which was observed in past work regardless of trait anxiety level (Hainaut et al., 2011). As gait requires dynamic balance control as compared to static balance control experienced during quiet standing, these results give insight into possible gait behaviours during locomotion. Considering that there was no observable difference in postural control efficiency based on trait anxiety in either prior study, the same may hold true when simply walking without external influences of threat. Additionally, these previous studies were done on samples more closely related to the sample used in our study, with the same measure of trait anxiety (STAI Y2), and predominately university-aged students who were recruited from a university campus much like our study. Thus, it is possible that the accepetion of the null hypothesis that trait anxiety does not influence gait or posture or during regular walking and balance control in young adults may be the true case within the population.

Another possible reason for the lack of influence of trait anxiety on single task walking in young adults may be due to the relative simplicity of the task. It has been suggested that gait differences from affect may not be seen without influence of other factors (such as an increased cognitive load) as there is a connection between affective symptoms (anxiety, depression) and executive functioning (Eysenck et al., 2007; Patience et al., 2019). The Attentional Control Theory (ACT) also suggests that the influence of anxiety on tasks is more prevalent when a primary or secondary task requires inhibition or task switching functions of the central executive (Eysenck et al., 2007). ACT further suggests that greater effects of trait anxiety on task efficiency would be seen under more cognitively or emotionally stressful situations. As the simple walking task did not require additional executive functions as would be seen from dual tasking, nor was it emotionally stressful, there was no observable effect of trait anxiety on gait behaviour. When considering the lack of influence of trait anxiety on gait during single tasks, it is possible that without converging attentional streams (i.e., from threat or from tasks, as were the second and third objectives of this study), the gait responses of young neurotypical individuals do not differ based on personality traits like anxiety. Thus, single-task walking alone may not be enough to evoke increased cognitive load that would differentiate how people with higher levels of trait anxiety could walk differently.

Finally, recent studies investigating other affective conditions, such as depression, on gait in young adult populations have also indicated that there is no association between depressive or affective symptoms (measured by Positive and Negative Affect Schedule and Beck Depression Inventory 2nd Edition) with gait velocity during a 10-metre-walk-test (Kumar et al., 2021). In general, depression and trait anxiety are highly correlated, as was also indicated from the exploratory findings within our study (see appendices). The literature on depression and gait in young adults further suggests again that there may be age-related differences when investigating affective conditions and gait, as young adults have different cognitive features than older adults which could interfere with gait (Kumar et al., 2021). These findings further suggest that young adults with affective conditions such as anxiety or depression may not walk differently as they are able to execute gait more automatically with minimal cognitive interference. Although depression was not formally entered as a predictor in any of the models for gait in this study, due to high correlation to trait anxiety, the lack of influence on gait behaviour may be similar. Overall, the findings suggest that the influence of trait anxiety on gait may be more apparent in young adults when they are tasked with stimuli that evokes stress or requires executive functioning.

In summary, trait anxiety was not a significant predictor of gait behaviour during regular walking. This may be due to the fact that they were not put under challenging enough conditions to evoke stress-responses in trait anxious individuals, which is addressed within my second objective.

6.2 Trait anxiety does impact gait in threatening situations in young healthy adults

The second objective of this study was to understand the impact of trait anxiety on gait when walking under threatening conditions. This objective builds from the primary objective as the simple walking task may not have been challenging or stressful enough to evoke gait differences based on trait anxiety levels. It was hypothesized that higher trait anxiety levels would result in slower speeds, spending more time in double support and increased step length variability when walking under threatening conditions. The findings demonstrated that when participants walked in the high threat condition, higher levels of trait anxiety did predict a decrease in velocity and increase time spent in double limb support as compared to regular walking, with no impact on variability.

Based on the current literature to date, this study was the first to determine that trait anxiety can predict gait behaviour during state-anxiety provoking situations in young adults. The results of this study partially supported the outlined hypotheses, and are in line with previous literature regarding state anxiety responses at elevation, with and without influences of trait anxiety (Delbaere et al., 2009; Brown et al., 2002; Ehgoetz Martens et al., 2015a). Previous studies that were conducted on young adults with similar ages and characteristics as this thesis study, also demonstrated a decrease in velocity when walking at elevation (under state anxiety provoking conditions) (Delbaere et al., 2009; Brown et al., 2002). While the effect of walking at elevation on velocity was observed and predicted by trait anxiety levels in our study, neither of the two previous studies noted whether there were trait-based differences in gait at elevation. Only one study used a very similar apparatus with VR-stimulated elevation to evoke state anxiety and determine how trait anxiety could exacerbate gait responses to height; however, this was done on an elderly population with Parkinson’s Disease (PD) (Ehgoetz Martens et al., 2015). Interestingly, while it was found again that highly trait anxious individuals walked slower when at elevation, it was speculated that there may not have been the same results in healthy controls with anxiety (Ehgoetz Martens et al., 2015). This is because they suspected the differences between trait anxiety on gait in the PD groups were due in part to basal ganglia damage from the disease which impacts limbic and motor circuit connectivity through the nucleus accumbens (Ehgoetz Martens et al., 2015). However, our current study was able to identify trait-based differences in healthy, young adults using a similar threat paradigm, suggesting there may be a neural basis of trait anxiety alone that could also influence motor output in stressful situations. Similar to what is seen in major anxiety disorders, there may be greater reactivity of the amygdala and its rostral and caudal projections to the limbic cortex and dorsolateral prefrontal cortex which are involved in sensory integration and conscious control of locomotion (Staab et al., 2013). As gait requires the integration of vestibular, visual, and proprioceptive (somatosensory) sensory inputs, various stimuli may alter gait responses (Beurskens et al., 2012). By modifying the integration of visual inputs to focus on the threatening response (i.e., staying on the plank to avoid falling), gait may become more “cautious” (i.e., slower) through the vestibulo-parabrachial nucleus network (Balaban & Thayer, 2001). This can be explained through the caudal projections of the parabrachial nucleus to vestibular nuclei which mediates anxiety responses to locomotion, as well as noradrenergic pathways from the locus coeruleus to mediate arousal on vestibular reflex performance and motor activity (Balaban, 2002). Both the vestibulo-parabrachial network and coeruleo-vestibular network mediate posture and balance during anxiety changes and may highlight the neurological underpinning of anxiety-mediated responses on gait (Balaban, 2002). Additionally, it is also documented within ACT that under threatening conditions, individuals with high trait anxiety experience greater impacts of state anxiety as they preferentially attend towards the threat rather than to the primary task of walking from one point to another (Eysenck et al., 2007). Overall, under threat, trait anxious individuals will still perform the task effectively by completing the walking trial, however with a reduced movement efficiency that could be seen from the slower walking speeds in our study.

Finally, the primary distinctions of our study’s findings come from methodological changes addressing previous studies limitations when examining trait anxiety on standing balance during anxiogenic situations (Hainaut et al., 2011; Zaback et al., 2015). These previous studies had noted that trait anxiety was not a predictor for eyes-open balance changes during threat, which may have been due to limitations of their study methods (Hainaut et al., 2011; Zaback et al., 2015). For instance, Hainaut et al., (2011) suggested that perhaps changes to postural control were not identified as the Stroop interference task was not challenging enough to evoke state anxiety. Our study used a VR-environment that effectively induced higher levels of self-perceived anxiousness during the elevated conditions as compared to the ground, and saw significant differences between these conditions based on trait anxiety levels. Further, Hainaut et al., (2011) had classified anxiety levels by "very low" or "intermediate" as opposed to examining the effect of trait anxiety as a continous variable as an attempt to predict behaviour, which was done in our current study. Additionally, Zaback et al., (2015) noted trait anxiety differences may not have been seen at elevation as the low threat level was still elevated above-ground (80cm), and suggested that future studies should have low threat conditions be closer to the ground. In our study, the contrast between conditions was more apparent as the virtual plank was laid flat on the ground in the low threat condition and was only virtually elevated above ground in the elevated conditions. Therfore, our current study was able to see significant changes in gait based on trait anxiety by using immersive postural threat paradigms and improving methodological concerns.

Overall, the findings of this study are generally in line with the previous literature on gait behaviour during situational (state) anxiety situations pertaining to postural threat. The study improved some fundamental methodological concerns from previous standing balance studies on trait anxiety responses during quiet standing under postural threat. We were able to identify trait anxiety as a predictor of reduced speed and increased double support time when comparing single-task walking at elevation (high threat) to ground-level walking (low threat). Given that the perceived risk of completing walking tasks at elevation may be higher in individuals with higher trait anxiety levels, it is reasonable that a more cautious and slow gait is adapted in order to avoid falling. However, it still remains to understand whether trait anxiety compromises gait based on cognitive processing differences in healthy young adults, as was examined in the final objective of this study.

6.3 Attentional capacity may be reduced by trait anxiety particularly during threatening situations in young healthy adults which impacts gait control

The final objective of this thesis was to understand whether greater processing demands of dual tasks imposed further detriments in individuals with higher anxiety levels when compared to respective single task performance. This relationship was tested at both the ground and elevated levels to understand whether combining a threatening task with the dual task will further diminish cognitive capacity when computing multiple streams of information and worsen gait. It was hypothesized that higher trait anxiety levels would predict slower gait, more time in double support, and higher variability when comparing dual task conditions to single task at both elevated and ground levels. It was also hypothesized that the greatest detriments to gait would be seen in the elevated, dual task condition as this imposed the greatest processing demands. The influence of trait anxiety on dual task walking has not previously been examined in young adults with trait anxiety, thus, study hypotheses were informed by studies that had examined this relationship in elder adults, as well as adults with PD and high or low levels of trait anxiety (Ehgoetz Martens et al., 2018).

The hypothesis that trait anxiety may impose additional cognitive load while dual task walking was not confirmed at the ground (low threat) level in our study and this opposes findings from previous literature in clinical populations. In previous work, elderly PD patients with higher levels of anxiety walked with more step length variability and reduced velocity than healthy controls when dual task walking in the absence of threat (Ehgoetz Martens et al., 2018). A possible reason this relationship was experienced in PD and not in healthy young adults is due to different cognitive demands. In PD patients with anxiety, it is hypothesized that anxiety poses a limbic load (similar to a cognitive load from dual tasking) via limbic circuitry through the basal ganglia, where dopaminergic neurons are degenerating in the substantia nigra pars compacta and impacting the basal ganglia network (affecting gait) as well (Blandini et al., 2000). Thus, anxious PD patients may have trouble performing two tasks without threat due to the anxiety posing similar cognitive demands as a dual task which would lead to detriments in single task walking that may not be seen in healthy controls. In healthy young adults, their cognition is intact and there is no degeneration of neurons or circuity present to support this explanation of cognitive demand when comparing dual to single task walking. Prior work has also noted that older adults have more limits on cogntive resources available to compute dual tasks than young adults in general, suggesting young adults experience less of an impact of dual task performance (Mahboobin et al., 2007). The same study on postural control utilized a dual task paradigm and noted that compared to older adults, young adults experience faster reaction times and non-significant dual task costs of task switching in the absence of threat (Mahboobin et al., 2007). Further, dual task studies on young adults free of cognitive impairments have also shown that double limb support does not increase when a memory task was done alone while walking (i.e., digit span+walking), and only when interfering with another task (i.e., fine motor task+digit span+walking) (Ebersbach et al., 1995). Both of these findings suggest that simply performing a dual task on its own may not be cognitively challenging enough for young adults to require more attentional demands to perform. Also, most dual task studies use different tasks with varying attentional and motor requirements; however, those with more central processing involved (i.e., task switching, inhibition) may be more impacted by anxiety and in turn, gait may be altered (Eysenck et al., 2007). Overall, young adults free of cognitive impairments may not experience dual task effects in the absence of threat as the task may not be challenging enough alone to require additional executive control processes to complete.

Building from these findings, when examining the role of attention during the elevated (anxiety-inducing) condition in young, healthy adults, the results of this thesis supported the hypotheses. In our study, higher trait anxiety levels predicted reductions in velocity and increased time spent in double support during elevated, dual task walking when compared to single task walking at elevation. Additionally, when comparing the elevated dual task to the ground dual task, gait was more variable (as seen through increase in step length variability). These findings regarding trait anxiety are novel, however, prior work on young adults who walked on elevated walkways while performing a dual task also indicated more time spent in double support and slower velocity compared to ground (Gage et al., 2003). Additionally, a study on young, adult climbers bouldering at elevation examined dual-task (neutral/fear-related word recall) during climbing has also demonstrated a decrease in both climbing efficiency (holds/meter) and distance (m) when tasked with word recall during bouldering above ground (Green et al., 2014). These findings support our hypotheses that emotional stimuli may interfere with motor behaviour during complex tasks requiring cognitive processing, though neither prior study took trait anxiety into account.

Moreover, the competition for cognitive resources is also higher in more challenging environments which involve processing both emotions and cognition that maintain balance and integrate networks involved in sensory-motor processing (Redfern et al., 2017). When considering trait anxiety in the relationship between state anxiety and gait, ACT explains that trait anxiety can reduce performance effectiveness and efficiency in stressful situations (Eysenck et al., 2007). Dual tasks performed under threat may be more challenging as trait anxiety has been related to deficiencies in the executive control network which give rise to the tendancy to constantly direct attention towards sources of threat (Pacheco-Ungetti et al., 2010). These individuals with higher trait anxiety may have impoverished prefrontal control of attention when responding to threatening tasks and maintaing efficient walking behaviour simultaneously (Bishop, 2009). Both changes in processing competition and diverging of attentional focus between the threatening stimuli and cognitive task will slow response time and result in a reduced ability to achieve tasks (Bishop, 2009). This theory was supported in our study as step length variability significantly increased when considering the effect of threat on task, which can reflect lower executive functioning (Holtzer et al., 2012). This finding suggests that the elevated dual-task required more competition for attentional resources to compute than the ground-level dual-task (Nordin et al., 2010). Accordingly, it is reasonable that the greatest gait changes were seen in dual-task, elevated conditions as attention was focused towards attending to threat and walking slower or more “cautiously” to avoid falling. If it is assumed that the processing capacity of multiple tasks is limited, then performance in one or the other must decline in order to effectively complete them both. As attention may be diverted towards the threat under threatening scenarios, in order to maintain cognitive task performance across trials, gait performance became less efficient. In our study, this was seen through reductions in speed, more time with both feet on the ground, and increased step length variability when challenged with computing both a threat and attentional task as opposed to an attentional task in the absence of threat. Therefore, higher anxiety levels may have been indicative of a reduced ability to achieve tasks such as walking with opposing attentional demands from cognitive and affective threatening stimuli, resulting in slower gait patterns.

In summary, the current study did not find that trait anxiety altered gait during dual task compared to single task walking at the ground level. However, higher trait anxiety levels were a significant predictor of slower velocity, longer time spent in double support, and increased step length variability when dual tasking at elevation compared to dual task walking at the ground. Prior work supports the notion that the complexity of the task (i.e., dual tasking at elevated as opposed to ground level) would result in exacerbated gait, and that this difference is also based on individual's capacity to perform the tasks in general (McIsaac et al., 2015). Based on the understanding that trait anxious individuals have reduced capacity to tend to attentional demands, and that the elevation will increase anxiety and impose further demands on attentional allocation, trait anxious individuals have less efficient gait in situations evoking state anxiety and imposing cognitive load. The findings of this current study are in line with these hypotheses, which indicate that trait anxiety may interfere with attentional control in healthy young adults, but only when there are affective (emotional) influences. Additionally, correlational analyses found within the appendices found that trait anxiety was significantly correlated with depression, elements of concious movement processing, processing inefficiences, fall-related ruminations, and a greater fear of heights. Based on Masters & Maxwell's Theory of Reinvestment, and studies highlighting the impact of reinvestment on gait (Ellmers & Young, 2018; Young et al., 2016), it can be noted that increased conscious movement processing could impact gait by reducing velocity and increasing time spent in double limb support by reducing automaticity (Young et al., 2020). This is similar to how individuals with phobic postural vertigo (PPV), a condition arising from postural instability when under posturally threatening conditions, tend to adapt their walking (Brandt, 1966). Individuals with PPV tend to walk slower under height-induced perceptual stimuli and exhibit a reduced cognitive processing speed when dual tasking as they may be allocating more attention to posture than healthy individuals (Schniepp et al., 2014). Both findings suggest that individuals who have a higher tendancy to react to threats (i.e., highly trait anxious, or having PPV) will internally focus more on their movements, disrupting automaticity and resulting in slower walking speeds. Overall, trait anxious individuals may focus more on their gait under threat as there is a fear of falling and concentration on multiple tasked involved, experiencing reduced movement automaticity and disruptions in their gait behaviour. These results, altogether, suggest that having both an increased attentional load and physiological arousal from threat may underly the relationship between trait anxiety on gait.

7.0 Limitations and Future Directions

There are several strengths of our study. The first of which lies in the ability to effectively induce arousal levels through the VR environment while minimizing potential harm and safety risks for the population. Additionally, we used a within-subjects design to understand the impact of trait anxiety on a healthy population when faced with different conditions alternating cognitive load and threat. Finally, we used a neurotypical, young, adult population free of cognitive impairments to reduce aging effects on cognition that may have interfered with gait behaviour during dual task and/or threat conditions.

It is also important to acknowledge relevant and necessary limitations within this study which may be addressed by future work. For example, while the SAM was used to measure self-reported levels of arousal relating to anxiousness, it may have been useful to measure electrodermal activity (EDA)/galvanic skin conductance (GSR) as well to confirm the self reported data. Prior work has used EDA from electrodes placed on the thenar and hypothenar eminances of the non-dominant hand to measure the mean amplitude of the signal to conclude whether arousal levels varied between conditions (Zaback et al., 2015). By coupling self-report with EDA, we would be able to better conclude whether arousal varied between situations, and could tease apart potential arousal differences related to the different dual task conditions as well. Additionally, it is possible that the cognitive task in and of itself was not challenging enough to impose an overload of processing demands which would divert attention away from the task of walking, as the number of errors made across the tasks were consistent across all conditions and did not differ from baseline performance. It is possible that young adults without cognitive impairments may be less likely to experience cognitive overload from increased demands of the environment (i.e., dual tasks) during regular walking, and therefore will respond less to this cognitive probe when there are no competing environmental (external) distractors. A future direction may be to increase the difficulty of the task by introducing elements of task switching perhaps by asking individuals to perform a cognitive and motor task together as this has been demonstrated to increase double support time in healthy adults (Ebersbach et al., 1995). Finally, it could be argued that although prior work has used a fixed order of threat condition presentation (Cleworth et al., 2012; Adkin et al., 2000), this may be a limitation of our work as opposed to a randomized presentation of stimuli.

Overall, this was the first study to investigate how trait anxiety interacts with cognitive load when under situations of threat. Therefore, future studies should be done in more diverse populations with larger samples of people to understand whether attentional load may further alter the relationship between trait anxiety on gait.

8.0 Conclusion & Further Directions

To our knowledge, this study was the first to examine the effect of trait anxiety on walking during state anxiety-inducing conditions, and to combine this with dual tasks. Results suggested that gait velocity was reduced, and double support time was increased by higher trait anxiety levels under posture-threatening conditions, and also when dual tasking during posture-threatening conditions. Additionally, it was seen that step length variability also increased when considering the effect of task on threat (i.e., looking at the dual task at elevation compared to ground). Though, there was no influence of trait anxiety on gait during regular (single task) walking or when considering dual tasking during regular ground level walking. These results suggest that when considering subclinical levels of anxiety, there may not be any impacts seen during simple forms of walking. As higher levels of trait anxiety result in more exacerbated responses during situations of state anxiety, trait anxiety predicting gait behaviour changes during situations of postural threat and not in the absence of threat are in line with this understanding. It appears that during these more challenging scenarios, which may also be representative of the complexities of day-to-day life, the influence of trait anxiety on gait behaviour becomes apparent. Future studies should further investigate the relationship between anxiety and cognition during various walking conditions, with different dual tasks to assess whether ground-level differences in adults may exist with more challenging tasks. As well, future studies should investigate these relationships in elder populations and neurodegenerative populations to further understand the neural underpinnings of the relationship between cognition and emotion on gait. These findings can also be further applied towards elderly individuals who may experience threat-related anxiety from heights such as climbing stairs in order to understand gait behaviour and mitigate fall risk. If trait anxiety also worsens gait behaviour for elderly populations during these conditions, it may be beneficial to implement more holistic treatments that mitigate anxiety symptoms to improve gait efficiency.

Overall, these findings can be used to predict movement control in different situations based on trait anxiety level, attentional demand, and threat, in order to make dynamic human models. Each factor must be considered in explaining how humans walk the way they do when generating predictive gait models within fields of artificial intelligence and human computer interactions.

References

Adkin, A. L., & Carpenter, M. G. (2018). New insights on emotional contributions to human postural control. *Frontiers in Neurology*, *9,* 1–8. https://doi.org/10.3389/fneur.2018.00789

Adkin, A. L., Frank, J. S., Carpenter, M. G., & Peysar, G. W. (2000). Postural control is scaled to level of postural threat. *Gait and Posture*, *12*(2), 87–93. https://doi.org/10.1016/S0966-6362(00)00057-6

Adkin, A. L., Frank, J. S., Carpenter, M. G., & Peysar, G. W. (2002). Fear of falling modifies anticipatory postural control. *Experimental brain research*, *143*(2), 160-170.

Alexander, R. M. (1984). The gaits of bipedal and quadrupedal animals. *The International Journal of Robotics Research*, *3*(2), 49-59.

Al-Yahya, E., Dawes, H., Smith, L., Dennis, A., Howells, K., & Cockburn, J. (2011). Cognitive motor interference while walking: A systematic review and meta-analysis. *Neuroscience and Biobehavioral Reviews*, *35*(3), 715–728. https://doi.org/10.1016/j.neubiorev.2010.08.008

Avanzino, L., Lagravinese, G., Abbruzzese, G., & Pelosin, E. (2018). Relationships between gait and emotion in Parkinson's disease: A narrative review. *Gait and Posture*, *65*, 57–64. https://doi.org/10.1016/j.gaitpost.2018.06.171

Awh, E., Vogel, E. K., & Oh, S. H. (2006). Interactions between attention and working memory. *Neuroscience*, *139*(1), 201-208.

Azevedo, C., Espiau, B., Amblard, B., & Assaiante, C. (2007). Bipedal locomotion: toward unified concepts in robotics and neuroscience. *Biological Cybernetics*, *96*(2), 209-228.

Balaban, C. D. (2002). Neural substrates linking balance control and anxiety. *Physiology & behavior*, *77*(4-5), 469-475.

Balaban, C. D., & Thayer, J. F. (2001). Neurological bases for balance–anxiety links. *Journal of anxiety disorders*, *15*(1-2), 53-79.

Bernstein, N. (1966). The co-ordination and regulation of movements. *The co-ordination and regulation of movements*.

Beurskens, R., & Bock, O. (2012). Age-related deficits of dual-task walking: a review. *Neural Plasticity*.

Bishop, S. J. (2009). Trait anxiety and impoverished prefrontal control of attention. *Nature Neuroscience*, *12*(1), 92–98. https://doi.org/10.1038/nn.2242

Blandini, F., Nappi, G., Tassorelli, C., & Martignoni, E. (2000). Functional changes of the basal ganglia circuitry in Parkinson's disease. *Progress in neurobiology*, *62*(1), 63-88.

Brandt, T. (1996). Phobic postural vertigo. *Neurology*, *46*(6), 1515-1519.

Broadbent, D., & Broadbent, M. (1988). Anxiety and attentional bias: State and trait. *Cognition and Emotion*, *2*(3), 165–183. https://doi.org/10.1080/02699938808410922

Brown, L. A., Doan, J. B., McKenzie, N. C., & Cooper, S. A. (2006). Anxiety-mediated gait adaptations reduce errors of obstacle negotiation among younger and older adults: Implications for fall risk. *Gait and Posture*, *24*(4), 418–423. https://doi.org/10.1016/j.gaitpost.2005.09.013

Brown, L. A., & Frank, J. S. (1997). Postural compensations to the potential consequences of instability: kinematics. *Gait & Posture*, *6*(2), 89-97.

Brown, L. A., Gage, W. H., Polych, M. A., Sleik, R. J., & Winder, T. R. (2002). Central set influences on gait. *Experimental brain research*, *145*(3), 286-296.

Calvo, M. G., & Eysenck, M. W. (1992). Anxiety and Performance: The Processing Efficiency Theory. *Cognition and Emotion*, *6*(6), 409–434. https://doi.org/10.1080/02699939208409696

Carpenter, M. G., Frank, J. S., Silcher, C. P., & Peysar, G. W. (2001). The influence of postural threat on the control of upright stance. *Experimental Brain Research*, *138*(2), 210–218. https://doi.org/10.1007/s002210100681

Clark, D. J. (2015). Automaticity of walking: Functional significance, mechanisms, measurement and rehabilitation strategies. *Frontiers in Human Neuroscience*, *9*(MAY), 1–13. https://doi.org/10.3389/fnhum.2015.00246

Cleworth, T. W., Chua, R., Inglis, J. T., & Carpenter, M. G. (2016). Influence of virtual height exposure on postural reactions to support surface translations. *Gait & Posture*, *47*, 96-102.

Cleworth, T. W., Horslen, B. C., & Carpenter, M. G. (2012). Influence of real and virtual heights on standing balance. *Gait & posture*, *36*(2), 172-176.

Connor, P., & Ross, A. (2018). Biometric recognition by gait: A survey of modalities and features. *Computer vision and image understanding*, *167*, 1-27.

de Melker Worms, J. L. A., Stins, J. F., van Wegen, E. E. H., Loram, I. D., & Beek, P. J. (2017). Influence of focus of attention, reinvestment and fall history on elderly gait stability. *Physiological Reports*, *5*(1), 1–9. https://doi.org/10.14814/phy2.13061

Delbaere, K., Sturnieks, D. L., Crombez, G., & Lord, S. R. (2009). Concern about falls elicits changes in gait parameters in conditions of postural threat in older people. *Journals of Gerontology - Series A Biological Sciences and Medical Sciences*, *64*(2), 237–242. https://doi.org/10.1093/gerona/gln014

Deligianni, F., Guo, Y., & Yang, G. Z. (2019). From Emotions to Mood Disorders: A Survey on Gait Analysis Methodology. *IEEE Journal of Biomedical and Health Informatics*, *23*(6), 2302–2316. https://doi.org/10.1109/JBHI.2019.2938111

Doumas, M., Smolders, C., & Krampe, R. T. (2008). Task prioritization in aging: Effects of sensory information on concurrent posture and memory performance. *Experimental Brain Research*, *187*(2), 275–281. https://doi.org/10.1007/s00221-008-1302-3

Ebersbach G., Dimitrijevic, M.R., Poewe. W. (1995). Influence of concurrent tasks on gait: a dual-task approach. *Perceptual and Motor Skills, 81*(1), 107-113.

Ehgoetz Martens, K. A., Ellard, C. G., & Almeida, Q. J. (2014). Does anxiety cause freezing of gait in Parkinson’s disease? *PLoS ONE*, *9*(9). https://doi.org/10.1371/journal.pone.0106561

Ehgoetz Martens, K. A., Ellard, C. G., & Almeida, Q. J. (2015a). Anxiety-provoked gait changes are selectively dopa-responsive in Parkinson’s disease. *European Journal of Neuroscience*, *42*(4), 2028–2035. https://doi.org/10.1111/ejn.12928

Ehgoetz Martens, K. A., Ellard, C. G., & Almeida, Q. J. (2015b). Virtually-induced threat in Parkinson’s: Dopaminergic interactions between anxiety and sensory-perceptual processing while walking. *Neuropsychologia*, *79*, 322–331. https://doi.org/10.1016/j.neuropsychologia.2015.05.015

Ehgoetz Martens, K. A., Silveira, C. R. A., Intzandt, B. N., & Almeida, Q. J. (2018). Overload from anxiety: A non-motor cause for gait impairments in Parkinson’s disease. *Journal of Neuropsychiatry and Clinical Neurosciences*, *30*(1), 77–80. https://doi.org/10.1176/appi.neuropsych.16110298

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 during adaptive gait. *PLoS ONE*, *11*(11), 1–20. https://doi.org/10.1371/journal.pone.0166063

Ellmers, T. J., Cocks, A. J., Kal, E. C., & Young, W. R. (2020). Conscious movement processing, fall-related anxiety, and thevisuomotor control of locomotion in OlderAdults. *Journals of Gerontology - Series B Psychological Sciences and Social Sciences*, *75*(9), 1911–1920. https://doi.org/10.1093/geronb/gbaa081

Ellmers, T. J., & Young, W. R. (2018). Conscious motor control impairs attentional processing efficiency during precision stepping. *Gait and Posture*, *63*, 58–62. https://doi.org/10.1016/j.gaitpost.2018.04.033

Eysenck, M. W., Derakshan, N., Santos, R., & Calvo, M. G. (2007). Anxiety and cognitive performance: Attentional control theory. *Emotion*, *7(*2), 336–353. https://doi.org/10.1037/1528-3542.7.2.336

Feldman, R., Schreiber, S., Pick, C. G., & Been, E. (2019). Gait, balance, mobility and muscle strength in people with anxiety compared to healthy individuals. *Human Movement Science*, *67*, 102513. https://doi.org/10.1016/j.humov.2019.102513

Gage, W. H., Sleik, R. J., Polych, M. A., McKenzie, N. C., & Brown, L. A. (2003). The allocation of attention during locomotion is altered by anxiety. *Experimental Brain Research*, *150*(3), 385–394. https://doi.org/10.1007/s00221-003-1468-7

Hainaut, J. P., Caillet, G., Lestienne, F. G., & Bolmont, B. (2011). The role of trait anxiety on static balance performance in control and anxiogenic situations. *Gait and Posture*, *33*(4), 604–608. https://doi.org/10.1016/j.gaitpost.2011.01.017

Halovic, S., & Kroos, C. (2018). Not all is noticed: Kinematic cues of emotion-specific gait. *Human Movement Science*, *57*, 478–488. https://doi.org/10.1016/j.humov.2017.11.008

Hanson, K. L., Medina, K. L., Padula, C. B., Tapert, S. F., & Brown, S. A. (2011). Impact of Adolescent Alcohol and Drug Use on Neuropsychological Functioning in Young Adulthood:10-year Outcomes. *Journal of Child and Adolescent Substance Abuse*, *20*(2), 135–154. https://doi.org/10.1080/1067828X.2011.555272

Hauck, Laura J., Mark G. Carpenter, and James S. Frank. (2008) "Task-specific measures of balance efficacy, anxiety, and stability and their relationship to clinical balance performance." *Gait & posture 27*(4), 676-682.

Hausdorff, J. M., Schweiger, A., Herman, T., Yogev-Seligmann, G., & Giladi, N. (2008). Dual-task decrements in gait: Contributing factors among healthy older adults. *Journals of Gerontology - Series A Biological Sciences and Medical Sciences*, *63*(12), 1335–1343. https://doi.org/10.1093/gerona/63.12.1335

Holtzer, R., Wang, C., & Verghese, J. (2012). The relationship between attention and gait in aging: facts and fallacies. *Motor control*, *16*(1), 64-80.

Huffman, J. L., Horslen, B. C., Carpenter, M. G., & Adkin, A. L. (2009). Does increased postural threat lead to more conscious control of posture?. *Gait & posture*, *30*(4), 528-532.

Ishigami, Y., Eskes, G. A., Tyndall, A. V., Longman, R. S., Drogos, L. L., & Poulin, M. J.

(2016). The Attention Network Test-Interaction (ANT-I): reliability and validity in healthy older adults. *Experimental Brain Research*, *234*(3), 815–827. https://doi.org/10.1007/s00221-015-4493-4

Julian, L. J. (2011). *Measures of Anxiety*. *63*(November), 467–472. https://doi.org/10.1002/acr.20561

Kang, G. E., & Gross, M. M. (2016). The effect of emotion on movement smoothness during gait in healthy young adults. *Journal of Biomechanics*, *49*(16), 4022–4027. https://doi.org/10.1016/j.jbiomech.2016.10.044

Kennedy, R. S., Lane, N. E., Berbaum, K. S., & Lilienthal, M. G. (1993). Simulator sickness questionnaire: An enhanced method for quantifying simulator sickness. *The international journal of aviation psychology*, *3*(3), 203-220.

Kerr, B., Condon, S. M., & McDonald, L. A. (1985). Cognitive spatial processing and the regulation of posture. *Journal of Experimental Psychology: Human Perception and Performance*, *11*(5), 617.

Lelard, T., Stins, J., & Mouras, H. (2019). Postural responses to emotional visual stimuli. *Neurophysiologie Clinique*, *49*(2), 109–114. https://doi.org/10.1016/j.neucli.2019.01.005

Mahboobin, A., Loughlin, P. J., & Redfern, M. S. (2007). A model-based approach to attention and sensory integration in postural control of older adults. *Neuroscience letters*, *429*(2-3), 147-151.

Masters, R., & Maxwell, J. (2008). The theory of reinvestment. *International Review of Sport and Exercise Psychology*, *1*(2), 160–183. https://doi.org/10.1080/17509840802287218

McKenzie, N. C., & Brown, L. A. (2004). Obstacle negotiation kinematics: Age-dependent effects of postural threat. *Gait and Posture*, *19*(3), 226–234. https://doi.org/10.1016/S0966-6362(03)00060-2

McIsaac, T. L., Lamberg, E. M., & Muratori, L. M. (2015). Building a framework for a dual task taxonomy. *BioMed Research International*.

Michalak, J., Troje, N. F., Fischer, J., Vollmar, P., Heidenreich, T., & Schulte, D. (2009). Embodiment of sadness and depression—gait patterns associated with dysphoric mood. *Psychosomatic medicine*, *71*(5), 580-587.

Montepare, J. M., Goldstein, S. B., & Clausen, A. (1987). The identification of emotions from gait information. *Journal of Nonverbal Behavior*, *11*(1), 33–42. https://doi.org/10.1007/BF00999605

Nordin, E., Moe-Nilssen, R., Ramnemark, A., & Lundin-Olsson, L. (2010). Changes in step-width during dual-task walking predicts falls. *Gait & posture*, *32*(1), 92-97.

Pacheco-Unguetti, A. P., Acosta, A., Callejas, A., & Lupiáñez, J. (2010). Attention and anxiety: Different attentional functioning under state and trait anxiety. *Psychological science*, *21*(2), 298-304.

Panayiotou, G., & Vrana, S. R. (2004). The role of self-focus, task difficulty, task self-relevance, and evaluation anxiety in reaction time performance. *Motivation and Emotion*, *28*(2), 171-196.

Patience, J., Lai, K. S. P., Russell, E., Vasudev, A., Montero-Odasso, M., & Burhan, A. M. (2019). Relationship between mood, thinking, and walking: a systematic review examining depressive symptoms, executive function, and gait. *The American Journal of Geriatric Psychiatry*, *27*(12), 1375-1383.

Pieruccini-Faria, F., Ehgoetz Martens, K. A., Silveira, C. R., Jones, J. A., & Almeida, Q. J. (2014). Interactions between cognitive and sensory load while planning and controlling complex gait adaptations in Parkinson’s disease. *BMC neurology*, *14*(1), 1-12.

Pirker, W., & Katzenschlager, R. (2017). Gait disorders in adults and the elderly: A clinical guide. *Wiener Klinische Wochenschrift*, *129*(3–4), 81–95. https://doi.org/10.1007/s00508-016-1096-4

Redfern, M. S., Chambers, A. J., Jennings, J. R., & Furman, J. M. (2017). Sensory and motoric influences on attention dynamics during standing balance recovery in young and older adults. *Experimental brain research*, *235*(8), 2523-2531.

Sanders, R. D., & Gillig, P. M. (2010). Gait and its assessment in psychiatry. *Psychiatry (Edgmont)*, *7*(7), 38.

Salthouse, T. A. (2009). When does age-related cognitive decline begin?. *Neurobiology of Aging*, *30*(4), 507-514.

Schniepp, R., Wuehr, M., Huth, S., Pradhan, C., Brandt, T., & Jahn, K. (2014). Gait characteristics of patients with phobic postural vertigo: effects of fear of falling, attention, and visual input. *Journal of neurology*, *261*(4), 738-746.

Spielberger, C. D. (1971). Notes and comments trait-state anxiety and motor behavior. *Journal of Motor Behavior*, *3*(3), 265–279. https://doi.org/10.1080/00222895.1971.10734907

Spielberger, C. D. (1983). *State-Trait Anxiety Inventory for Adults (STAI-AD)* [Database record].

APA PsycTests.

Spielberger, C. D. (2010). State-Trait anger expression inventory. *The Corsini encyclopedia of psychology*, 1-1.

Spinhoven, P. H., Ormel, J., Sloekers, P. P. A., Kempen, G. I. J. M., Speckens, A. E., & van Hemert, A. M. (1997). A validation study of the Hospital Anxiety and Depression Scale (HADS) in different groups of Dutch subjects. *Psychological medicine*, *27*(2), 363-370.

Staab, J. P., Balaban, C. D., & Furman, J. M. (2013). Threat assessment and locomotion: clinical applications of an integrated model of anxiety and postural control. *Seminars in Neurolog*y, *33*(3), 297-306).

Sylvester, C. M., Corbetta, M., Raichle, M. E., Rodebaugh, T. L., Schlaggar, B. L., Sheline, Y. I., Zorumski, C. F., & Lenze, E. J. (2012). Functional network dysfunction in anxiety and anxiety disorders. *Trends in Neurosciences*, *35*(9), 527–535. https://doi.org/10.1016/j.tins.2012.04.012

Tombaugh, T. N. (2004). Trail Making Test A and B: Normative data stratified by age and education. *Archives of Clinical Neuropsychology*, *19*(2), 203–214. https://doi.org/10.1016/S0887-6177(03)00039-8

Woollacott, M., & Shumway-Cook, A. (2002). Attention and the control of posture and gait: A review of an emerging area of research. *Gait and Posture*, *16*(1), 1–14. https://doi.org/10.1016/S0966-6362(01)00156-4

Wu, T., & Hallett, M. (2005). The influence of normal human ageing on automatic movements. *Journal of Physiology*, *562*(2), 605–615. https://doi.org/10.1113/jphysiol.2004.076042

Wu, T., Kansaku, K., & Hallett, M. (2004). How Self-Initiated Memorized Movements Become Automatic: A Functional MRI Study. *Journal of Neurophysiology*, *91*(4), 1690–1698. https://doi.org/10.1152/jn.01052.2003

Wulf, G., Shea, C., & Park, J. H. (2001). Attention and motor performance: Preferences for and advantages of an external focus. *Research Quarterly for Exercise and Sport*, *72*(4), 335–344. https://doi.org/10.1080/02701367.2001.10608970

Xie, T., Cao, M., & Pan, Z. (2020). Applying Self-Assessment Manikin (SAM) to Evaluate the Affective Arousal Effects of VR Games. *PervasiveHealth: Pervasive Computing Technologies for Healthcare*, 134–138. https://doi.org/10.1145/3383812.3383844

Yogev-Seligmann, G., Hausdorff, J. M., & Giladi, N. (2008). The role of executive function and attention in gait. *Movement Disorders*, *23*(3), 329–342. https://doi.org/10.1002/mds.21720

Young, W. R., Ellmers, T. J., Kinrade, N. P., Cossar, J., & Cocks, A. J. (2020). Re-evaluating the measurement and influence of conscious movement processing on gait performance in older adults: Development of the Gait-Specific Attentional Profile. *Gait & Posture*, *81*, 73-77.

Young, W. R., Olonilua, M., Masters, R. S. W., Dimitriadis, S., & Mark Williams, A. (2016). Examining links between anxiety, reinvestment and walking when talking by older adults during adaptive gait. *Experimental Brain Research*, *234*(1), 161–172. https://doi.org/10.1007/s00221-015-4445-z

Zaback, M., Adkin, A. L., & Carpenter, M. G. (2019). Adaptation of emotional state and standing balance parameters following repeated exposure to height-induced postural threat. *Scientific Reports*, *9*(1), 1–12. https://doi.org/10.1038/s41598-019-48722-z

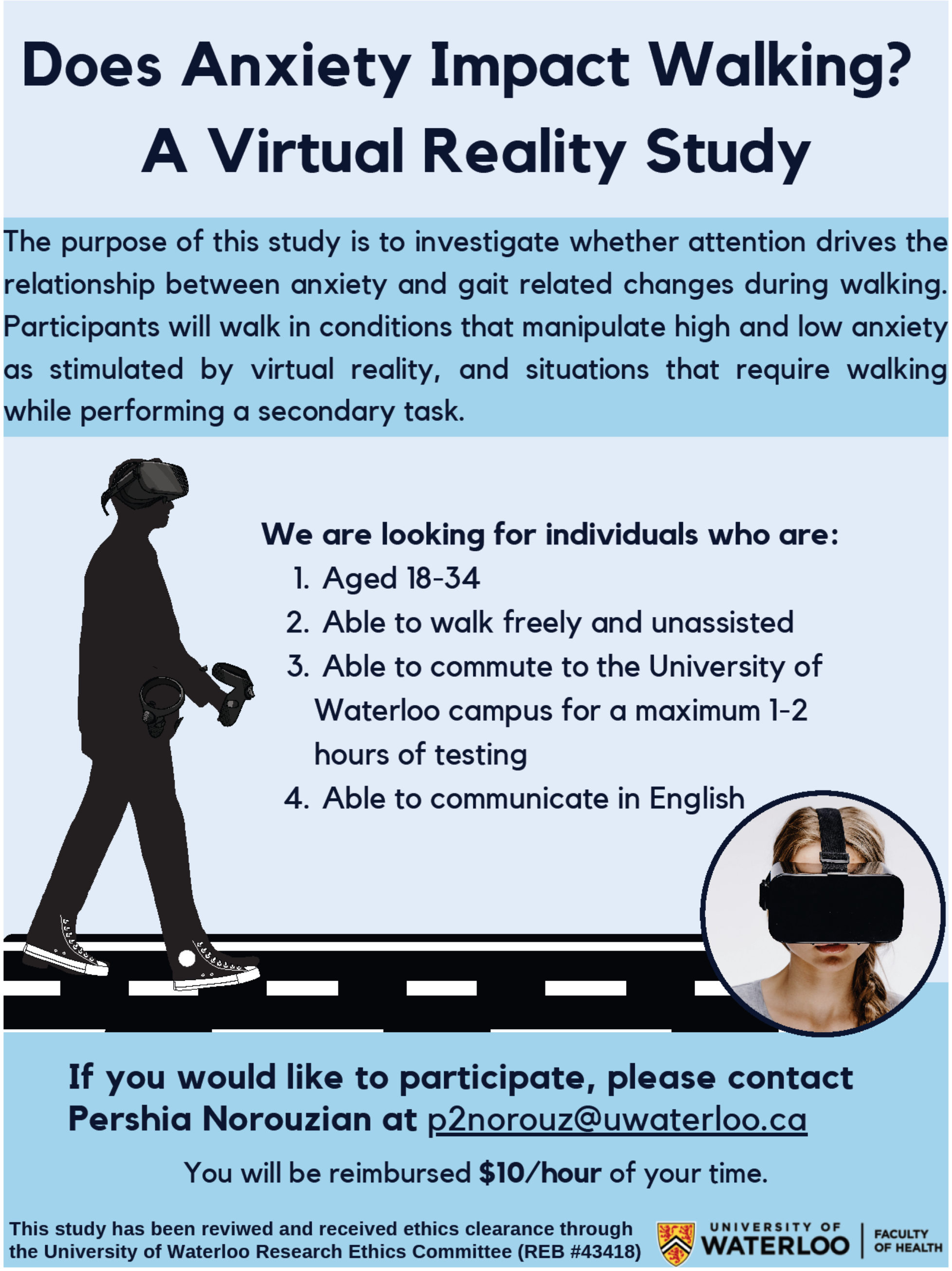
Zaback, M., Carpenter, M. G., & Adkin, A. L. (2016). Threat-induced changes in attention during tests of static and anticipatory postural control. *Gait and Posture*, *45*, 19–24. https://doi.org/10.1016/j.gaitpost.2015.12.033

Zaback, M., Cleworth, T. W., Carpenter, M. G., & Adkin, A. L. (2015). Personality traits and individual differences predict threat-induced changes in postural control. *Human Movement Science*, *40*, 393–409. https://doi.org/10.1016/j.humov.2015.01.015.

Zhang, W., Low, L., Schwenk, M., Mills, N., Gwynn, J., & Clemson, L. (2019). Review of Gait, Cognition, and Fall Risks with Implications for Fall Prevention in Older Adults with Dementia. *Dementia and Geriatric Cognitive Disorders*, *48*, 17 – 2.

APPENDIX A – Questionnaires

Appendix A-1 Study Recruitment Poster



Does Anxiety Impact Walking?
A Virtual Reality Study

The purpose of this study is to investigate whether attention drives the relationship between anxiety and gait related changes during walking. Participants will walk in conditions that manipulate high and low anxiety as stimulated by virtual reality, and situations that require walking while performing a secondary task.

We are looking for individuals who are:

1. Aged 18-34
2. Able to walk freely and unassisted
3. Able to commute to the University of Waterloo campus for a maximum 1-2 hours of testing
4. Able to communicate in English

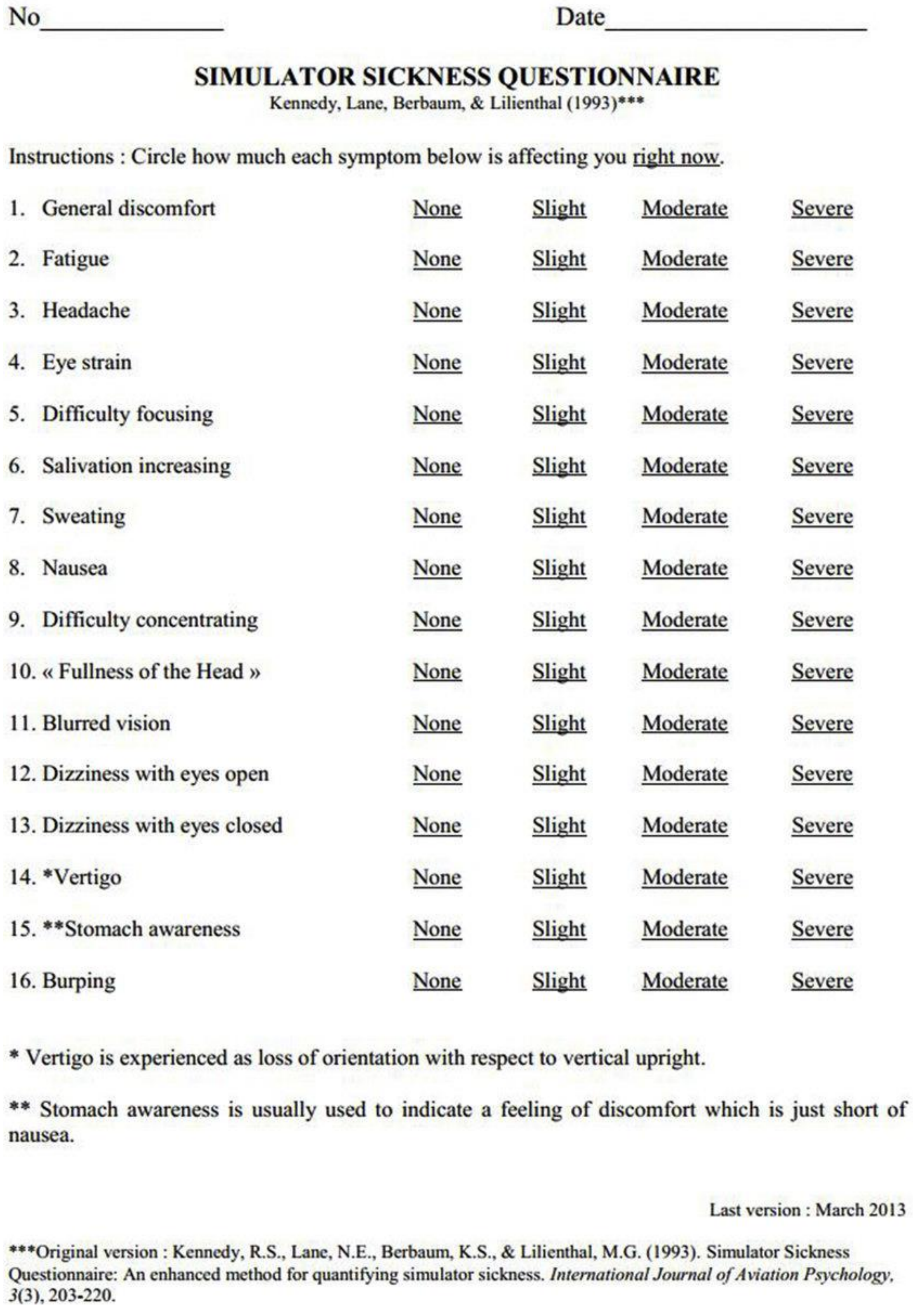
If you would like to participate, please contact Pershia Norouzian at p2norouz@uwaterloo.ca

You will be reimbursed **$10/hour** of your time.

This study has been reviwed and received ethics clearance through the University of Waterloo Research Ethics Committee (REB #43418)

UNIVERSITY OF WATERLOO | FACULTY OF HEALTH

Appendix A-2 Simulator Sickness Questionnaire and Scoring



No______________ Date___________________

SIMULATOR SICKNESS QUESTIONNAIRE

Kennedy, Lane, Berbaum, & Lilienthal (1993)***

Instructions : Circle how much each symptom below is affecting you right now.

1. General discomfort	None	Slight	Moderate	Severe
2. Fatigue	None	Slight	Moderate	Severe
3. Headache	None	Slight	Moderate	Severe
4. Eye strain	None	Slight	Moderate	Severe
5. Difficulty focusing	None	Slight	Moderate	Severe
6. Salivation increasing	None	Slight	Moderate	Severe
7. Sweating	None	Slight	Moderate	Severe
8. Nausea	None	Slight	Moderate	Severe
9. Difficulty concentrating	None	Slight	Moderate	Severe
10. « Fullness of the Head »	None	Slight	Moderate	Severe
11. Blurred vision	None	Slight	Moderate	Severe
12. Dizziness with eyes open	None	Slight	Moderate	Severe
13. Dizziness with eyes closed	None	Slight	Moderate	Severe
14. *Vertigo	None	Slight	Moderate	Severe
15. **Stomach awareness	None	Slight	Moderate	Severe
16. Burping	None	Slight	Moderate	Severe

* Vertigo is experienced as loss of orientation with respect to vertical upright.

** Stomach awareness is usually used to indicate a feeling of discomfort which is just short of nausea.

Last version : March 2013

***Original version : Kennedy, R.S., Lane, N.E., Berbaum, K.S., & Lilienthal, M.G. (1993). Simulator Sickness Questionnaire: An enhanced method for quantifying simulator sickness. *International Journal of Aviation Psychology, 3*(3), 203-220.

Walter, Hannah; Li, Ruixuan; Munafo, Justin; Curry, Christopher; Peterson, Nicolette; Stoffregen, Thomas. (2019). APAL Coupling Study 2019. Retrieved from the Data Repository for the University of Minnesota, https://doi.org/10.13020/XAMG-CS69.

A brief explanation of the Simulator Sickness Questionnaire (SSQ)

Each item is rated with the scale from none, slight, moderate to severe. Through some calculations, four representative scores can be found. Nausea-related subscore (N), Oculomotor-related subscore (O), Disorientation-related subscore (D) are the scores for the symptoms for the specific aspects. Total Score (TS) is the score representing the overall severity of cybersickness experienced by the users of virtual reality systems.

The calculations in the Simulator Sickness Questionnaire

None = 0
Slight = 1
Moderate = 2
Severe = 3

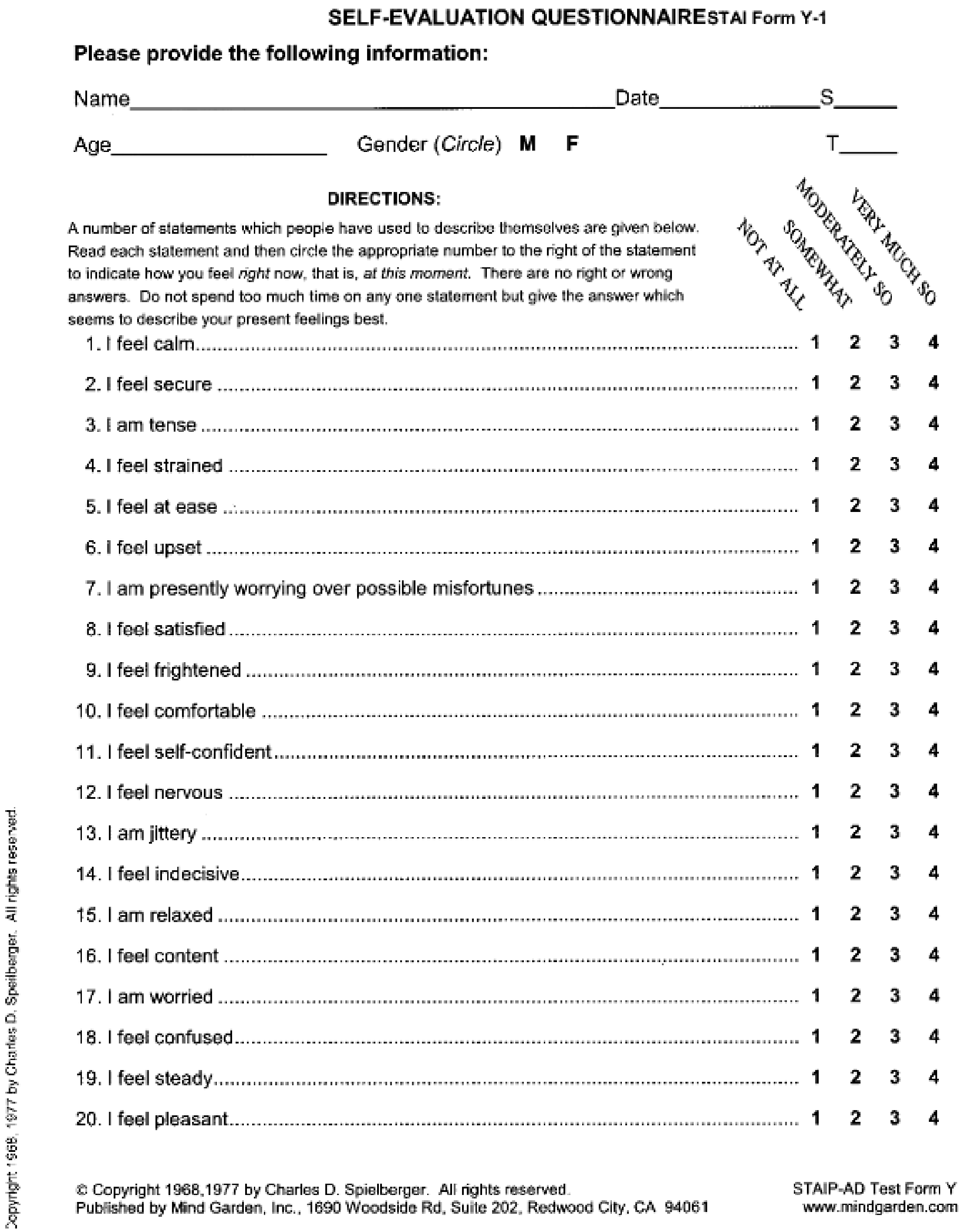
	Weights for Symptoms		
Symptoms	Nausea	Oculomotor	Disorientation
General discomfort	1	1	
Fatigue		1	
Headache		1	
Eye strain		1	
Difficulty focusing		1	1
Increased salivation	1		
Sweating	1		
Nausea	1		1
Difficulty concentrating	1	1	
Fullness of head			1
Blurred vision		1	1
Dizzy (eyes open)			1
Dizzy (eyes closed)			1
Vertigo			1
Stomach awareness	1		
Burping	1		
Total*	[1]	[2]	[3]

Score
Nausea = [1] × 9.54
Oculomotor = [2] × 7.58
Disorientation = [3] × 13.92
Total Score = ([1] + [2] + [3]) *3.74

---

* Total is the sum obtained by adding the symptoms scores. Omitted scores are zero

Appendix A-3 Spielberger State Trait Anxiety (STAI) Form and Scoring (Y1=State, Y2=Trait)



SELF-EVALUATION QUESTIONNAIRE STAI Form Y-1

Please provide the following information:

Name______________________________ Date____________ S_____

Age________________ Gender (*Circle*) **M** **F** T_____

DIRECTIONS:

A number of statements which people have used to describe themselves are given below. Read each statement and then circle the appropriate number to the right of the statement to indicate how you feel *right* now, that is, *at this moment*. There are no right or wrong answers. Do not spend too much time on any one statement but give the answer which seems to describe your present feelings best.

	NOT AT ALL	SOMEWHAT	MODERATELY SO	VERY MUCH SO
1. I feel calm	1	2	3	4
2. I feel secure	1	2	3	4
3. I am tense	1	2	3	4
4. I feel strained	1	2	3	4
5. I feel at ease	1	2	3	4
6. I feel upset	1	2	3	4
7. I am presently worrying over possible misfortunes	1	2	3	4
8. I feel satisfied	1	2	3	4
9. I feel frightened	1	2	3	4
10. I feel comfortable	1	2	3	4
11. I feel self-confident	1	2	3	4
12. I feel nervous	1	2	3	4
13. I am jittery	1	2	3	4
14. I feel indecisive	1	2	3	4
15. I am relaxed	1	2	3	4
16. I feel content	1	2	3	4
17. I am worried	1	2	3	4
18. I feel confused	1	2	3	4
19. I feel steady	1	2	3	4
20. I feel pleasant	1	2	3	4

Published by Mind Garden, Inc., 1690 Woodside Rd, Suite 202, Redwood City, CA 94061

STAIP-AD Test Form Y
www.mindgarden.com

SELF-EVALUATION QUESTIONNAIRE

STAI Form Y-2

Name____Date_________

DIRECTIONS

A number of statements which people have used to describe themselves are given below. Read each statement and then circle the appropriate number to the right of the statement to indicate how you *generally* feel. There are no right or wrong answers. Do not spend too much time on any one statement but give the answer which seems to describe how you generally feel.

	ALMOST NEVER	SOMETIMES	OFTEN	ALMOST ALWAYS
21. I feel pleasant	1	2	3	4
22. I feel nervous and restless	1	2	3	4
23. I feel satisfied with myself	1	2	3	4
24. I wish I could be as happy as others seem to be	1	2	3	4
25. I feel like a failure	1	2	3	4
26. I feel rested	1	2	3	4
27. I am "calm, cool, and collected"	1	2	3	4
28. I feel that difficulties are piling up so that I cannot overcome them	1	2	3	4
29. I worry too much over something that really doesn't matter	1	2	3	4
30. I am happy	1	2	3	4
31. I have disturbing thoughts	1	2	3	4
32. I lack self-confidence	1	2	3	4
33. I feel secure	1	2	3	4
34. I make decisions easily	1	2	3	4
35. I feel inadequate	1	2	3	4
36. I am content	1	2	3	4
37. Some unimportant thought runs through my mind and bothers me	1	2	3	4
38. I take disappointments so keenly that I can't put them out of my mind	1	2	3	4
39. I am a steady person	1	2	3	4
40. I get in a state of tension or turmoil as I think over my recent concerns and interests	1	2	3	4

Published by Mind Garden, Inc., 1690 Woodside Rd, Suite 202, Redwood City, CA 94061

State-Trait Anxiety Inventory for Adults Scoring Key (Form Y-1, Y-2)

Developed by Charles D. Spielberger in collaboration with R.L. Gorsuch, R. Lushene, P.R. Vagg, and G.A. Jacobs

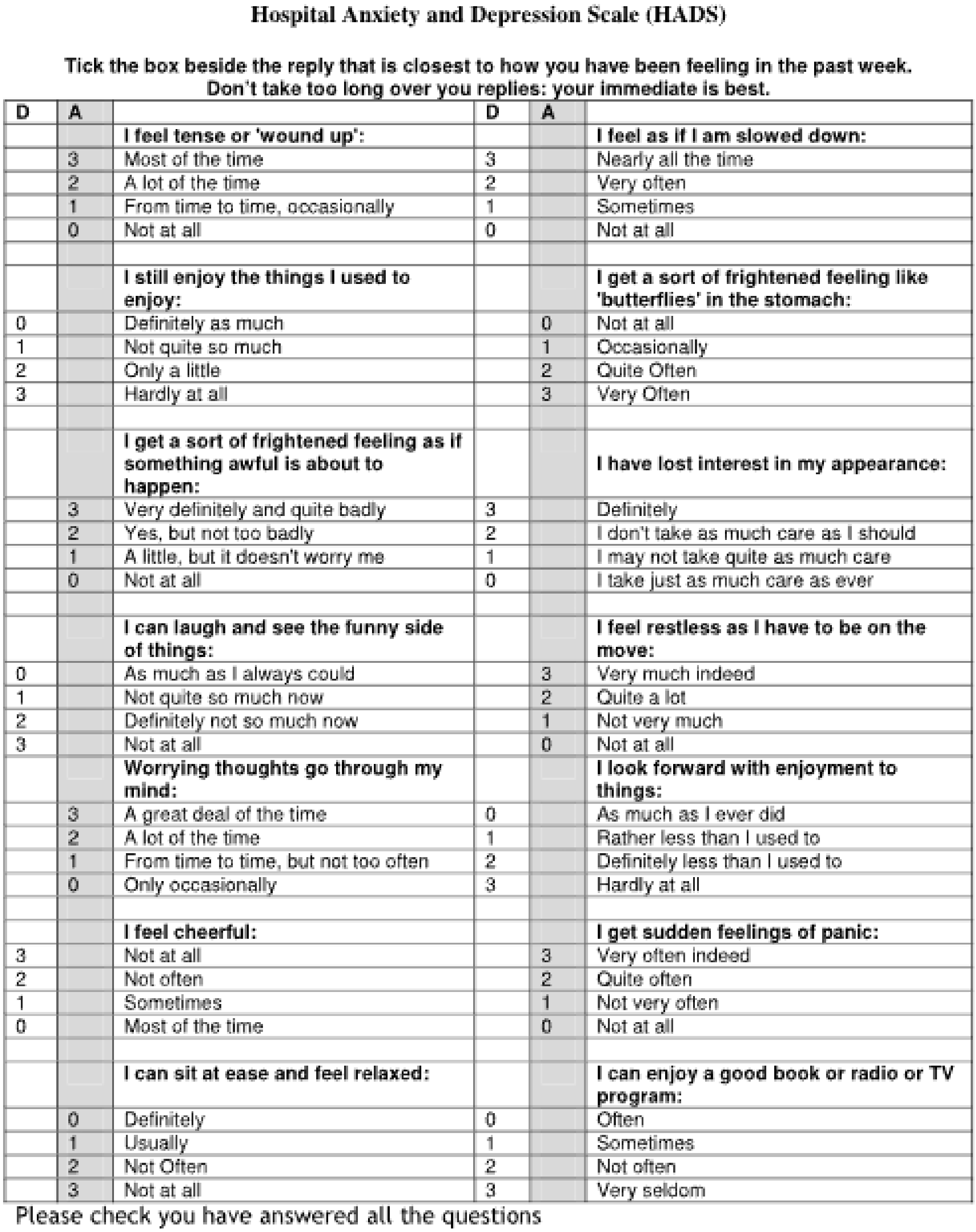
To use this stencil, fold this sheet in half and line up with the appropriate test side, either Form Y-1 or Form Y-2. Simply total the scoring **weights** shown on the stencil for each response category. For example, for question # 1, if the respondent marked 3, then the **weight** would be **2**. Refer to the manual for appropriate normative data.

Form Y-1	NOT AT ALL	SOMEWHAT	MODERATELY SO	VERY MUCH SO	**Form Y-2**	ALMOST NEVER	SOMETIMES	OFTEN	ALMOST ALWAYS
1.	4	3	2	1	21.	4	3	2	1
2.	4	3	2	1	22.	1	2	3	4
3.	1	2	3	4	23.	4	3	2	1
4.	1	2	3	4	24.	1	2	3	4
5.	4	3	2	1	25.	1	2	3	4
6.	1	2	3	4	26.	4	3	2	1
7.	1	2	3	4	27.	4	3	2	1
8.	4	3	2	1	28.	1	2	3	4
9.	1	2	3	4	29.	1	2	3	4
10.	4	3	2	1	30.	4	3	2	1
11.	4	3	2	1	31.	1	2	3	4
12.	1	2	3	4	32.	1	2	3	4
13.	1	2	3	4	33.	4	3	2	1
14.	1	2	3	4	34.	4	3	2	1
15.	4	3	2	1	35.	1	2	3	4
16.	4	3	2	1	36.	4	3	2	1
17.	1	2	3	4	37.	1	2	3	4
18.	1	2	3	4	38.	1	2	3	4
19.	4	3	2	1	39.	4	3	2	1
20.	4	3	2	1	40.	1	2	3	4

Published by Mind Garden, Inc., 1690 Woodside Rd, Suite 202, Redwood City, CA 94061

STAIP-AD Scoring Key
www.mindgarden.com

Appendix A-4 Hospital Anxiety and Depression Scale (HADS)



Hospital Anxiety and Depression Scale (HADS)

Tick the box beside the reply that is closest to how you have been feeling in the past week.
Don't take too long over you replies: your immediate is best.

D	A		D	A	
		I feel tense or 'wound up':			**I feel as if I am slowed down:**
	3	Most of the time	3		Nearly all the time
	2	A lot of the time	2		Very often
	1	From time to time, occasionally	1		Sometimes
	0	Not at all	0		Not at all
		I still enjoy the things I used to enjoy:			**I get a sort of frightened feeling like 'butterflies' in the stomach:**
0		Definitely as much		0	Not at all
1		Not quite so much		1	Occasionally
2		Only a little		2	Quite Often
3		Hardly at all		3	Very Often
		I get a sort of frightened feeling as if something awful is about to happen:			**I have lost interest in my appearance:**
	3	Very definitely and quite badly	3		Definitely
	2	Yes, but not too badly	2		I don't take as much care as I should
	1	A little, but it doesn't worry me	1		I may not take quite as much care
	0	Not at all	0		I take just as much care as ever
		I can laugh and see the funny side of things:			**I feel restless as I have to be on the move:**
0		As much as I always could		3	Very much indeed
1		Not quite so much now		2	Quite a lot
2		Definitely not so much now		1	Not very much
3		Not at all		0	Not at all
		Worrying thoughts go through my mind:			**I look forward with enjoyment to things:**
	3	A great deal of the time	0		As much as I ever did
	2	A lot of the time	1		Rather less than I used to
	1	From time to time, but not too often	2		Definitely less than I used to
	0	Only occasionally	3		Hardly at all
		I feel cheerful:			**I get sudden feelings of panic:**
3		Not at all		3	Very often indeed
2		Not often		2	Quite often
1		Sometimes		1	Not very often
0		Most of the time		0	Not at all
		I can sit at ease and feel relaxed:			**I can enjoy a good book or radio or TV program:**
	0	Definitely	0		Often
	1	Usually	1		Sometimes
	2	Not Often	2		Not often
	3	Not at all	3		Very seldom

Please check you have answered all the questions

Appendices A-5,6,7 (Height Questionnaires)

Participant Code: _______ **Surface Height: _______**

1. Please use the following scale to rate how confident you are that you can maintain your balance and avoid a fall during the walking task:

0……10……20……30……40……50……60……70……80…..90……100

I do not feel confident at all	**I feel moderately confident**	**I feel completely confident**

Score ______

Participant Code: _________________ Surface Height:___________

Please answer the following questions about how you honestly feel just after walking at this height using the following scale:

1	2	3	4	5	6	7	8	9
I don't feel at all				I feel this moderately				I feel this extremely

1. **I felt nervous when walking at this height**

Score_____

2. **I had lapses of concentration when walking at this height**

Score _____

3. **I had self doubts when walking at this height**

Score_____

4. **I felt myself tense and shaking when walking at this height**

Score _____

5. **I was concerned about being unable to concentrate when walking at this height**

Score _____

6. **I was concerned about doing the walking task correctly when walking at this height**

Score _____

7. **My body was tense when walking at this height**

Score _____

8. **I had difficulty focusing on what I had to do when walking at this height**

Score _____

9. **I was worried about my personal safety when walking at this height**

Score _____

10. **I felt my stomach sinking when walking at this height**

Score _____

11. **While trying to walk at this height, I didn't pay attention to the plank all of the time**

Score _____

12. **My heart was racing when walking at this height**

Score _____

13. **Thoughts of falling interfered with my concentration when walking at this height**

Score _____

14. **I was concerned that others would be disappointed with my walking performance at this height**

Score _____

15. **I found myself hyperventilating when walking at this height**

Score _____

16. **I found myself thinking about things not related to the walking task when walking at this height.**

Score _____

Participant Code: _________________ Surface Height:___________

Please answer the following questions about how you honestly feel just after walking at this height using the following scale:

1. Using the following scale, please rate how stable you felt when performing the walking task:

0……10……20……30……40……50……60……70……80…..90……100

I did not feel stable at all	**I felt moderately stable**	**I felt completely stable**

Score ________

---

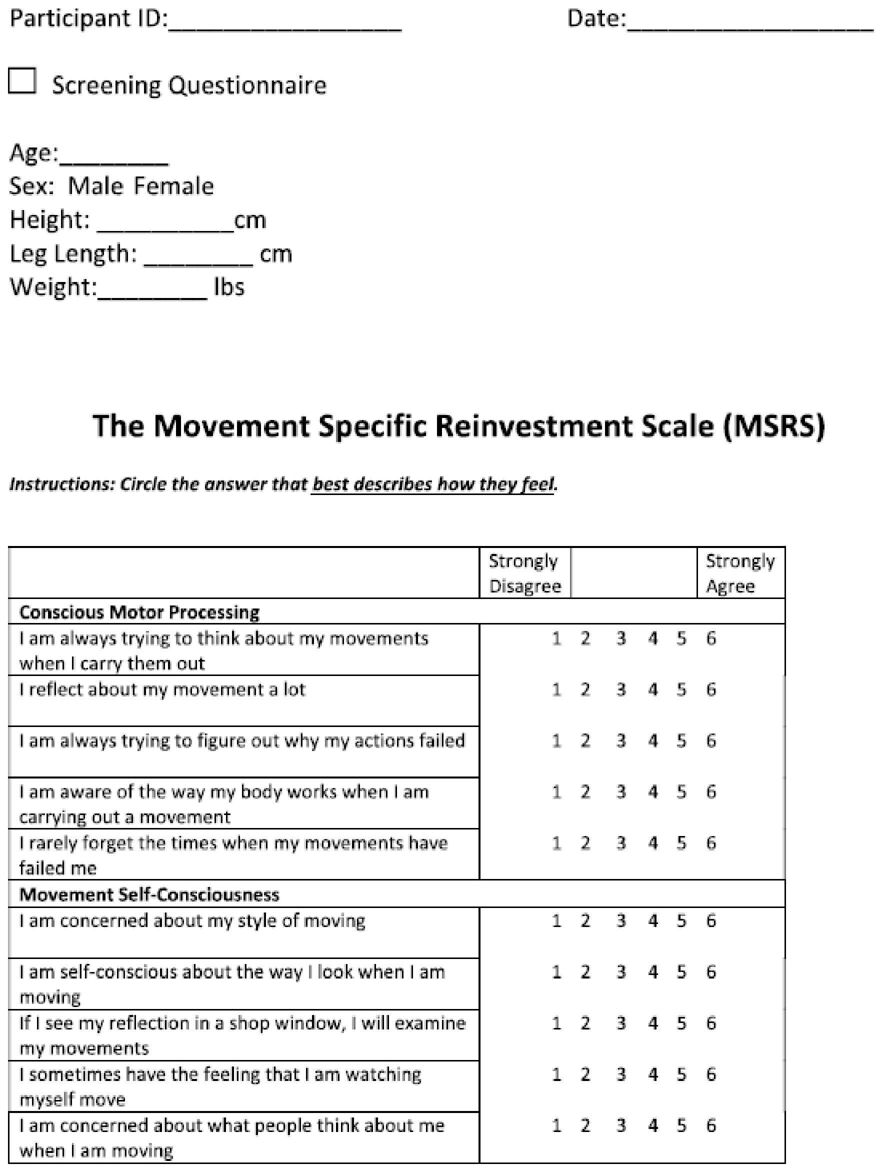
2. Using the following scale, please rate how fearful of falling you felt when performing the walking task:

0……10……20……30……40……50……60……70……80…..90……100

I did not feel fearful at all	**I felt moderately fearful**	**I felt fearful**

Score ________

Appendix A-8 Movement Specific Reinvestment Scale (MSRS)



Participant ID:_________________ Date:__________________

☐ Screening Questionnaire

Age:________
Sex: Male Female
Height: __________cm
Leg Length: ________ cm
Weight:________ lbs

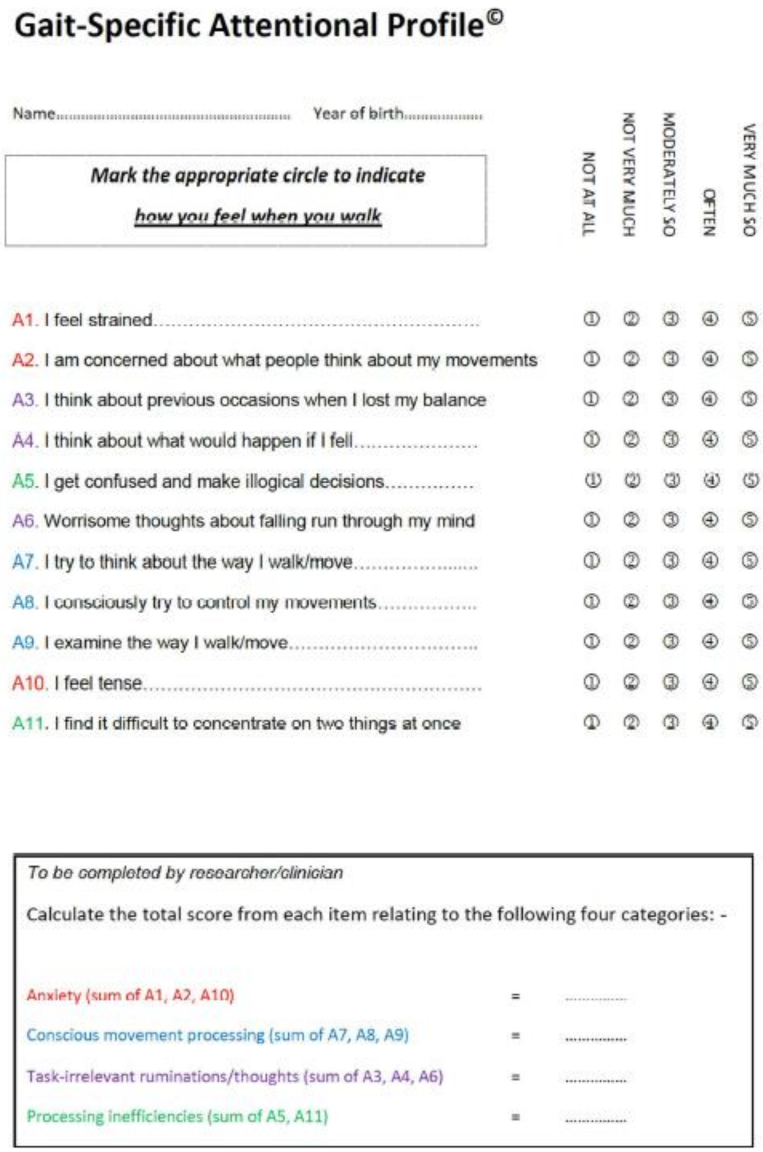
The Movement Specific Reinvestment Scale (MSRS)

Instructions: Circle the answer that best describes how they feel.

	Strongly Disagree					Strongly Agree
Conscious Motor Processing						
I am always trying to think about my movements when I carry them out	1	2	3	4	5	6
I reflect about my movement a lot	1	2	3	4	5	6
I am always trying to figure out why my actions failed	1	2	3	4	5	6
I am aware of the way my body works when I am carrying out a movement	1	2	3	4	5	6
I rarely forget the times when my movements have failed me	1	2	3	4	5	6
Movement Self-Consciousness						
I am concerned about my style of moving	1	2	3	4	5	6
I am self-conscious about the way I look when I am moving	1	2	3	4	5	6
If I see my reflection in a shop window, I will examine my movements	1	2	3	4	5	6
I sometimes have the feeling that I am watching myself move	1	2	3	4	5	6
I am concerned about what people think about me when I am moving	1	2	3	4	5	6

*note, each section of the MSRS is scored separately by summing the total points allocated to Conscious Motor Processing (CMP), or Movement Self-Consciousness (MSC).

Appendices A-9 Gait-Specific Attention Profile (GSAP)



Gait-Specific Attentional Profile©

Name.. Year of birth...................

Mark the appropriate circle to indicate

how you feel when you walk

	NOT AT ALL	NOT VERY MUCH	MODERATELY SO	OFTEN	VERY MUCH SO
A1. I feel strained...	①	②	③	④	⑤
A2. I am concerned about what people think about my movements	①	②	③	④	⑤
A3. I think about previous occasions when I lost my balance	①	②	③	④	⑤
A4. I think about what would happen if I fell.....................	①	②	③	④	⑤
A5. I get confused and make illogical decisions...............	①	②	③	④	⑤
A6. Worrisome thoughts about falling run through my mind	①	②	③	④	⑤
A7. I try to think about the way I walk/move......................	①	②	③	④	⑤
A8. I consciously try to control my movements.................	①	②	③	④	⑤
A9. I examine the way I walk/move................................	①	②	③	④	⑤
A10. I feel tense...	①	②	③	④	⑤
A11. I find it difficult to concentrate on two things at once	①	②	③	④	⑤

To be completed by researcher/clinician

Calculate the total score from each item relating to the following four categories: -

Anxiety (sum of A1, A2, A10) = ...

Conscious movement processing (sum of A7, A8, A9) = ...

Task-irrelevant ruminations/thoughts (sum of A3, A4, A6) = ...

Processing inefficiencies (sum of A5, A11) = ...

Appendix B - Supplementary Data and Figures

B1 – Trial by Condition effects

Trial effects were also examined to examine whether responses in anxiousness (arousal) or gait outcomes were homogenous over the trials. Individual, two-way repeated measures ANOVAs were run for SAM scores of arousal (self-reported anxiousness), and each of the primary gait outcomes (sum=4), with condition (ground-single, ground-dual, elevated-single, elevated-dual) and trial orders (1^{st}-5^{th}) as the two factors. Follow-up pairwise t-tests were conducted where main effects were significant. These variables were also graphically examined for distribution across condition blocks using boxplots and bar graphs. For all analyses required ANOVA, in cases where sphericity assumptions were violated, Greenhouse-Geisser corrections were applied.

B1-a. *Self-reported anxiety (SAM Ratings)*

When examining trial effects for SAM (self-reported anxiety) ratings by interpreting trial condition by trial order 2-way ANOVAs with both condition (G-ST, G-DT, E-ST, E-DT) and trial order (1^{st}, 2^{nd}, 3^{rd}, 4^{th}, 5^{th}) as factors, there was a main effect of condition (F(3,580)=35.6244, p<0.001), but no significant interaction effects (F(12,580)= 0.2242, p=0.9973) nor main effect of trial order (F(4,580)=0.4322, p=0.7854). Pairwise t-tests revealed that SAM ratings from the ground single task condition were significantly different from the SAM ratings of all other conditions (p-values <0.001), and that the ground dual task condition was significantly different from the elevated single and dual task conditions (p-values <0.001), but the two elevated conditions were not significantly different from each other (p <0.001). This demonstrates that SAM ratings were higher in both elevated conditions compared to the ground conditions, but the elevated conditions were not significantly different from one another (see figure B1-a). This also indicates that there was not a trial effect, suggesting that the self-reported anxiety perceived on the trials within each condition were not significantly different nor was there an interaction that would indicate significant differences that would limit against using the average of all trial data for the primary analyses.

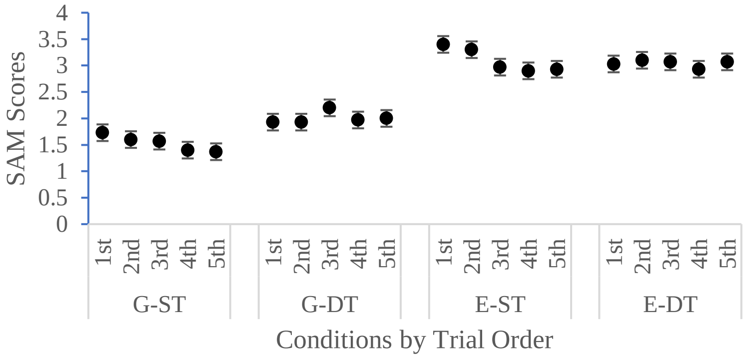


Figure B1-a. SAM scores for each of the trial conditions, organized by trial orders. *G-ST = Ground, single task condition; G-DT = Ground, dual task condition; E-ST = Elevated, single task condition; E-DT = Elevated, dual task condition. 1st, 2nd, 3rd, 4th, 5th indicates the order of the trial within the condition (i.e., 1st trial to last (5th) trial) in order. Error bars represent standard error.*

B1-b. *Double Limb Support Time*

When examining trial effects for time spent in double support, by interpreting trial condition by trial order 2-way ANOVAs with both condition (G-ST, G-DT, E-ST, E-DT) and trial order (1st, 2nd, 3rd, 4th, 5th) as factors, there was a main effect of condition (F(3,580)=24.025, p<0.001), but no main effect of trial order (F(12,580)= 1.003, p=0.405) nor significant interaction effects (F(4,580)=0.383, p=0.970). Pairwise t-tests revealed double support time was significantly different between each of the four conditions (p<0.001), but the ground dual task and elevated single task were not significantly different from each other. The ground single task condition had the smallest time spent in double support as compared to other conditions (all p-values <0.001), (see figure B1-b). There was increased time spent in double support when comparing ground dual task to ground single task, and elevated dual task to elevated single task (p<0.001), with the time spent in double support being the highest in the elevated dual task condition as compared to all other conditions (each p-value <0.001). Time spent in double support was higher in the ground dual task than the elevated single task (p<0.001).

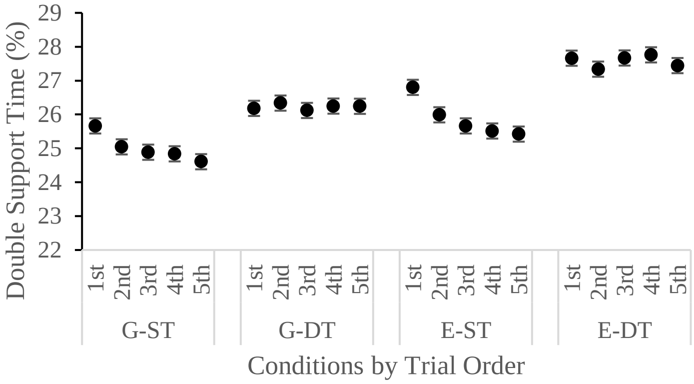


Figure B1-b. Mean Double Support Time for each of the trial conditions, organized by trial orders. *G-ST = Ground, single task condition; G-DT = Ground, dual task condition; E-ST = Elevated, single task condition; E-DT = Elevated, dual task condition. 1st, 2nd, 3rd, 4th, 5th indicates the order of the trial within the condition (i.e., 1st trial to last (5th) trial) in order. Error bars represent standard error*

B1-c. *Velocity*

When examining trial effects for velocity by interpreting trial condition by trial order 2-way ANOVAs with both condition (G-ST, G-DT, E-ST, E-DT) and trial order (1st, 2nd, 3rd, 4th, 5th) as factors, there was a main effect of condition (F(3,580)=32.580, p<0.001), but no main effect of trial order (F(12,580)= 1.701, p=0.148) nor significant interaction effects (F(4,580)=0.396, p=0.965). Pairwise t-tests revealed that the gait velocity during each of the conditions were all significantly different from one another (p-values <0.001) with velocity significant decreasing with increasing trial complexity (lowest velocity in elevated DT condition) (figure B1-c).

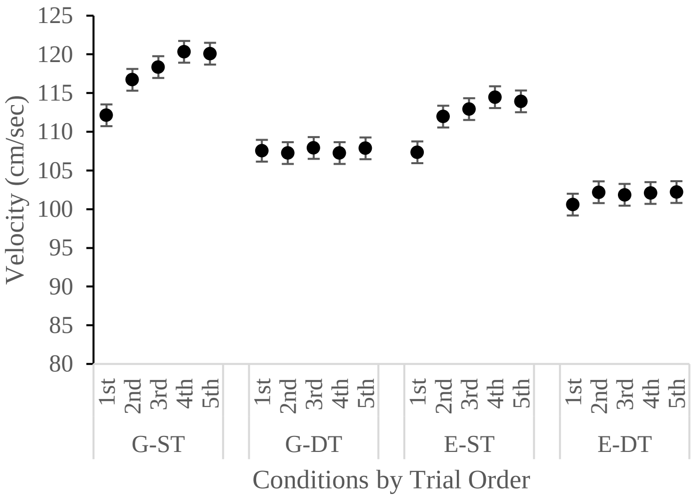


Figure B1-c. Mean Velocity for each of the trial conditions, organized by trial orders. *G-ST = Ground, single task condition; G-DT = Ground, dual task condition; E-ST = Elevated, single task condition; E-DT = Elevated, dual task condition. 1st, 2nd, 3rd, 4th, 5th indicates the order of the trial within the condition (i.e., 1st trial to last (5th) trial) in order. Error bars represent standard error*

B1-d. *Step Length Variability*

When examining trial effects for step length variability by interpreting trial condition by trial order 2-way ANOVAs with both condition (G-ST, G-DT, E-ST, E-DT) and trial order (1st, 2nd, 3rd, 4th, 5th) as factors, there was a main effect of condition (F(3,580)=6.247, p<0.001), but no main effect of trial order (F(12,580)= 0.704, p=0.589) nor significant interaction effects (F(4,580)=0.587, p=0.854). Pairwise t-tests revealed step length variability was significantly lower in the ground dual task compared to both the elevated single task and elevated dual tasks, respectively (both p<0.001). The ground single task condition was not significantly different from the other conditions (figure B1-d).

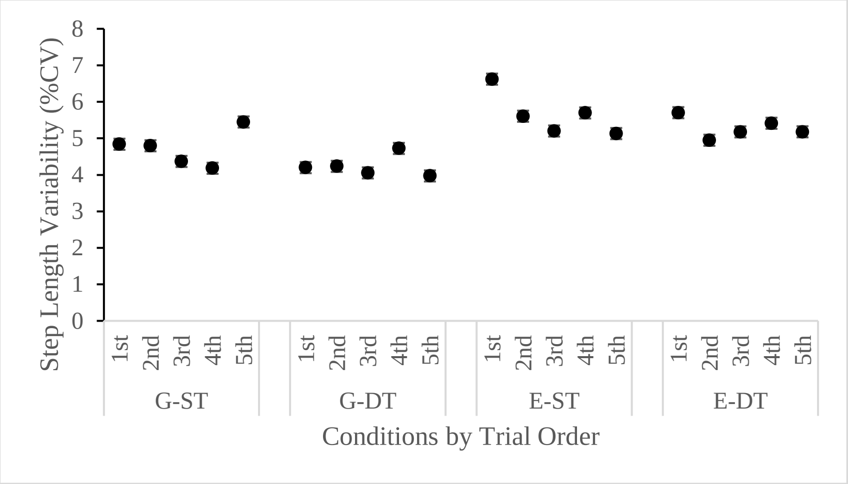


Figure B1-d. Step Length Variability for each of the trial conditions, organized by trial orders. *G-ST = Ground, single task condition; G-DT = Ground, dual task condition; E-ST = Elevated, single task condition; E-DT = Elevated, dual task condition. 1st, 2nd, 3rd, 4th, 5th indicates the order of the trial within the condition (i.e., 1st trial to last (5th) trial) in order. Error bars represent standard error*

B1-e. *Dual Task errors*

For the dual tasks errors, one-way within subjects repeated measures ANOVA revealed non-significant differences between baseline (seated), low and high threat conditions (F(2,58)=0.189, p=0.828) with baseline errors averaging 1.63 (1.35), low threat errors averaging 1.63 (1.37), and high threat errors averaging 1.52 (1.29). Additionally, two-tailed paired samples t-test revealed the dual task cost (DTC) of velocity was non-significant between the high and low threat conditions (t(29)=-0.6595, p=0.514) with DTC of velocity averaging 8.41 (31.68) in low threat, and 9.27 (57.63) in high threat.

B2 – Polynomial Regression (Quadratic and Cubic models for each objective)

Table B2-a. Univariate regression model results for gait outcomes (A) step length variability, (B) velocity, (C) mean double support time as dependent on baseline trait anxiety levels during single task walking at the ground level.

Model	**Outcome measure**	**Exposure**	$\boldsymbol{\beta}$	**B (SE)**	$\boldsymbol{R^2}$	**(95% CI)**	**p-value (regression)**
Linear 1A	Step length CV%	T-anx.mc	0.228	0.054 (0.044)	0.052	(-0.036, 0.114)	0.226
Quadratic 1A		T-anx.mc	0.230	0.055 (0.046)	0.052	(-0.038, 0.148)	0.486
		T-anx.sq	-0.013	0.000 (0.005)		(-0.010, 0.009)	
Cubic 1A		T-anx.mc	0.131	0.031 (0.088)	0.056	(-0.150, 0.213)	0.678
		T-anx.sq	-0.055	-0.001 (0.006)		(-0.013, 0.010)	
		T-anx.cube	0.129	0.000 (0.000)		(-0.001, 0.001)	
Linear 2B	Velocity (cm/s)	T-anx.mc	-0.034	-0.044 (0.244)	0.001	(-0.544, 0.457)	0.860
Quadratic 2B		T-anx.mc	-0.033	-0.043 (0.253)	0.001	(-0.562, 0.476)	0.985
		T-anx.sq	-0.003	0.000 (0.025)		(-0.052, 0.052)	
Cubic 2B		T-anx.mc	-0.091	-0.118 (0.490)	0.002	(-1.126, 0.890)	0.996
		T-anx.sq	-0.027	-0.004 (0.031)		(-0.068, 0.060)	
		T-anx.cube	0.076	0.000 (0.003)		(-0.005, 0.006)	
Linear 3C	DLS (mean %)	T-anx.mc	-0.192	-0.043 (0.042)	0.037	(-0.128, 0.042)	0.310
Quadratic 3C		T-anx.mc	-0.181	-0.041 (0.043)	0.040	(-0.129, 0.048)	0.578
		T-anx.sq	-0.055	-0.001 (0.004)		(-0.10, 0.008)	
Cubic 3C		T-anx.mc	-0.623	-0.140 (0.080)	0.112	(-0.304, 0.025)	0.371
		T-anx.sq	-0.240	-0.005 (0.005)		(-0.016, 0.005)	
		T-anx.cube	0.576	0.001 (0.000)		(0.000, 0.002)	

(**) in exposure column indicates variable is significant within the model ($p<0.05$).

Table B2-b. Univariate regression model results for gait outcomes (A) step length variability, (B) velocity, (C) mean double support time as dependent on baseline trait anxiety levels during single task walking at the elevated level.

Model	**Outcome measure**	**Exposure**	***β***	**B (SE)**	***R^2***	**(95% CI)**	**p-value (regression)**
Linear 4A	Step length CV%	T-anx.mc	0.344	0.096 (0.050)	0.118	(-0.005, 0.197)	0.063
Quadratic 4A		T-anx.mc	0.336	0.094 (0.051)	0.121	(-0.012, 0.199)	0.177
		T-anx.sq	0.046	0.001 (0.005)		(-0.009, 0.012)	
Cubic 4A		T-anx.mc	-0.082	-0.023 (0.096)	0.185	(-0.219, 0.174)	0.144
		T-anx.sq	-0.129	-0.004 (0.006)		(-0.016, 0.009)	
		T-anx.cube	0.544	0.001 (0.001)		(0.000, 0.002)	
Linear 5B	Velocity (cm/s)	T-anx.mc **	-0.390	-0.716 (0.320)	**0.152***	(-1.371, -0.061)	**0.033**
Quadratic 5B		T-anx.mc **	-0.397	-0.729 (0.331)	0.153	(-1.409, -0.049)	0.106
		T-anx.sq	0.037	0.007 (0.033)		(-0.061, 0.075)	
Cubic 5B		T-anx.mc	-0.449	-0.825 (0.642)	0.154	(-2.144, 0.495)	0.218
		T-anx.sq	0.015	0.003 (0.041)		(-0.081, 0.087)	
		T-anx.cube	0.068	0.001 (0.004)		(-0.007, 0.008)	
Linear 6C	DLS (mean %)	T-anx.mc	0.191	0.060 (0.059)	0.037	(-0.060, 0.181)	0.312
Quadratic 6C		T-anx.mc	0.209	0.066 (0.061)	0.045	(-0.058, 0.190)	0.626
		T-anx.sq	-0.094	-0.003 (0.006)		(-0.015, 0.009)	
Cubic 6C		T-anx.mc	-0.081	-0.026 (0.115)	0.076	(-0.263, 0.212)	0.359
		T-anx.sq	-0.216	-0.007 (0.007)		(-0.022, 0.008)	
		T-anx.cube	0.378	0.001 (0.001)		(-0.001, 0.002)	

(*) in R^2 column indicates this model had the best fit for the variable based on change in r-squared between each of the models resulting in significance. (**) in (exposure) column indicates $p<0.05$

Table B2-c. Univariate regression model results for gait outcomes (A) step length variability, (B) velocity, (C) mean double support time as dependent on baseline trait anxiety levels when comparing single task walking (difference scores) between elevated and ground single task conditions [magnitude effect of single task walking at elevation based on ground-level single task walking].

Model	**Outcome measure**	**Exposure**	***β***	**B (SE)**	**R^2**	**(95% CI)**	**p-value (regression)**
Linear 7A	Step length CV%	T-anx.mc	0.153	0.042 (0.051)	0.023	(-0.063, 0.146)	0.421
Quadratic 7A		T-anx.mc	0.142	0.039 (0.053)	0.027	(-0.069, 0.147)	0.764
		T-anx.sq	0.059	0.002 (0.005)		(-0.009, 0.012)	
Cubic 7A		T-anx.mc	-0.199	-0.054 (0.100)	0.069	(-0.259, 0.151)	0.284
		T-anx.sq	-0.084	-0.002 (0.006)		(-0.015, 0.011)	
		T-anx.cube	0.444	0.001 (0.001)		(-0.001, 0.002)	
Linear 8B	Velocity (cm/s)	T-anx.mc **	-0.481	-0.673 (0.232)	**0.231***	(-1.148, -0.197)	**0.007**
Quadratic 8B		T-anx.mc **	-0.490	-0.686 (0.240)	0.233	(-1.178, -0.197)	**0.028**
		T-anx.sq	0.051	0.007 (0.024)		(-0.042, 0.056)	
Cubic 8B		T-anx.mc	-0.505	-0.707 (0.465)	0.234	(-1.663, 0.250)	0.071
		T-anx.sq	0.045	0.006 (0.030)		(-0.054, 0.067)	
		T-anx.cube	0.019	0.000 (0.003)		(-0.005, 0.005)	
Linear 9C	DLS (mean %)	T-anx.mc **	0.445	0.103 (0.039)	**0.198***	(0.023, 0.184)	**0.014**
Quadratic 9C		T-anx.mc **	0.459	0.107 (0.041)	0.203	(0.023, 0.190)	**0.046**
		T-anx.sq	-0.075	-0.002 (0.004)		(-0.010, 0.007)	
Cubic 9C		T-anx.mc	0.490	0.114 (0.079)	0.204	(-0.048, 0.276)	0.110
		T-anx.sq	-0.062	-0.001 (0.005)		(-0.012, 0.009)	
		T-anx.cube	-0.041	-4.688E-5 (0.000)		(-0.001, 0.001)	

(*) in R^2 column indicates this model had the best fit for the variable based on change in r-squared between each of the models resulting in significance and being the least complex, *significant model. (**) in (exposure) column indicates $p<0.05$.*

Table B2-d. Univariate regression model results for gait outcomes (A) step length variability, (B) velocity, (C) mean double support time as dependent on baseline trait anxiety levels when comparing single vs dual task walking (difference scores) at the ground level.

Model	**Outcome measure**	**Exposure**	**β**	**B (SE)**	**R^2**	**(95% CI)**	**p-value (regression)**
Linear 10A	Step length CV%	T-anx.mc	-0.193	-0.048 (0.047)	0.037	(-0.144, 0.047)	0.308
Quadratic 10A		T-anx.mc	-0.188	-0.047 (0.048)	0.038	(-0.146, 0.052)	0.594
		T-anx.sq	-0.027	-0.001 (0.005)		(-0.011, 0.009)	
Cubic 10A		T-anx.mc	-0.504	-0.126 (0.092)	0.075	(-0.315, 0.062)	0.562
		T-anx.sq	-0.159	-0.004 (0.006)		(-0.016, 0.008)	
		T-anx.cube	0.412	0.001 (0.001)		(-0.001, 0.002)	
Linear 11B	Velocity (cm/s)	T-anx.mc	-0.234	-0.199 (0.157)	0.055	(-0.520, 0.122)	0.214
Quadratic 11B		T-anx.mc	-0.229	-0.195 (0.162)	0.055	(-0.528, 0.138)	0.883
		T-anx.sq	-0.028	-0.002 (0.016)		(-0.036, 0.031)	
Cubic 11B		T-anx.mc	-0.122	-0.104 (0.314)	0.060	(-0.749, 0.542)	0.736
		T-anx.sq	0.016	0.001 (0.020)		(-0.040, 0.042)	
		T-anx.cube	-0.139	-0.001 (0.002)		(-0.004, 0.003)	
Linear 12C	DLS (mean %)	T-anx.mc	0.125	0.014 (0.021)	0.016	(-0.029, 0.056)	0.511
Quadratic 12C		T-anx.mc	0.107	0.012 (0.021)	0.025	(-0.032, 0.056)	0.711
		T-anx.sq	0.098	0.001 (0.002)		(-0.003, 0.005)	
Cubic 12C		T-anx.mc	0.276	0.031 (0.041)	0.035	(-0.054, 0.116)	0.812
		T-anx.sq	0.169	0.002 (0.003)		(-0.004, 0.007)	
		T-anx.cube	-0.220	0.000 (0.000)		(-0.001, 0.000)	

(*) in R^2 column indicates this model had the best fit for the variable based on change in r-squared between each of the models resulting in significance and being the least complex,

significant model. (**) in (exposure) column indicates p<0.05.

Table B2-e. Univariate regression model results for gait outcomes (A) step length variability, (B) velocity, (C) mean double support time as dependent on baseline trait anxiety levels when comparing single vs dual task walking (difference scores) at the elevated level.

Model	**Outcome measure**	**Exposure**	***β***	**B (SE)**	**R^2**	**(95% CI)**	**p-value (regression)**
Linear 13A	Step length CV%	T-anx.mc	0.172	0.047 (0.050)	0.030	(-0.057, 0.150)	0.363
Quadratic 13A		T-anx.mc	0.163	0.044 (0.052)	0.032	(-0.063, 0.151)	0.645
		T-anx.sq	0.050	0.001 (0.005)		(-0.009, 0.012)	
Cubic 13A		T-anx.mc	0.597	0.161 (0.097)	0.101	(-0.039, 0.362)	0.419
		T-anx.sq	0.231	0.006 (0.006)		(-0.006, 0.019)	
		T-anx.cube	-0.565	-0.001 (0.001)		(-0.002, 0.000)	
Linear 14B	Velocity (cm/s)	T-anx.mc**	-0.401	-0.406 (0.175)	**0.161***	(-0.765, -0.047)	**0.028**
Quadratic 14B		T-anx.mc **	-0.365	-0.370 (0.178)	0.197	(-0.734, -0.005)	0.052
		T-anx.sq	-0.193	-0.020 (0.018)		(-0.056, 0.017)	
Cubic 14B		T-anx.mc	-0.290	-0.294 (0.344)	0.106	(-1.001, 0.413)	0.118
		T-anx.sq	-0.161	-0.016 (0.022)		(-0.061, 0.029)	
		T-anx.cube	-0.098	0.0000 (0.002)		(-0.004, 0.003)	
Linear 15C	DLS (mean %)	T-anx.mc**	0.404	0.087 (0.037)	**0.163***	(0.011, 0.163)	**0.027**
Quadratic 15C		T-anx.mc **	0.367	0.079 (0.038)	0.202	(0.002, 0.156)	**0.048**
		T-anx.sq	0.199	0.004 (0.004)		(-0.003, 0.012)	
Cubic 15C		T-anx.mc	0.354	0.076 (0.073)	0.202	(-0.074, 0.225)	0.113
		T-anx.sq	0.194	0.004 (0.005)		(-0.005, 0.014)	
		T-anx.cube	0.017	1.77E-5 (0.000)		(-0.001, 0.001)	

(*) in R^2 column indicates this model had the best fit for the variable based on change in r-squared between each of the models resulting in significance and being the least complex,

significant model. (**) in (exposure) column indicates p<0.05.

Table B2-f. Univariate regression model results for gait outcomes (A) step length variability, (B) velocity, (C) mean double support time as dependent on baseline trait anxiety levels when comparing dual task walking (difference scores) between elevated and single task conditions [effect of dual task walking in elevated condition based on dual task walking on ground].

Model	**Outcome measure**	**Exposure**	***β***	**B (SE)**	R^2	**(95% CI)**	**p-value (regression)**
Linear 16A	Step length CV%	T-anx.mc**	0.402	0.136 (0.059)	**0.162***	(0.016, 0.257)	**0.028**
Quadratic 16A		T-anx.mc **	0.382	0.130 (0.061)	0.172	(0.006, 0.254)	0.078
		T-anx.sq	0.106	0.004 (0.006)		(-0.009, 0.016)	
Cubic 16A		T-anx.mc	0.688	0.234 (0.115)	0.207	(-0.002, 0.470)	0.105
		T-anx.sq	0.234	0.008 (0.007)		(-0.007, 0.023)	
		T-anx.cube	-0.399	-0.001 (0.001)		(-0.002, 0.001)	
Linear 17B	Velocity (cm/s)	T-anx.mc **	-0.626	-0.879 (0.207)	**0.391***	(-1.304, -0.455)	**<0.001**
Quadratic 17B		T-anx.mc **	-0.612	-0.861 (0.214)	0.396	(-1.300, -0.422)	**0.001**
		T-anx.sq	-0.070	-0.010 (0.021)		(-0.054, 0.034)	
Cubic 17B		T-anx.mc **	-0.638	-0.896 (0.415)	0.396	(-1.749, -0.044)	**0.004**
		T-anx.sq	-0.081	-0.011 (0.026)		(-0.066, 0.043)	
		T-anx.cube	0.033	0.000 (0.002)		(-0.004, 0.005)	
Linear 18C	DLS (mean %)	T-anx.mc **	0.565	0.176 (0.049)	**0.319***	(0.077, 0.276)	**0.001**
Quadratic 18C		T-anx.mc **	0.556	0.174 (0.050)	0.321	(0.070, 0.277)	**0.005**
		T-anx.sq	0.046	0.001 (0.005)		(-0.009, 0.012)	
Cubic 18C		T-anx.mc	0.511	0.159 (0.098)	0.322	(-0.041, 0.360)	**0.016**
		T-anx.sq	0.027	0.001 (0.006)		(-0.012, 0.014)	
		T-anx.cube	0.059	9.126E-5 (0.001)		(-0.001, 0.001)	

(*) in R^2 column indicates this model had the best fit for the variable based on change in r-squared between each of the models resulting in significance and being the least complex, significant model. (**) in (exposure) column indicates p<0.05.

B3 – Bivariate Correlations between psychological/cognitive factors and anxiety

To understand which predictor variables may explain additional variance in the relationship between trait anxiety and gait, bivariate correlations (Pearson) were conducted on descriptive and participant characteristics of interest based on a priori relevance to trait anxiety. There was no significant collinearity between the predictor variables (Pearson r>0.8).

Trait anxiety was significantly correlated with higher levels of: state anxiety (Pearson R=0.61, p<0.01), depression (Pearson R=0.63, p<0.01), each subcategory of the gait specific attention profile (anxiety: R=0.38, p<0.05; conscious movement processing: R=0.50, p<0.05; focus on task irrelevant ruminations: R=0.38, p<0.05; and processing inefficiency: R=0.52, p<0.01), and greater fear of heights (see Table B3 below).

Table B3. Bivariate Correlations

Individual Characteristics	**T-ANX**	**S-ANX**	**T-CMP**	**T-MSC**	**HADS-D**	**GSAP-A**	**GSAP-C**	**GSAP-T**	**GSAP-E**	**BBC**	**FoH**
T-ANX	1	0.61 **	-0.08	0.20	0.63 **	0.38*	0.50*	0.38*	0.52 **	-0.16	0.41*
2. State Anxiety	-	1	-0.08	0.03	0.29	0.03	0.01	-0.18	0.20	0.04	0.32

Two-tailed: p<0.01 (**), p<0.05 (*)

T-ANX: Trait anxiety (STAI-Y2), S-ANX: State anxiety (STAI-Y1), T-CMP: Trait conscious movement processing (MSRS), T-MSC: Trait movement self-conscious, HADS-D: Depression column of Hospital Anxiety and Depression Scale, GSAP-A: Anxiety score of GSAP, GSAP-C: Conscious movement processing score of GSAP, GSAP-T: Focus on task-irrelevant rumination/thoughts from GSAP, GSAP-E: Processing inefficiency from GSAP, BBC: Baseline Balance Confidence (1-100%), FoH: Fear of heights (1-10).

Trait anxiety was significantly correlated with higher levels of state anxiety at baseline, inreased fear of heights, higher levels of each category of gait specific attention profiles (anxiety, conscious movement processing, task irrelevant ruminations, processing inefficiency), and higher levels of depression.