

Emotional, cognitive, and postural adaptations to repeated postural threat exposure

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Abstract

This thesis investigated initial threat-induced changes in emotional, cognitive, and postural control measures and adaptation of these measures to repeated threat exposure in healthy young and older adults. Twenty-seven young and twenty-seven older adults stood on a platform under no threat and threat conditions. Postural threat was manipulated by altering the expectation of a temporally and directionally unpredictable mediolateral support surface translation during quiet standing. Regardless of age, participants were more anxious, reported broad changes in attention focus, and increased centre of pressure (COP) amplitude and frequency with first threat exposure. With early threat exposure, participants were less anxious and increased COP frequency. With repeated threat exposure, participants were less anxious, reported reductions in threat-induced changes in attention focus, and decreased high frequency COP displacements. These results suggest young and older adults demonstrate similar patterns of emotional, cognitive, and postural adaptations to initial and repeated threat exposure.

Keywords: Adaptation, age, anxiety, attention, posture

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Chapter One: Literature Review

1.1 Postural control

Postural control is a complex sensorimotor process involving the integration of visual, vestibular, and somatosensory afferents and generation of coordinated patterns of muscle activity to achieve stable, upright posture (Horak, 2006; Maki & McIlroy, 1996a). Postural control regulates the dynamic relationship between the body's centre of mass (COM; position on body where the total body mass is equally distributed; Winter, 1995) and base of support (BOS; area of the body that contacts the environment; Maki & McIlroy, 1996a), using anticipatory and/or reactive strategies (Maki & McIlroy, 1997). Therefore, postural control concerns the act of maintaining, achieving, or restoring stability (Pollock, Durward, Rowe, & Paul, 2000), and is essential for balance and movement.

Postural control is influenced by a dynamic interaction between individual, task, and environmental contexts (Huxham, Goldie, & Patla, 2001). Subsequently, damage to mechanisms underlying postural control may result in unique balance impairments that are context-specific, however, functional deficits do not always occur (Horak, 2006). Individuals may develop compensatory strategies that allow them to remain stable in certain situations but may augment instability in other situations. For example, neuropathic individuals may compensate for reductions in critical somatosensory information by increasing reliance on visual information, which increases fall risk when they navigate a dimly lit environment (Horak, 2006). This creates challenges, even for highly-trained clinicians, when attempting to identify the source of a balance impairment that is masked by specific compensatory strategies. Therefore, stability must be

challenged under different environmental and task constraints to comprehensively evaluate postural control (Horak, 2006; Huxham et al., 2001).

During quiet stance, humans are unable to remain completely still. Research has theorized that postural sway functions as an exploratory mechanism that ensures a certain quantity and/or quality of sensory information regarding the body's position is acquired and processed by the central nervous system (CNS; Carpenter, Murnaghan, & Inglis, 2010). For older individuals with impaired vestibular function or neuropathy, increasing body sway is likely an advantageous compensatory strategy to acquire sensory information critical for postural control. However, greater amounts of postural sway are associated with increased fall risk in older adults (Maki, Holliday, & Topper, 1994), particularly when the COM is close to the BOS limits (Maki & McIlroy, 1996a).

The CNS utilizes anticipatory postural control strategies to maintain stability prior to an expected perturbation to balance (Maki & McIlroy, 1997). Anticipatory postural adjustments (APAs) involve appropriately timed and scaled muscle activity, which 1) stabilize the COM in preparation of a destabilizing movement (e.g., arm raise while standing) or expected postural perturbation, or 2) destabilize the COM to facilitate movement initiation (e.g., gait initiation). If body movement is initiated by an external disturbance to the COM such as a perturbation during quiet stance, a reactive movement strategy is used to recover stability. Reactive postural control refers to the ability of the CNS to counteract a destabilization caused by an external perturbation and maintain postural stability despite the COM being displaced (Pollock et al., 2000). Recovery of balance following a small destabilization can be accomplished by increasing tone in the ankle dorsiflexors/plantarflexors and/or hip flexors (Winter, 1995). In response to larger

destabilizations, a stepping strategy may be required to accommodate greater COM displacement by increasing the boundaries of the BOS (Maki & McIlroy, 1997). The reactive postural strategy selected by the CNS is dependent on several factors including, but not limited to, available sensory information, the nature of the support surface, and the magnitude and direction of the perturbation applied to the body (Shumway-Cook & Woollacott, 2006).

To control the vertical projection of the COM within the BOS, the CNS activates muscles that generate and apply force to the support surface. This force, the centre of pressure (COP; weighted average of pressure applied by the foot on the support surface; Winter, 1995), reflects CNS involvement in controlling the position of the COM through the generation of ankle torques in the anteroposterior (AP) plane, and lateral weight shifts in the mediolateral (ML) plane (Winter, 1995). The difference between the COM and the COP is proportional to the horizontal acceleration of the COM and is indicative of the COP's role in correcting postural sway errors (Winter, 1995). Therefore, the COP is a useful measure to assess balance performance during a variety of balance tasks. Ground reaction forces and moments applied to the support surface can be measured using a force plate and used to calculate COP. During quiet standing, position and frequency-based summary measures describing characteristics of COP movement can be calculated in AP and ML directions. COP mean position (MPOS-COP) represents the average position of the COP over the trial duration and is often referenced to the position of the ankle joint in the AP direction (Carpenter, Frank, & Silcher, 1999) to describe how far forward or backward individuals lean. MPOS-COP can be subtracted from each COP signal to unbiased the signal prior to calculating COP root mean square (RMS-COP) and mean power

frequency (MPF-COP) measures. RMS-COP reflects the amplitude of COP displacement variability and MPF-COP reflects the average frequency contained within the COP power spectrum after fast Fourier transformation. For this thesis, which examines quiet standing, COP is the primary measure used to quantify balance performance.

1.2 Age-related changes in postural control

Sensorimotor components of postural control are significantly affected with age and may contribute to postural instability (Alexander, 1994; Maki & McIlroy, 1996a; Sturnieks, St George, & Lord, 2008). For example, increases in postural sway have been observed when feedback from visual, somatosensory, and vestibular systems are experimentally reduced in older adults (Lord, Clark, & Webster, 1991). Increased postural sway during quiet stance is a characteristic change in postural control associated with ageing (Laughton et al., 2003; McClenaghan et al., 1996) that may compensate for age-related reductions in essential sensory information (Carpenter et al., 2010). It is also well established that ageing is associated with reductions in muscle mass and muscle strength (Goodpaster et al., 2006). Reduced muscle strength, particularly in lower extremities, is associated with increased fall risk (Moreland, Richardson, Goldsmith, & Clase, 2004) and increased postural sway in older adults (Lord et al., 1991). Lower extremity muscle weakness may also contribute to age-related deterioration of anticipatory and reactive components of postural control. For example, older adults have been shown to generate inappropriately scaled anticipatory postural adjustments (Maki, 1993) and disorganized activation and/or reduced magnitude of postural muscle activity when responding to an external perturbation (Maki & McIlroy, 1996a).

Mounting evidence has identified lateral instability as a major contributor to increased fall risk among older adults (Hilliard et al., 2008; Lord, Rogers, Howland, & Fitzpatrick, 1999; Maki & McIlroy, 1996a; Rogers & Mille, 2003). Age-related changes in quiet stance appear to be more pronounced in the ML direction (McClenaghan et al., 1996), and ML measures of postural sway are associated with past (Lord et al., 1999), future (Swanenburg, de Bruin, Uebelhart, & Mulder, 2010) and recurring falls (Stel, Smit, Pluijm, & Lips, 2003). However, factors related to the ability to respond to lateral perturbations may more accurately predict falls in older adults (Hilliard et al., 2008). When quiet stance is laterally perturbed, restoration of ML stability is achieved through trunk control, hip abduction/adduction, and correct spatiotemporal placement of the stepping foot (Rogers & Mille, 2003). Research has shown that older adults have poorer trunk control during quiet stance (Gill et al., 2001) and appear more likely to take multiple steps when responding to lateral perturbations compared to young adults (Maki, Edmondstone, & McIlroy, 2000).

While the above age-related physiological changes are often regarded as primary contributors to increased fall risk in older adults, emotional factors, such as fear and anxiety, may also contribute to postural control in older adults. Regardless of fall history, older adults with a fear of falling demonstrated increased AP COP amplitude during quiet standing compared to non-fearful older adults (Maki, Holliday, & Topper, 1991). Due to limitations associated with the cross-sectional design of this study, the authors were unable to determine whether fear of falling elicited postural control deficits, or if older adults were fearful due to postural control deficits. Therefore, research has attempted to systematically investigate the relationship between emotions and postural control.

1.3 Emotional influences on postural control

Fear of falling is a psychological factor associated with falls in older adults (Cumming, Salkeld, Thomas, & Szonyi, 2000; Delbaere, Close, Brodaty, Sachdev, & Lord, 2010; Hadjistavropoulos, Delbaere, & Fitzgerald, 2011) and estimates suggest that about half of all community-dwelling older adults are fearful of falling (Brouwer, Musselman, & Culham, 2004; Yardley & Smith, 2002). Fear of falling is also associated with poor balance and strength, and negative behavioural outcomes such as activity restriction, loss of independence, and reduced quality of life (Legters, 2002; Scheffer, Schuurmans, van Dijk, van der Hooft, & de Rooij, 2008). Direct comparisons of fearful and non-fearful older adults revealed an increased COP amplitude during quiet standing in fearful older adults compared to non-fearful older adults (Maki et al., 1991).

Neurological evidence suggests increases in postural sway are observed during the activation of neural pathways associated with increasing vigilance and anxiety (Balaban & Thayer, 2001) and may be due to sustained activation of postural control mechanisms involved in high risk situations (Staab, Balaban, & Furman, 2013). Individuals with pathological anxiety disorders (Perna et al., 2001; Redfern, Furman, & Jacob, 2007) also sway at larger amplitudes during standing compared to their healthy counterparts. These individuals frequently experience symptoms of dizziness due to vestibular dysfunction (Jacob, Furman, Durrant, & Turner, 1996) and are prone to develop overreliance on non-vestibular sensory systems, leaving them susceptible to instability in situations with complex or moving visual stimuli (Redfern et al., 2007). However, changes in postural control have also been reported in a sample of state anxious individuals, free of

pathological anxiety (Wada, Sunaga, & Nagai, 2001). Together, these studies suggest that there is a relationship between emotions and postural control.

Researchers have exposed healthy young adults to anxiety-inducing stimuli to explore emotional influences on postural control independent of physiological changes associated with aging and/or pathology. One approach is to present healthy young individuals with images from the International Affective Picture System, which can be indexed based on valence and arousal (Lang, Bradley, & Cuthbert, 1997). During quiet stance, viewing unpleasant images (e.g., mutilation) elicits a stiffening response, characterized by increases in COP frequency and reductions in COP amplitude (Azevedo et al., 2005; Facchinetti, Imbiriba, Azevedo, Vargas, & Volchan, 2006), and studies have reported either a forward (Stins & Beek, 2007) or backward lean (Hillman, Rosengren, & Smith, 2004) in response to these images. Independent manipulation of arousal and valence revealed increases in COP frequency when viewing images high in arousal but not valence (Horslen & Carpenter, 2011). In addition, previous experience with aversive life events has been shown to modulate this response, with the greatest reductions in COP amplitude observed in individuals who have experienced multiple aversive events (Hagenaars, Stins, & Roelofs, 2012).

Social evaluative threat, manipulated by expert evaluation (Geh, Beauchamp, Crocker, & Carpenter, 2011) and negative feedback (Doumas, Morsanyi, & Young, 2018) has been shown to influence postural control. For example, older adults had greater COP frequency and amplitude during two-legged stance with eyes closed, reduced duration on a one-legged stance task, and both young and older adults improved performance on a maximum functional forward reach task when performing a series of

clinical balance tests in the presence of an expert evaluator compared to performing these tasks without an evaluator present (Geh et al., 2011). These results suggest that older adults may be more susceptible to the effects of social anxiety on postural control and highlight the importance of accounting for psychological factors during clinical assessment. Furthermore, negative feedback during simultaneous performance of a postural and arithmetic task with time pressure has been shown to reduce COP amplitude during quiet standing (Doumas et al., 2018). However, it is unclear how negative feedback independently affects postural control as previous research has shown that individuals performing an arithmetic task during quiet stance have increased physiological arousal and adopt a forward lean (Maki & McIlroy, 1996b).

The effects of anticipatory anxiety on postural control have been investigated by delivering an unpredictable aversive sound (100 dB SPL) through headphones during quiet standing (Ishida, Saitoh, Wada, & Nagai, 2010). When anticipating the aversive sound, individuals had increased arousal levels and demonstrated increases in COP sway area, as well as increased COP power within 0.1–0.5 Hz band in the ML direction and increased COP power within 0.5–1.0 Hz in the AP direction (Ishida et al., 2010).

Another approach to investigate the effects of emotions on postural control is to increase the likelihood, or perceived consequences of instability. Often, this involves manipulating the height at which individuals stand or altering the expectation of receiving a postural perturbation. This thesis will review the contributions of both the surface height model and postural perturbation model to our understanding of the direct effects of postural threat on postural control and the physiological and psychological mechanisms underlying these effects.

1.4 Postural threat

1.4.1 Surface height model

Postural threat is most commonly induced by experimentally manipulating the height at which individuals stand; this manipulation establishes a perceived risk of instability and increases the negative consequences of a moment of instability (Brown & Frank, 1997). Standing at or close to the edge of an elevated platform elicits increases in physiological arousal indices including electrodermal activity (Brown, Polych, & Doan, 2006; Davis, Campbell, Adkin, & Carpenter, 2009; Huffman, Horslen, Carpenter, & Adkin, 2009; Pasman, Murnaghan, Bloem, & Carpenter, 2011; Zaback, Cleworth, Carpenter, & Adkin, 2015) and blood pressure (Carpenter et al., 2006; Sturnieks, Delbaere, Brodie, & Lord, 2016), as well as self-reports of more anxiety (Carpenter et al., 2006; Hauck, Carpenter, & Frank, 2008; Huffman et al., 2009; Pasman et al., 2011; Zaback et al., 2015), and greater fear of falling (Davis et al., 2009; Huffman et al., 2009; Pasman et al., 2011). Individuals also report other psychological changes including decreased confidence in balance abilities (Davis et al., 2009; Hauck et al., 2008; Huffman et al., 2009; Pasman et al., 2011; Zaback et al., 2015) and decreased perceptions of stability (Hauck et al., 2008; Huffman et al., 2009; Pasman et al., 2011) when standing under conditions of height-related threat. These findings provide converging evidence for the use of this model to investigate the influence of emotional state on postural control.

Quiet stance is the most common postural task that has been studied using the surface height model. When standing at, or close to the edge of an elevated platform up to 1.6 m above the ground, healthy young adults (Adkin, Frank, Carpenter, & Peysar, 2000; Carpenter et al., 1999; Carpenter, Frank, Silcher, & Peysar, 2001a; Hauck et al., 2008;

Zaback et al., 2015), healthy older adults (Brown et al., 2006; Carpenter et al., 2006; Sturnieks et al., 2016), and individuals with Parkinson's disease (Pasman et al., 2011) demonstrate reductions in COP amplitude and increases in COP frequency compared to standing at ground level. Postural threat effects on postural control are more pronounced when visual information is available and when standing at the platform edge (Carpenter et al., 1999). In addition, threat-related changes in postural control are scaled to the level of threat, with increasing surface heights up to 1.6 m eliciting progressive increases in COP frequency and decreases in COP amplitude (Adkin et al., 2000). Based on the theoretical basis that the body is modeled as an inverted pendulum (Winter, 1995), reductions in COP amplitude coupled with increases in COP frequency in the AP direction are representative of an ankle stiffening strategy (Winter, Patla, Prince, Ishac, & Gielo-Periczak, 1998). The CNS increases ankle joint stiffness by adjusting plantarflexor and dorsiflexor muscle tone, resulting in tighter control over the COM within the BOS (Winter et al., 1998). Experimental evidence has confirmed this hypothesis, demonstrating increased co-contraction of lower leg muscles and reductions in COM displacements when threatened by increases in surface height (Carpenter et al., 2001a). The stiffening strategy observed under height-related threat is typically accompanied by a posterior shift of the COP-MPOS, which represents leaning away from the platform edge (Adkin et al., 2000; Brown et al., 2006; Carpenter et al., 2001a; Huffman et al., 2009; Stins, Roerdink, & Beek, 2011; Zaback et al., 2015).

Researchers have also examined the effects of height-induced postural threat on anticipatory and reactive components of postural control. Height-induced postural threat elicits reductions in APA peak amplitude and velocity (Adkin, Frank, Carpenter, &

Peysar, 2002; Zaback et al., 2015), as well as significant delays and reductions in lower leg muscle activity (Adkin et al., 2002). Furthermore, APAs are initiated earlier when performing a rapid leg raise task (Gendre, Yiou, Gélât, Honeine, & Deroche, 2016; Yiou, Deroche, Do, & Woodman, 2011) but not when performing a rise-to-toes task (Adkin et al., 2002) at elevated surface heights compared to ground level. Reductions in COM displacement have been observed in response to forward pushes to the trunk (Brown & Frank, 1997) and unexpected support surface rotations (Carpenter, Frank, Adkin, Paton, & Allum, 2004) at height. Increased surface height also elicits increased amplitude of balance-correcting responses of arm, trunk, and leg muscles, earlier deltoid responses, and reductions in trunk, pelvis, and leg angular displacements (Carpenter et al., 2004). These studies provide evidence for the influence of postural threat on neuromuscular mechanisms that contribute to dynamic postural control.

Reductions in COP amplitude and increases in COP frequency during quiet stance appear to be a characteristic response to increases in surface height. However, this response is inconsistent with the strategy observed in fearful older adults standing on the ground (i.e., increased amplitude of COP displacements; Maki et al., 1991). A possible explanation for this discrepancy is that the surface height manipulation elicits an anxious response rather than a fear response. Fear is conceptualized as a state of sustained activation of cortex-amygdala processes while anxiety may influence a greater range of CNS processes including multisensory integration, which may differentially contribute to postural control (Staab et al., 2013). By increasing the height of the platform on which individuals stand to > 9 m, individuals demonstrate significant increases in COP amplitude (Alpers & Adolph, 2008; Nakahara et al., 2000; Simeonov & Hsiao, 2001)

compared to reductions in COP amplitude observed at lower heights. Direct comparison of self-reported fearful and non-fearful young adults revealed that both groups leaned away from the edge and demonstrated increased COP frequency when standing at 3.2 m, however, fearful individuals significantly increased COP amplitude compared to non-fearful individuals (Davis et al., 2009). Similarly, comparisons of trait-anxious and non-anxious older adults revealed that both groups increased COP frequency when standing on an elevated platform 65 cm above ground level, however, non-anxious older adults reduced COP amplitude whereas trait-anxious older adults demonstrated no change (Sturnieks et al., 2016). Collectively, these studies suggest that threat-related postural control is influenced by the level of postural threat and/or individual tendencies to experience anxiety or fear.

1.4.2 Postural perturbations

Postural threat has also been manipulated by altering the expectation of receiving a postural perturbation. When standing in anticipation of receiving a support surface translation, healthy young individuals increase self-reports of state anxiety and demonstrate increased physiological arousal (Johnson, Zaback, Tokuno, Carpenter, & Adkin, 2017; Phanthanourak, Cleworth, Adkin, Carpenter, & Tokuno, 2016), which supports the use of standing in anticipation of receiving a postural perturbation to assess postural threat influences on postural control. When characteristics of an upcoming perturbation are known, the CNS issues a preparatory motor command to preselect the muscles involved in the postural response and the sequence of their activation (Shumway-Cook & Woollacott, 2006). The resultant anticipatory posture is largely

influenced by the context of the perturbation. For example, when anticipating a support surface translation in the AP plane, leaning forward is the most appropriate strategy as it has been shown to efficiently counteract both forward and backward body movement caused by a perturbation (Maki & Whitelaw, 1993). However, changes in quiet standing such as leaning may not be advantageous in anticipation of a perturbation that can occur in multiple potential directions (Carpenter et al., 2004). Quiet stance in anticipation of a perturbation may facilitate the postural response to a perturbation (Horak, Diener, & Nashner, 1989; Rajachandrakumar, Mann, Schinkel-Ivy, & Mansfield, 2018; Tokuno, Carpenter, Thorstensson, & Cresswell, 2006). For example, leaning in the same direction as an AP support surface translation has been associated with less overall muscle activity and earlier antagonistic muscle onsets, compared to leaning in the opposite direction (Tokuno et al., 2006). In addition to leaning, healthy individuals have been shown to modify quiet stance in anticipation of a perturbation by scaling ankle torque to predictable support surface displacement velocities and amplitudes (Horak & Diener, 1994). These adjustments, which are intact in healthy individuals, are impaired in many individuals with neurologic deficits (Horak & Diener, 1994).

Healthy young adults anticipating an AP support surface translation demonstrate increases in COP amplitude and frequency (Johnson et al., 2017) and adopt a forward lean; changes in forward leaning have been associated with threat-induced changes in anxiety and arousal (Johnson et al., 2017; Maki & Whitelaw, 1993). When standing in anticipation of receiving vibratory calf muscle stimulation, healthy young adults adopt a strategy that is observed in patients with phobic postural vertigo (i.e., increased high frequency sway; Holmberg, Tjernström, Karlberg, Fransson, & Magnusson, 2009;

Querner, Krafczyk, Dieterich, & Brandt, 2000). Furthermore, healthy young adults increase trunk sway amplitude and velocity in the pitch and roll directions when anticipating an external trunk perturbation (Shaw, Stefanyk, Frank, Jog, & Adkin, 2012). These studies provide converging evidence for anxiety-related increases in postural sway when standing in anticipation of receiving a postural perturbation.

Age may alter the ability to appropriately adjust postural control under certain threatening contexts. In contrast to the increase in trunk sway that is adopted by young adults, older adults reduce trunk sway in the roll (lateral) direction when anticipating a forward push or backward pull to the trunk (Shaw et al., 2012). Older adults tend to be more unstable in the ML direction (Maki & McIlroy, 1996a), and reducing trunk sway in anticipation of a perturbation is associated with greater instability (i.e., increased frequency of compensatory stepping; Rajachandrakumar et al., 2018). Therefore, anxious older adults appear to adopt an inappropriate postural control strategy when standing in anticipation of receiving a postural perturbation, which may put them at greater risk of falling.

Anticipatory and reactive postural control is also influenced by the threat of a perturbation. APA onsets were significantly delayed, and APA magnitudes were significantly greater in healthy young adults when anticipating a support surface translation (Phanthanourak et al., 2016). Fearful older adults demonstrate increased co-contraction of tibialis anterior and gastrocnemius muscles immediately following deceleration of a perturbation compared to non-fearful older adults (Okada, Hirakawa, Takada, & Kinoshita, 2001), and it has been suggested that fear of falling contributes to

the tendency to utilize multiple steps to recover balance from an unpredictable perturbation (Maki et al., 2000).

1.5 Potential mechanisms underlying threat-related changes in postural control

1.5.1 Physiological and psychological changes

Despite evidence of state emotional and postural changes with postural threat, the mechanisms underlying these responses are not completely understood. Postural threat elicits increases in physiological arousal (Brown et al., 2006; Carpenter et al., 2006; Davis et al., 2009; Huffman et al., 2009; Johnson et al., 2017; Phanthanourak et al., 2016; Zaback et al., 2015), which has been associated with increases in COP frequency (Horslen & Carpenter, 2011) and leaning (Maki & McIlroy, 1996b) during quiet stance and may contribute to threat-induced changes in postural control. Individuals also self-report increases in state anxiety and fear when threatened (Huffman et al. 2009; Pasman et al., 2011), which have been associated with increases in COP frequency (Davis et al., 2009), increases in COP amplitude (Johnson et al., 2017), and leaning further away from the edge (Huffman et al., 2009). Additionally, decreases in balance confidence have been reported when threatened (Carpenter et al., 2006; Davis et al., 2009; Hauck et al., 2008; Huffman et al., 2009; Pasman et al., 2011; Zaback et al., 2015), which has been associated with increases in COP frequency (Carpenter et al., 2006; Huffman et al., 2009). Collectively, these studies provide evidence for a relationship between state physiological and psychological changes and threat-related changes in postural control. State and trait psychological variables have been associated with changes in threat-induced postural control and are listed in Table 1.

Table 1. Associations between threat-induced changes in postural control and state psychological changes.

Reference	Threat	Postural measure	Psychological variable(s)
Carpenter et al., 2006	Height	↑ ML RMS-COP	↑ State anxiety
		↑ AP MPF-COP	↓ State coping efficacy
Hauck et al., 2008	Height	↓ AP MPF-COP	↑ State confidence
		↑ AP RMS-COP	↑ State perceived stability
Davis et al., 2009	Height	↑ AP MPF-COP	↑ State fear of falling
		↑ AP RMS-COP	↑ State fear of falling
Huffman et al., 2009	Height	↑ AP MPF-COP	↓ State balance confidence
		↓ AP MPOS-COP	↑ State CMP
			↑ State MSC
			↑ State anxiety
			↓ State perceived stability
Zaback et al., 2015	Height	↑ AP MPF-COP	↓ Trait PRT
		↑ AP RMS-COP	↑ Trait PRT
			↑ Trait CMP
		↓ AP RMS-COP	↓ Trait MSC
		↓ AP MPOS-COP	↑ Trait CMP
		↓ Trait PRT	
Zaback et al., 2016	Height	↓ APA amplitude	↑ Attention to TRS
		↑ AP MPF-COP	↑ Attention to MP
		↓ AP RMS-COP	↑ Attention to SRS
			↓ Attention to MP
Johnson et al., 2017	Perturbation	↑ AP MPF-COP	↑ Attention to SRS*
		↑ AP RMS-COP	↑ State anxiety
			↑ Attention to MP*
		↑ AP MPOS-COP	↑ Attention to MP*

Note: ML = mediolateral; RMS = root mean square; COP = centre of pressure; AP = anteroposterior; MPF = mean power frequency; CMP = conscious motor processing; MSC = movement self-consciousness; PRT = physical risk-taking; APA = anticipatory postural adjustment; TRS = threat-related stimuli; MP = movement processes.

* relationship was identified after perturbation experience. ↑ represents an increase, ↓ represents a decrease. For AP MPOS-COP, a ↑ represents a forward lean and a ↓ represents a backward lean

1.5.2 Changes in sensory gain and cortical activity

Sensory systems essential for postural control are influenced by postural threat. For example, postural threat elicits increases in muscle spindle sensitivity in lower leg muscles (Davis et al., 2011; Horslen, Murnaghan, Inglis, Chua, & Carpenter, 2013) and reductions in Ib reflexes associated with Golgi tendon organs (Horslen, Inglis, Blouin, & Carpenter, 2017). In addition, gains of vestibulo-spinal (Naranjo, Allum, Inglis, & Carpenter, 2015; Naranjo et al., 2016) and vestibulo-ocular (Naranjo et al., 2016) reflexes increase when threatened. Balance responses that are evoked through stimulation of the vestibular system also increase when threatened (Horslen, Dakin, Inglis, Blouin, & Carpenter, 2014; Lim et al., 2017) and evidence suggests feedback components of these responses contribute to increases observed at height (Osler, Tersteeg, Reynolds, & Loram, 2013). Cortical activity is also influenced by postural threat; the peak-to-peak amplitude of the N1 cortical response is increased when responding to a series of unexpected perturbations under high postural threat conditions compared to low threat (Adkin, Campbell, Chua, & Carpenter, 2008; Sibley, Mochizuki, Frank, & McIlroy, 2010). The N1 response is a negative potential occurring approximately 100-200ms following the onset of a perturbation and may represent error detection between expected and actual postural states (Adkin et al., 2008). In contrast, postural threat does not significantly alter earlier cortical potentials (Davis et al., 2011; Sibley et al., 2010).

1.5.3 Changes in perception

Changes in perception have also been reported when standing at elevated surface heights. Fear or anxiety have been associated with changes in visual perceptions of height

magnitude (Clerkin, Cody, Stefanucci, Proffitt, & Teachman, 2009), auditory perception of the intensity of auditory tones (Siegel & Stefanucci, 2011), and tactile perception of the magnitude of pain (Rhudy & Meagher, 2000). When threatened by increases in surface height, individuals generally overestimate bodily symptoms related to anxiety (Alpers & Adolph, 2008) and demonstrate a disparity between conscious perception of postural sway and real changes in postural control (Cleworth & Carpenter, 2016). This disparity between perception of sway and real postural sway may be a result of the modifications to the sensory systems mentioned above. Alternatively, it may be due to a shift in attention toward conscious control of posture. In addition to the mechanisms identified above, attention appears to contribute to threat-related changes in postural control. This thesis will focus on attention and its role in modifying postural control under no threat and threat conditions.

1.6 Influence of attention on postural control

1.6.1 Cognitive requirements for postural control

Postural control was traditionally considered an automatic sensorimotor skill, without the requirement of higher cognitive processes (Woollacott & Shumway-Cook, 2002). However, evidence from dual task paradigms has confirmed a relationship between cognitive function and postural control (Kerr, Condon, & McDonald, 1985; Lajoie, Teasdale, Bard, & Fleury, 1993; Teasdale, Bard, Larue, & Fleury, 1993; Woollacott & Shumway-Cook, 2002). The dual task paradigm assumes that processing capacity is finite (Kahneman, 1973) and that concurrent performance of a cognitive and postural task compete for attentional resources; if this capacity is exceeded, performance

on one or both tasks is compromised. Thus, dual task interference can be assessed by comparing differences in single task performance on the cognitive and postural task and simultaneous performance of both tasks. When performing a cognitive and postural task simultaneously, research has shown performance impairments on the cognitive task (Kerr et al., 1985; Lajoie et al., 1993; Maylor & Wing, 1996; Teasdale et al., 1993) and postural task (Pellecchia, 2003; Redfern, Jennings, Martin, & Furman, 2001a), which reflects prioritization of one task over the other. For example, increasing cognitive demand via challenging cognitive tasks has been shown to decrease ML COP displacement variability and increase ML COP frequency during quiet standing (Polskaia & Lajoie, 2016). The relationship between cognition and postural control is influenced by numerous factors such as the complexity of the postural (Lajoie et al., 1993; Redfern et al., 2001a) or cognitive task (Kerr et al., 1985), arousal (Brown, Sleik, Polych, & Gage, 2002; Gage, Sleik, Polych, McKenzie, & Brown, 2003; Maki & McIlroy, 1996b), and age (Huxhold, Li, Schmiedek, & Lindenberger, 2006; Lajoie, Teasdale, Bard, & Fleury, 1996; Woollacott & Shumway-Cook, 2002).

The attentional demands for postural control are generally greater in older compared to younger adults (Lajoie et al., 1996; Maylor & Wing, 1996; Redfern et al., 2001a; Teasdale et al. 1993) and as a result, older adults tend to commit more available attention to postural control (Redfern et al., 2001a; Woollacott & Shumway-Cook, 2002). Experimental manipulation of sensory systems, which elicits reweighting of sensory contributions to postural control, places increased attentional demands on older adults but not young adults (Shumway-Cook & Woollacott, 2000) and evidence suggests that sensory integration essential for postural control requires some degree of attention

(Redfern et al., 2001a). Furthermore, age-related declines in sensory system function are associated with impaired cognitive processing (Li & Lindenberger, 2002), which has been identified as a significant risk factor for increased falls (Holtzer et al., 2007). One approach to assess age-related cognitive declines is to observe whether older adults stop walking while talking (Lundin-Olsson, Nyberg, & Gustafson, 1997). Stop walking while talking may reflect greater attentional demands for movement in older adults, however, recent research has demonstrated that older adults who stop walking while talking have a greater tendency to focus attention internally and consciously control movement compared to older adults who do not stop walking while talking, independent of general levels of cognitive function (Young, Olonilua, Masters, Dimitriadis, & Williams, 2016). Therefore, consciously controlling movement appears to be an important cognitive factor that may contribute to postural control.

1.6.2 Attention focus

A large body of evidence has reported benefits to motor performance and learning when directing attention toward the effect of a movement (i.e., external focus of attention) when performing a motor skill compared to directing attention toward the mechanics of a movement (i.e., internal focus of attention; Wulf, 2013). The constrained action hypothesis suggests that adopting an internal focus of attention interferes with the automatic processes involved in postural control, whereas adopting an external focus of attention allows these automatic processes to remain uninterrupted (Wulf, McNevin, & Shea, 2001). This phenomenon has been shown to benefit performance on a variety of postural tasks across several age groups, including older adults (Wulf, 2013).

Under certain circumstances such as performing a motor skill under psychological pressure, the performer of the task reinvests cognitive effort into consciously controlling movement (Masters & Maxwell, 2008). Consciously attending to movement execution involves processing task-relevant declarative knowledge in working memory, which disrupts movement automaticity (Masters & Maxwell, 2008) and subsequently, impairs motor learning and performance (Masters, 1992; Vuillerme & Nafati, 2007). This process, termed ‘movement reinvestment’ is an individual personality trait (Masters, Polman, & Hammond, 1993) and can be assessed using the Movement Specific Reinvestment Scale (MSRS; Masters, Eves, & Maxwell, 2005). The MSRS assesses two domains of movement reinvestment; conscious motor processing (CMP) and movement self-consciousness (MSC). CMP is an assessment of an individual’s tendency for consciously controlling or monitoring the mechanics of movement during a task and MSC measures an individual’s concern about the appearance of their movement during a task. Higher scores on the MSRS have been associated with greater ML postural sway amplitude in young adults (Uiga, Capio, Ryu, Wilson, & Masters, 2018), duration of Parkinson’s disease (Masters, Pall, MacMahon, & Eves, 2007), individuals with knee pain (Selfe et al., 2015), functional impairment after a stroke (Orrell, Masters, & Eves, 2009), and increased fall risk in older adults (Wong, Masters, Maxwell, & Abernethy, 2008). Although these domains are often considered together as a unidimensional trait, research has found weak associations between them and findings suggest each domain may differentially affect performance (van Ginneken et al., 2017). This literature provided the impetus for exploring state changes in movement reinvestment under conditions of increased postural threat. Since movement reinvestment is elicited by fall-

related anxiety in older adults who are at risk of falling (Wong et al., 2008), it is important to understand the relationship between conscious control or monitoring of movement and postural control.

1.6.3 Threat-induced changes in attention

Brown et al. (2002) calculated a prioritization index to quantify the relationship between cognitive and postural task performance under threat and no threat conditions. When performing the Brooks' Spatial Letter task while standing under conditions of height-induced postural threat, young adults increased both postural and cognitive task performance compared to no threat conditions. In contrast, older adults performed worse on the cognitive task but improved performance on the postural task. This finding suggests older adults prioritize posture at the expense of cognitive task performance (Brown et al., 2002). The effect of postural threat on dual-task performance has also been demonstrated during gait as evidenced by increased reaction times to a concurrent probe reaction time task while walking along an elevated walkway (Gage et al., 2003). It was hypothesized that the relationship between impaired processing efficiency and postural threat is mediated by consciously controlling movement (Gage et al., 2003); this hypothesis has been experimentally confirmed (Ellmers & Young, 2018).

Research has theorized that postural control strategies observed in individuals with phobic postural vertigo (i.e., increases in > 0.1 Hz COP displacements during quiet standing) are a result of consciously controlling movement during quiet standing that can be normalized by directing attention away from posture (Wuehr, Brandt, & Schniepp, 2017). Experimental evidence indicates that healthy young adults report adopting greater

conscious control of posture when standing (Huffman et al., 2009; Johnson et al., 2017; Zaback, Carpenter, & Adkin, 2016) or walking (Ellmers & Young, 2018; Young et al., 2016) under conditions of postural threat compared to no threat conditions. Using a modified version of the MSRS, Huffman et al. (2009) measured state changes in CMP and MSC and found that participants reported greater levels of both state CMP and state MSC when standing at 3.2m compared to ground level. Furthermore, increases in state anxiety and CMP were associated with threat-induced posterior leaning (Huffman et al., 2009), confirming a direct relationship between threat-related changes in attention and postural control. Relationships between trait movement reinvestment and threat-induced changes in postural control have also been identified. For example, individuals prone to consciously control movement processes (high in trait CMP) are more likely to lean further away from the edge of a high platform and exhibit larger COP amplitudes, whereas individuals more self-conscious of the appearance of their movement (high in trait MSC) are more likely to exhibit smaller COP amplitudes (Zaback et al., 2015).

Consciously controlling or monitoring movement may not be the only change in attention focus that occurs when threatened. Based on assumptions of Attentional Control Theory (ACT), anxious individuals have an attentional bias to threat-related stimuli but invest additional on-task effort to maintain task performance and/or employ alternative processing strategies to help alleviate anxiety (Eysenck, Derakshan, Santos, & Calvo, 2007). This assumption has been supported by research using a dot probe paradigm, which has shown that fearful older adults have difficulty disengaging from fall-relevant stimuli (Brown, White, Doan, & de Bruin, 2011). Accordingly, fearful or anxious older adults may fail to identify environmental features that could potentially serve as

obstacles, which can negatively impact balance performance and movement planning. With attention shifted away from proactive postural control during cognitively demanding tasks, anxious older adults may increase fall risk due to a reduction in working memory of visual-spatial information of their environment (Young & Williams, 2015).

The assumptions of ACT were experimentally confirmed using an open-ended question (i.e., “What did you think about or direct your attention toward during the balance task?”) coupled with a follow-up interview to assess changes in attention focus when standing under no threat and height-related threat conditions (Zaback et al., 2016). Based on participant responses, five attention focus categories were generated including attention to movement processes, task objectives, threat-related stimuli, self-regulatory strategies, and task-irrelevant information. When threatened by increases in surface height, individuals directed more attention to movement processes, threat-related stimuli, and self-regulatory strategies, and less attention to task objectives and task-irrelevant information compared to no threat conditions (Zaback et al., 2016). Furthermore, threat-induced increases in attention focus to movement processes were associated with greater increases in COP frequency while threat-induced decreases in attention to movement processes and/or increases in attention to self-regulatory strategies were associated with greater decreases in COP amplitude (Zaback et al., 2016).

Johnson et al. (2017) quantified attention focus in young adults standing under no threat and threat conditions using the attention focus categories identified by Zaback et al. (2016). Postural threat was manipulated by altering 1) the expectation of a postural perturbation during stance, and 2) experience with the perturbation. The postural

perturbation was a temporally and directionally unpredictable support surface translation in the forward or backward direction. There were three threat conditions: 1) no threat of a perturbation, 2) threat of a perturbation without prior threat experience, and 3) threat of a perturbation with threat experience. Individuals anticipating a support surface translation exhibited increased arousal and self-reported anxiety, and reported directing more attention to movement processes, threat-related stimuli, and self-regulatory strategies, and less attention to task-irrelevant information compared to standing without the possibility of a perturbation (Johnson et al., 2017). When anticipating the perturbation without prior experience, individuals demonstrated increases in COP frequency and amplitude. However, after experiencing a perturbation, individuals further increased COP frequency and decreased COP amplitude. Relationships between threat-related changes in anxiety, attention focus, and postural control were also identified. For example, prior to experiencing a support surface perturbation, threat-induced change in self-reported anxiety was the strongest contributor to changes in COP amplitude, compared to no threat conditions (Johnson et al., 2017). Conversely, threat-induced changes in attention focus were the strongest contributors to changes in postural control after experiencing the threat. Specifically, threat-induced increases in attention to movement processes were associated with leaning further forward and increases in COP amplitude, while threat-induced increases in attention to self-regulatory strategies were associated with increases in COP frequency (Table 1). This work provided evidence for a direct relationship between threat-induced changes in postural control and changes in attention focus when standing with the threat of an unpredictable support surface translation that was dependent on threat experience. Although experience was shown to influence threat-

related postural changes, participants only experienced two perturbations in this study. Thus, it is unknown how threat-induced changes in attention focus adapt over longer exposure periods to postural threat.

1.7 Adaptation to postural threat

Adaptation refers to a series of adjustments that allow a process to function more adequately in a given situation and is critical for effective postural control. Adaptation allows humans to adjust sensorimotor systems in response to changing task and environmental constraints and underlies the ability to improve postural control with training or practice (Horak, Henry, & Shumway-Cook, 1997). Efficient postural control adaptation relies on 1) expectation of task or environmental characteristics (Horak et al., 1989) and 2) experience with task or environmental characteristics (Maki & Whitelaw, 1993). When static postural control is challenged via repeated exposure to vibratory stimulation of calf muscles, stability is maintained through postural control adaptations including gradual decreases in vibration-induced body sway (Fransson, Johansson, Hafström, & Magnusson, 2000; Tjernström, Fransson, Hafström, & Magnusson, 2002) and adopting a forward lean (Fransson, Kristinsdottir, Hafstrom, Magnusson, & Johansson, 2004). Adaptations of the postural response to perturbations have also been observed. Typically, a platform perturbation with unknown magnitude and velocity produces an overcompensated initial postural response (Hansen, Woollacott, & Debu, 1988; Horak et al., 1989), otherwise known as the first trial reaction (Allum, Tang, Carpenter, Oude Nijhuis, & Bloem, 2011). It has been suggested that the first trial reaction is a consequence of a generalized startle response, which habituates with

repeated perturbations (Campbell, Squair, Chua, Inglis, & Carpenter, 2013). Likewise, the amplitude of postural reactions may be reduced with practice or exposure to the threat in healthy young adults, particularly when the magnitude and direction of perturbations are identical (Hansen et al., 1988). Afferent feedback assists with scaling the magnitude of postural responses to the magnitude and velocity of the perturbation; this adaptation occurs within 3-20 identical perturbations (Horak et al., 1989).

Adaptation of postural control is an important assumption of exercise interventions aimed at reducing falls in older adults. Many fall-prevention studies have subjected older adults to repeated trials of unexpected transient support surface perturbations to explore adaptation of postural reactions over time. During the first trial of a series of perturbations, older adults exhibit poorer compensatory stepping responses compared to young adults (Maki et al., 2000; Mille, Johnson, Martinez, & Rogers, 2005; Mille et al., 2013). For example, older adults exhibit greater body displacement (Dijkstra, Horak, Kamsma, & Peterson, 2015) and adopt a distinct cross-over compensatory stepping strategy compared to young adults who typically use a single sideways step during lateral compensatory stepping (Maki et al., 2000; Mille et al., 2005). Despite these differences in postural strategy compared to young adults, older adults maintain the ability to adapt postural responses. For example, older adults can adapt compensatory responses to match performance of young adults with repeated perturbations (Dijkstra et al., 2015). Older adults can also adapt AP (Fransson et al., 2004) and ML postural control (Patel, Fransson, & Magnusson, 2009) to repeated vibratory calf muscle stimulation. However, impaired adaptation of postural control to sinusoidally moving platforms has been observed in older adults (Bugnariu & Sveistrup, 2006; Fujiwara, Kiyota, Maeda, &

Horak, 2007), which suggests that older adults may not adapt to all forms of postural perturbations. Furthermore, an inability to adapt to repeated perturbations has been observed in patients with Parkinson's disease (Nanhoe-Mahabier et al., 2012).

Limited work has explored individuals' capacity to adapt threat-related postural changes. When exposed to repeated vibratory perturbations, patients with PPV were unable to reduce high frequency postural sway with visual information removed but reduced postural sway more than healthy controls when standing with eyes open (Tjernström, Fransson, Holmberg, Karlberg, & Magnusson, 2009). The authors suggest that visual information imposes a sensory mismatch for PPV patients, which elicits a threat to stability and forces them to adapt postural control. When anticipating a postural threat in the form of an external perturbation, healthy young adults lean further forward (Maki & Whitelaw, 1993; Johnson et al., 2017) but gradually reduce forward leaning with gained experience (Maki & Whitelaw, 1993). Individuals also increase COP amplitude and frequency when initially threatened but reduce COP amplitude and further increase COP frequency after gaining experience with the threat (Johnson et al., 2017). Arousal may mediate threat-induced adaptations of postural control. For example, reductions in forward leaning observed with repeated threat exposure were associated with reductions in arousal (Maki & Whitelaw, 1993). This speculation is supported by evidence demonstrating impaired adaptation to vibratory calf muscle stimulation with sleep deprivation (Patel et al., 2008). Collectively, this research suggests that repeated exposure to postural threat elicits postural control adaptations. However, research has suggested that adaptation of postural control occurs independent of postural threat (Brown & Frank, 1997). For example, displacement of the COM became gradually less

restricted as young adults responded to a series of forward pushes to the trunk, regardless of postural threat (Brown & Frank, 1997).

1.8 Limitations to current research

It has been established that individuals report broad changes in attention focus when threatened, including consciously controlling or monitoring movement (Huffman et al., 2009; Johnson et al., 2017; Zaback et al., 2016), attending to threat-related stimuli, and using coping strategies to reduce anxiety (Johnson et al., 2017; Zaback et al., 2016). However, threat-induced changes in attention focus and their context-dependent relationships with postural control are only generalizable to healthy young adults. Based on age-related differences in attentional requirements for postural control (Woollacott & Shumway-Cook, 2002), older adults may not direct attention to loci of attention focus reported in young adults when threatened. Alternatively, older adults may report directing attention to loci of attention focus that were not captured by previous research (Zaback et al., 2016). Regardless, quantification of threat-induced changes in attention focus of older adults is warranted. The relationships between threat-induced changes in attention focus and postural control are also dependent on threat experience (Johnson et al., 2017). However, these relationships were calculated after participants had experienced only two perturbations, and postural control has been shown to adapt with somewhat longer periods of threat exposure (Brown & Frank, 1997; Maki & Whitelaw, 1993). Therefore, threat-induced changes in anxiety, attention focus, and postural control may also adapt with repeated threat exposure.

Chapter Two: Rationale, Purpose, & Hypotheses

2.1 *Rationale*

Postural control is a complex sensorimotor process that is influenced by an individual's emotional state (Delbaere et al., 2010; Hadjistavropoulos et al., 2011; Staab et al., 2013; Young & Williams, 2015). By manipulating postural threat, researchers can investigate the influence of fall-related emotions such as fear and anxiety on postural control. Often, this involves manipulating the height at which individuals stand or altering the expectation of receiving a postural perturbation. For example, young (Zaback et al., 2015) and older adults (Carpenter et al., 2006) lean away from the edge and adopt a stiffening strategy when standing at, or close to the edge of an elevated platform. When standing in anticipation of receiving an AP support surface translation at ground level, young adults lean forward and increase COP amplitude and frequency (Johnson et al., 2017). Collectively, this research provides evidence for context-dependent changes in postural control (i.e., related to leaning and COP amplitude) under threat. In addition, age may alter the ability to adjust postural control under certain threat contexts (Shaw et al., 2012). Compared to young adults, who increase trunk sway when standing in anticipation of receiving an external perturbation to the trunk, older adults reduce lateral trunk sway (Shaw et al., 2012). Individuals are more unstable (i.e., increased frequency of compensatory stepping) when adopting this type of strategy prior to receiving a postural perturbation (Rajachandrakumar et al., 2018), so older adults may adopt a threat-induced postural control strategy that puts them at greater risk of falling (Maki & McIlroy, 1996a). Therefore, age-related differences in postural control may be revealed using a perturbation threat.

Threat-induced changes in attention focus contribute to changes in postural control with threat experience (Johnson et al., 2017). Compared to young adults, older adults have a greater attentional requirement for balance (Lajoie et al., 1996; Maylor & Wing, 1996; Redfern et al., 2001a) and may commit more available attention to postural control (Woollacott & Shumway-Cook, 2002). Directing more attention to postural control has been shown to influence performance on different postural tasks (Vuillemere & Nafati, 2007; Wulf, 2013), and has the potential to influence threat-induced changes in postural control (Johnson et al., 2017; Zaback et al., 2016). Thus, attention may be an important contributor to the initial differences in threat-induced (i.e., perturbation) postural control observed between healthy young and older adults (Shaw et al., 2012) and may contribute to adaptation of threat-induced postural control.

There is some evidence to suggest that young adults can modulate threat-induced postural control changes based on previous experience (Brown & Frank, 1997; Johnson et al., 2017; Maki & Whitelaw, 1993). However, this work is limited by the predictability of the perturbation direction (i.e., forward push to the trunk; Brown & Frank, 1997) and the limited period of exposure to the threat (i.e., two perturbations; Johnson et al., 2017). Furthermore, older adults' capacity to adapt threat-induced postural control changes has not been explored. Fall-prevention studies have shown that older adults initially exhibit poorer stepping responses compared to young adults (Maki et al., 2000; Mille et al., 2005, 2013) but can improve stepping responses with repeated perturbations (Dijkstra et al., 2015). Research has confirmed a link between compensatory responses and quiet standing prior to receiving a perturbation in young adults (Horak et al., 1989; Maki & Whitelaw, 1993; Rajachandrakumar et al., 2018; Tokuno et al., 2006), so compensatory

response adaptation may translate to adaptation of quiet stance. However, the influence of fall-related anxiety on these adaptive processes remains unknown. Exploring individuals' capacity to adapt threat-related responses might have important implications for the assessment of balance and the design and evaluation of interventions for older adults progressively debilitated by pathological anxiety or fear of falling (Zijlstra et al., 2007).

2.2 *Purpose and hypotheses*

The purpose of this thesis was to investigate initial threat-induced changes in emotional, cognitive, and postural control measures and the adaptation of these responses to repeated threat exposure in healthy young and older adults. Threat was manipulated by changing the expectation of a postural perturbation (ML support surface translation) during quiet standing. There was a no threat condition (no possibility of a perturbation), and first, early, and repeated threat exposure conditions (possibility of a temporally and directionally unpredictable perturbation). It was hypothesized that postural threat would elicit an emotional response and broad changes in attention focus in young and older adults that would return toward no threat levels with repeated threat exposure. In addition, it hypothesized that older adults would direct more attention to specific elements of attention focus including movement processes and threat-related stimuli compared to young adults. It was also hypothesized that age-related differences in postural control would emerge when initially threatened but would gradually diminish with repeated threat exposure, and young and older adults would adapt threat-induced changes in postural control with repeated threat exposure.

Chapter Three: Methods

3.1 *Participants*

Twenty-eight healthy older adults (13 female, mean \pm one standard deviation (SD) age = 70.1 ± 4.0 years, height = 170.9 ± 8.6 cm, weight = 75.6 ± 14.4 kg) and twenty-eight healthy young adults (17 female, mean \pm SD age = 22.2 ± 3.8 years, height = 171.4 ± 9.4 cm, weight = 69.8 ± 12.2 kg) volunteered to participate in this study. Participants were independently living in the community and were naïve to the general experimental procedure. Participants were excluded if they self-reported any neurological or musculoskeletal condition that could influence postural control or if they scored ≤ 23 (Carson, Leach, & Murphy, 2018) on the Montreal Cognitive Assessment (MoCA; (Nasreddine et al., 2005). Each participant provided written informed consent prior to the start of the experiment.

3.2 *Procedure*

All experimental procedures were approved by the Brock University Research Ethics Board (Appendix A) and the University of British Columbia Clinical Research Ethics Board (Appendix B). Data collection was conducted at two sites (Neural Control of Posture and Movement Laboratory, University of British Columbia, Vancouver, British Columbia and the Biomechanics and Motor Control Laboratory, Brock University, St. Catharines, Ontario). The experimental configuration and the ability for participants to step to recover balance was consistent between the two sites.

3.2.1 *Individual characteristics*

First, the primary student investigator administered the MoCA to each participant (Nasreddine et al., 2005). The MoCA assesses cognitive abilities across several domains including memory, attention, language, concentration, verbal abstraction, and visuospatial abilities. It is used as a brief screening tool for mild cognitive impairment and is more sensitive than the Mini-Mental State Examination for detecting individuals with mild cognitive impairment (Dong et al., 2012). Scores on the MoCA range from 0-30, with a score of ≥ 26 representative of normal cognitive functioning, although re-examination of this guideline has recommended a cut-off score of ≥ 23 (Carson et al., 2018).

Next, participants completed a series of questionnaires assessing specific individual characteristics. The Demographic and Health questionnaire was used to obtain demographic (e.g., age, sex) measures, fall history (number of falls in the past year), and any significant medical conditions that could affect postural control (Appendix C). Anthropometric measures (e.g., height, weight, foot length, heel to ankle length) were obtained after completing this questionnaire.

The Activity-Specific Balance Confidence Scale (ABC; Powell & Myers, 1995; Appendix D) was used to assess participants' confidence in maintaining balance during the performance of activities of daily living (e.g., walking around the house). This questionnaire features 16-items rated on a numerical scale from 0% ("no confidence") to 100% ("extremely confident"). Each participant's ABC score is determined by summing the score for each item on the questionnaire and dividing by 16. Scores at or above 80% are indicative of a high level of physical functioning (Myers, Fletcher, Myers, & Sherk,

1998), while scores below 67% are predictive of older adults who are at risk of falling (Lajoie & Gallagher, 2004).

The State-Trait Anxiety Inventory (STAI; Spielberger, Gorsuch, Lushene, Vagg, & Jacobs, 1983; Appendix E) was used to assess trait anxiety. This questionnaire features 20-items that reflect an individual's tendency for anxious feelings (e.g., "I feel nervous and restless"). Each item is rated on a 4-point Likert scale from 1 ("Almost never") to 4 ("Almost always") based on how often participants generally experience each statement. Therefore, scores on the STAI range from 20-80 with higher scores representing greater trait anxiety.

The Movement Specific Reinvestment Scale (MSRS; Masters et al., 2005; Appendix F) was used to assess an individual's tendency to reflect on aspects of their movement. This questionnaire features two 5-item subscales assessing conscious motor processing (CMP; e.g., "I rarely forget the times when my movements have failed me, however slight the failure") and movement self-consciousness (MSC; e.g., "I'm self-conscious about the way I look when I am moving"). Each item is rated on a 6-point Likert scale from "Strongly disagree" to "Strongly agree". Each subscale ranges from 5-30, with higher scores on the CMP and MSC subscales representing a greater tendency to consciously control movements and reflect on or monitor one's movement style, respectively.

The Everyday Risk-Taking Scale (ERTS; Butler, Lord, Taylor, & Fitzpatrick, 2015; Appendix G) was used to assess an individual's tendency to perform daily activities that may place them at a greater risk of falling (e.g., "Do you sit down to put on your shoes and socks?"). This questionnaire features 10-items that are rated on a 4-point

Likert scale from 1 (“Always”) to 4 (“Never”). The ERTS ranges from 10-40, with higher scores representing a greater tendency to avoid performing activities associated with a greater risk of falling.

The Domain-Specific Risk-Taking Scale (DOSPERT; Blais & Weber, 2006; Appendix H) was used to assess an individual’s tendency to perform risky behaviours across five domains (ethical, social, health and safety, financial, and recreational). This questionnaire features 30-items that are rated on a 7-point Likert scale ranging from 1 (“Extremely unlikely”) to 7 (“Extremely likely”). Due to the nature of the threat used in this thesis, only the six items contained within the recreational domain were examined (e.g., “Going down a ski run that is beyond your ability”). Thus, this subscale ranges from 7-42, with higher scores representing a greater tendency to engage in activities that impose a physical risk.

3.2.2 *Experimental configuration*

Participants stood on a force plate (OR6-7, AMTI, Watertown, MA, USA, $n=27$; BP-400600-OP, AMTI, Watertown, MA, USA, $n=29$) embedded in a wooden platform (0.9 m x 1.6 m, $n=27$; 0.6 m x 1.2 m, $n=29$) for all conditions (Figure 1). The force plate and platform were affixed to a 4.3 m linear positioning stage (H2W Technologies Inc., Valencia, CA, USA), with a total elevation of 0.3 m. Previous research has shown that standing on a platform with an elevation of 0.3 m and no step restriction is insufficient to impose any height-related threat effects (Carpenter et al., 1999). Participants stood barefoot with their arms relaxed at their sides, and their gaze focused on an eye-level target located on the wall 2.5 m away. Participants’ stance width was equidistant to their

foot length and was kept consistent across all conditions by outlining participants' feet with tape. Throughout the experiment, participants wore a harness attached to a track along the ceiling. The harness did not bear any weight during quiet stance and only provided support in the event of a loss of balance. A spotter stood behind participants during all trials to ensure safety.

3.2.3 Postural threat manipulation

Postural threat was manipulated through the expectation of receiving a postural perturbation to upright stance. The perturbation was a temporally and directionally unpredictable support surface translation that could occur in the left- or rightward direction (displacement = 0.25 m, peak velocity = 0.6 m/s, peak acceleration = 1.4 m/s²). Participants stood with no expectation of receiving a perturbation (No Threat) and with the expectation of receiving a perturbation (Threat). An outline of the No Threat and Threat trials is presented in Figure 1 and Appendix I.

Participants completed one 60 s practice trial of quiet standing with the platform position locked and with no expectation of receiving a perturbation to minimize possible first trial effects on postural control (Adkin et al., 2000) and to prime the state questionnaires (see Section 3.3.2 and 3.3.3); data from this trial were not analyzed. Next, participants completed another 60 s quiet standing trial with the platform locked and no expectation of receiving a perturbation (No Threat). Following this trial, participants observed the platform translate once in either direction while seated in a chair positioned away from the platform. This was done to provide participants with information about the nature of the threat that may be experienced. Participants then completed 24 trials in the

Threat condition where they stood quietly on the platform with the expectation that it could translate at any time during the trial. A perturbation was delivered after a random delay (from 5-60 s) following the start of each trial. Participants completed 24 trials in the Threat condition, and subsequently, responded to 24 unpredictable perturbations. Following each trial, participants dismounted the platform. After specific trials, participants completed a series of questionnaires (see Section 3.3.2 and 3.3.3); participants stood for a 20 s rest period after all other trials. No restrictions were placed on the strategy that participants could use to recover balance (i.e., participants were free to step). To minimize fatigue, participants were given a rest period in between trials and were encouraged to rest if they began to feel fatigued.

During specific trials in the Threat condition, a postural perturbation occurred after a 60 s delay (i.e. participants stood for an entire 60 s with the expectation of receiving a perturbation). These trials represented 60 s of quiet standing in anticipation of receiving a perturbation and could be used to compare 60 s standing trials. During the first trial of the Threat condition (prior to gaining perturbation experience), participants stood for a full 60 s before receiving a perturbation (Threat_{FIRST}). Participants received a perturbation during the second (rightward at 15 s) and third (leftward at 45 s) trials of the Threat condition and stood for 60 s during the fourth Threat trial before receiving a perturbation (Threat_{EARLY}). This early section of the protocol resembles the threat protocol used in previous research (Johnson et al., 2017) and was used to determine the effects of first and early threat exposure. The only difference was that there was no perturbation delivered after the Threat_{FIRST} and Threat_{EARLY} conditions in the Johnson et al. (2017) study. During the last Threat trial, participants stood for 60 s before receiving a

perturbation; this trial represented repeated threat exposure (Threat_{REPEATED}). All other trials in the Threat condition (i.e., trials where a perturbation could occur anytime between 5 and 60 s following the start of the trial) served to prevent predictability of threat timing and were excluded from statistical analysis. The exposure period to the threat, including all Threat trials and completion of state questionnaires following specific trials, was approximately 50 minutes. The order of trials in the threat condition was fixed across all participants (see Figure 1 and Appendix I).

A second No Threat trial was performed after the Threat condition to account for a possible order effect between threat conditions (Adkin et al., 2000). Like the first No Threat trial, participants stood for 60 s with the platform position locked and no expectation of receiving a perturbation.

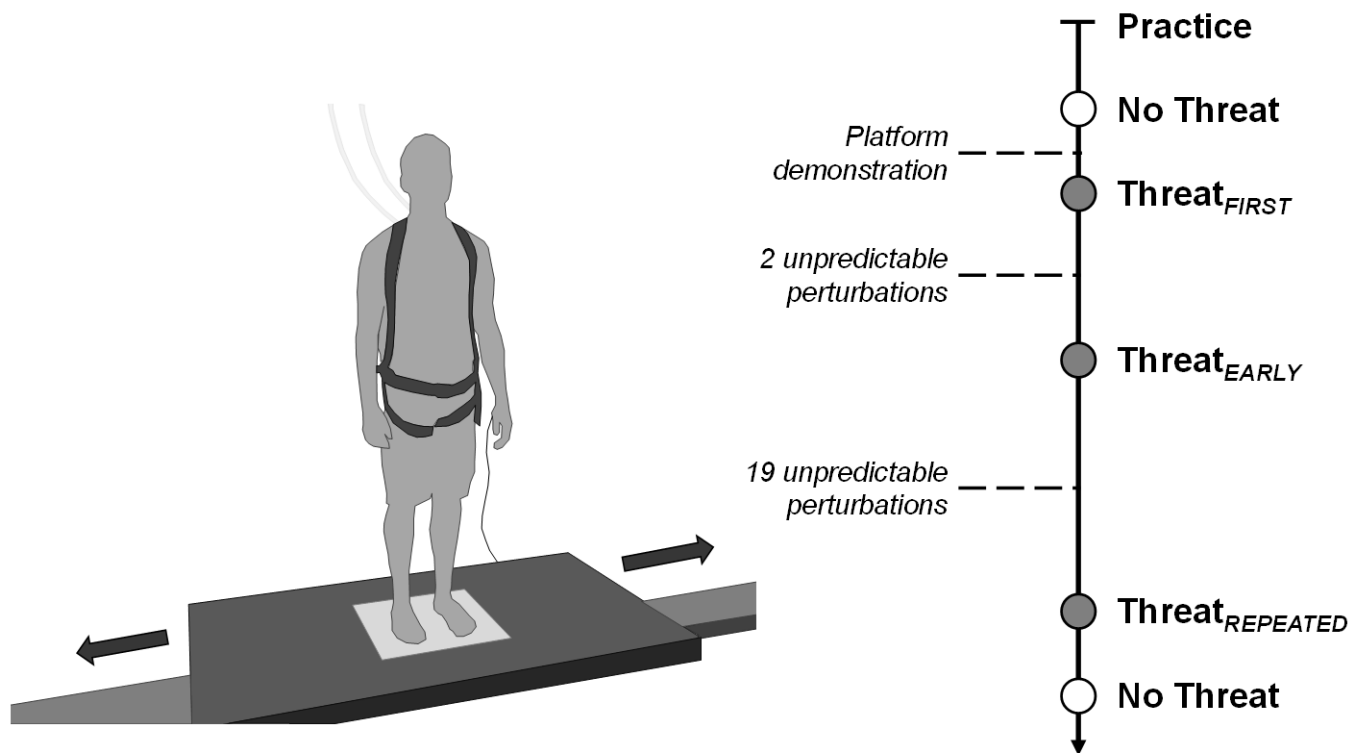


Figure 1. Outline of experimental configuration and experimental procedure. White circles represent 60 second No Threat trials and grey circles represent 60 second Threat trials used in the statistical analysis. See Appendix I for timing (range 5-60 s) and direction (left / right) of each perturbation in the series, as well as timing of questionnaires

3.3 *Dependent measures*

3.3.1 *Physiological arousal*

To estimate changes in physiological arousal, electrodermal activity (EDA) was measured using an exosomatic method outlined by Boucsein and colleagues (2012). A constant voltage of 0.5 V was applied to two silver-silver chloride (Ag/AgCl) electrodes (EL-507, BIOPAC Systems Inc., USA), which were placed on the thenar and hypothenar eminences of the non-dominant hand (EDA100C, BIOPAC Systems Inc., USA, $n=27$; Model 2502SA, CED, UK, $n=29$). Prior to electrode placement, a skin preparation gel was applied to the palmar recording sites to improve skin conductivity (NuPrep, Weaver and Company, USA). EDA data was A/D sampled at 100 Hz (Micro1401, CED, UK, $n=27$; Power1401, CED, UK, $n=29$), and recorded using Spike2 software (CED, Cambridge, UK). From EDA data, electrodermal responses (EDRs) were calculated. EDRs represent a tonic measurement of electrodermal activity, and were defined as a peak greater than 0.08 $\mu\text{S/s}$ that remained greater than 0.04 $\mu\text{S/s}$ for at least 400 ms to either side of the peak (Boucsein et al., 2012). All EDA calculations were performed using a custom MATLAB script (MATLAB R2018a, MathWorks, USA).

3.3.2 *State psychological measures*

Following each 60 s No Threat standing trial and selected 60 s Threat standing trials (see Appendix I), participants completed two questionnaires assessing state anxiety and attention focus while seated on a chair located away from the platform. State questionnaires were only given on select Threat trials to prevent predictability of 60 s

threat trials. The state anxiety questionnaire was comprised of two elements of state anxiety: worry-related anxiety (1 item) and somatic anxiety (1 item). Worry-related anxiety was rated on a scale ranging from 0 (“I was not at all worried”) to 100 (“I was very worried”) for the question “How worried were you when performing the balance task (e.g., worried about losing balance, worried about performing the task incorrectly, etc.)?”. Somatic anxiety was rated on a scale ranging from 0 (“I did not feel anxious at all”) to 100 (“I felt very anxious”) for the question “How physically anxious (e.g., tense or nervous) did you feel when performing the balance task?”. Responses to both questions were averaged to produce a total state anxiety score (Johnson et al., 2017; Appendix J).

3.3.3 *Attention focus measures*

Participants rated how much they thought about or directed attention to information related to (1) movement processes, (2) task objectives, (3) threat-related stimuli, (4) self-regulatory strategies, and (5) task-irrelevant information following each 60 s trial (Appendix K; Johnson et al., 2017; Zaback et al., 2016). Examples were provided for each category. Each item was rated on a 9-point Likert scale from 1 (“Not at all”) to 9 (“Very much so”). An additional space at the bottom of the questionnaire provided participants with the opportunity to list any additional thoughts they had during the previous trial.

3.3.4 *Postural control measures*

Ground reaction forces and moments from the force plate were sampled at 100 Hz and low-pass filtered offline using a second order dual-pass Butterworth filter with a cut-off frequency of 5 Hz. The COP signal was calculated in both the AP and ML directions. MPOS-COP was calculated to determine the average location of the COP over each 60 s trial and was referenced to the ankle joint in the AP direction and participants' midstance in the ML direction. MPOS-COP was subtracted from each COP signal to un-bias the signal prior to calculating RMS-COP and MPF-COP measures. RMS-COP reflects the magnitude of COP position variability over each 60 s trial and MPF-COP reflects the average frequency contained within the COP power spectrum after fast Fourier transformation. These summary measures have been traditionally used to assess postural threat effects on COP control, however, they may not be sensitive enough to detect more dynamic properties of postural control (Williams, McClenaghan, & Dickerson, 1997). Power spectrum analysis is a useful technique which is more sensitive to dynamic properties of postural control (Singh, Taylor, Madigan, & Nussbaum, 2012) and may provide insight into contributions of sensory inputs to postural control (Redfern, Yardley, & Bronstein, 2001b). In addition, high frequency components of COP adjustments may be more sensitive to the effects of anxiety (Holmberg et al., 2009; Krafczyk et al., 1999). Power spectrum analysis was performed using a resolution of 0.0244 Hz and average power contained within low (0-0.1 Hz), medium (0.1-1.0 Hz), high (1.0-2.5 Hz), and very high (2.5-5.0 Hz) frequency bands were calculated. Thus, there were 14 postural control dependent measures.

3.4 *Statistical analysis*

3.4.1 *Descriptive statistics*

Descriptive statistics for individual characteristics, as well as state psychological, physiological, attention focus, and postural control measures were calculated for each age group across all postural threat conditions.

3.4.2 *Paired samples t-tests: No Threat conditions*

Paired samples t-tests were performed on all dependent measures to determine if the two No Threat trials were similar (Figure 2). Only two of 14 measures were significantly different between No Threat trials. Compared to the first No Threat trial, EDRs were lower in young and older adults and RMS-COP was greater in young adults but not older adults in the No Threat 2 trial. Based on these results, only the first No Threat trial was used in the subsequent statistical analyses (Johnson et al., 2017).

3.4.3 *Repeated measures ANOVA: Age, and No Threat and Threat conditions*

Separate repeated measures analysis of variance (RM-ANOVA) procedures with between-subject (age; young, old) and within-subject (threat; No Threat, Threat_{FIRST}, Threat_{EARLY}, Threat_{REPEATED}) factors were performed for each emotional, cognitive, and postural control dependent measure. For the RM-ANOVAs, a *p*-value of < 0.05 was used to indicate statistical significance.

Where significant threat main effects were identified, planned comparisons were performed to answer specific hypotheses. To determine the effects of first threat exposure without the confound of perturbation experience (Johnson et al., 2017), the Threat_{FIRST} condition was compared to the No Threat condition. Threat_{EARLY} was compared to Threat_{FIRST} to assess early threat exposure effects, and Threat_{REPEATED} was compared to Threat_{EARLY} to assess repeated threat exposure effects (Figure 2). The criterion for statistical significance was adjusted by dividing α by the number of planned comparisons to control for Type I error probability (Field, 2013). Therefore, comparisons were considered statistically significant at $p < 0.016$. Where significant interaction effects were identified, the above planned comparisons were conducted separately for young and older adult groups.

Note, to address concerns regarding the use of two testing sites, this analysis was conducted separately for each site (see Table 2). As significant main effects and interaction effects were the same for each site, data were collapsed for the remainder of the analysis.

Table 2. Outline of participant characteristics

	Brock University	University of British Columbia
Young adults	14 (11 F, 3 M)	13 (5 F, 8 M)
Older adults	11 (6 F, 5 M)	16 (7 F, 9 M)

Note: F = female; M = male

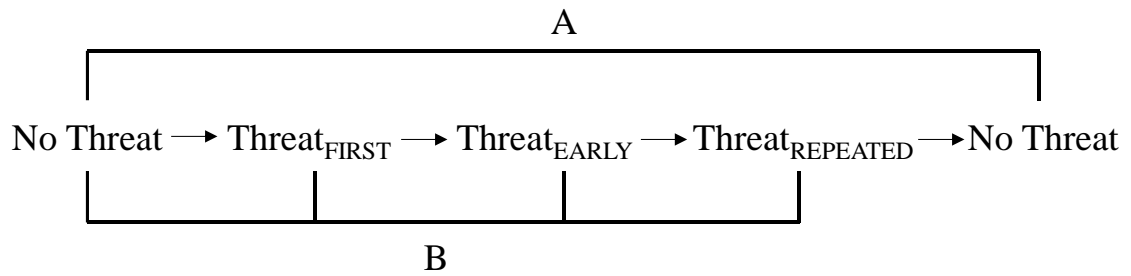


Figure 2. Outline of planned comparisons conducted in the course of the statistical analysis. A) paired samples t-tests were performed to determine whether the two No Threat conditions were similar, and B) planned comparisons were conducted to determine the effect of first, early, and repeated postural threat exposure on all dependent measures.

Chapter Four: Results

4.1 *Outliers and statistical assumptions*

All variables, including individual characteristics, and dependent measures for all experimental conditions were screened for univariate outliers within each age group. Data for these variables were converted to standardized z-scores and any z-score greater or less than ± 3.29 was identified as a univariate outlier. Any variables corresponding to this criterion were examined and replaced by a value ± 3 standard deviations of the mean in the direction it was previously outlying. Following replacement of each outlying variable, data were re-screened and any new outlying variables were replaced using this method (Tabachnick & Fidell, 2007). This procedure was repeated until there were no remaining outliers. One participant from each age group was identified as an outlier across multiple variables and was not included in the final statistical analysis. Therefore, the total sample size was 27 healthy older adults (13 female, mean \pm SD age = 70.0 ± 4.1 years, height = 170.4 ± 8.3 cm, weight = 75.4 ± 14.6 kg) and 27 healthy young adults (16 female, mean \pm SD age = 22.2 ± 3.9 years, height = 171.5 ± 9.6 cm, weight = 69.0 ± 11.7 kg).

Normality was assessed by calculating skewness and kurtosis statistics for each variable. Each skewness and kurtosis statistic was converted to a z-score by dividing each value by its standard error. Values greater or less than ± 3.29 were considered significantly skewed or kurtotic at $p < 0.001$ (Field, 2013). Some variables were identified as significantly skewed or kurtotic, although only minimally (Field, 2013). Despite some values violating the assumption of normality, all self-report variables were not transformed as these values reflect participants' true perceptions. Logarithmic transformations were performed on all COP power spectrum analysis data prior to

statistical analyses to correct for violations of normality. Initial uncorrected skewness and kurtosis values are presented in Table 3 for young adults and Table 4 for older adults.

Levene's test was used to assess the assumption of homogeneity of variance, which tests the null hypothesis that the variance for a given variable is roughly constant across groups (Field, 2013). While some variables moderately departed from this assumption, corrections were deemed unnecessary since this violation is only problematic with unequal group sizes (Field, 2013). Thus, the assumption of homogeneity of variance was met.

Mauchly's test was used to assess the assumption of sphericity, which tests the null hypothesis that the variances of the differences between conditions are roughly equal (Field, 2013). Where Mauchly's test indicated a violation of the assumption of sphericity, degrees of freedom were adjusted using the Greenhouse-Geisser estimate (Field, 2013).

Table 3. Skewness and kurtosis statistics for state cognitive, emotional, and postural measures for each threat condition for young adults.

	No Threat		Threat _{FIRST}		Threat _{EARLY}		Threat _{REPEATED}	
	Skewness	Kurtosis	Skewness	Kurtosis	Skewness	Kurtosis	Skewness	Kurtosis
EDRs	.328	-.904	-1.573	3.056*	-.442	-.117	.117	-.911
State Anxiety	2.476*	5.245*	-.348	-.875	-.053	-.867	.909	.035
Movement Processes	1.073	-.128	.302	-1.251	-.111	-1.499	.458	-1.407
Task Objectives	1.016	.418	-.121	-1.242	.282	-.861	.993	.063
Threat-related Stimuli	2.605*	5.704*	.687	-.382	.733	-.330	1.365	1.410
Self-regulatory Strategies	1.594*	1.353	1.065	.766	1.383	2.432	1.259	.851
Task-Irrelevant Information	.743	-.738	1.364	1.522	.829	-.023	.529	.047
ML MPOS-COP	-1.042	3.494*	.582	-.059	.068	-.688	-.199	-.670
ML RMS-COP	.904	.352	.554	-.109	.844	.457	.107	-.847
ML MPF-COP	.333	.094	.141	-1.052	.685	-.024	.843	1.627
ML 0-0.1 Hz	1.743*	2.969*	1.525*	1.955	1.489*	1.838	2.065*	4.147*
ML 0.1-1 Hz	2.524*	6.376*	1.940*	4.257*	2.156*	4.616*	1.719*	2.978*
ML 1-2.5 Hz	1.771*	3.273*	1.355	.604	1.389	.587	1.630*	2.123
ML 2.5-5 Hz	2.389*	4.870*	1.726*	2.906*	2.132*	4.331*	1.976*	3.729*
AP MPOS-COP	.549	-1.158	.464	-.774	.489	-.765	.521	-.923
AP RMS-COP	1.545*	2.814	1.387	2.856	1.836*	3.270*	.820	.464
AP MPF-COP	1.243	2.720	1.300	.411	1.105	.786	1.253	1.422
AP 0-0.1 Hz	1.266	.890	.894	-.102	1.053	-.148	.985	-.060
AP 0.1-1 Hz	2.102*	4.866*	1.902*	6.289*	3.164*	11.372*	.995	.644
AP 1-2.5 Hz	4.362*	21.024*	1.824*	2.646	1.541*	1.161	1.075	.175
AP 2.5-5 Hz	2.782*	8.029*	.998	-.192	1.898*	3.605*	2.768*	9.315*

Note: EDRs = electrodermal responses; ML = mediolateral; MPOS = mean position; COP = centre of pressure; RMS = root mean square; MPF = mean power frequency; AP = anteroposterior.

* indicates significant skewness or kurtosis with $p < 0.001$.

Table 4. Skewness and kurtosis statistics for state cognitive, emotional, and postural measures for each threat condition for older adults.

	No Threat		Threat _{FIRST}		Threat _{EARLY}		Threat _{REPEATED}	
	Skewness	Kurtosis	Skewness	Kurtosis	Skewness	Kurtosis	Skewness	Kurtosis
EDRs	.226	-.872	1.122	3.237*	.656	.065	.066	-.291
State Anxiety	1.965*	3.540*	-.348	-.875	.540	-.854	1.279	1.702
Movement Processes	.720	.323	.173	-1.080	.177	-1.310	.256	-1.493
Task Objectives	1.845*	3.196*	.725	-.855	.670	-.758	.799	-.971
Threat-related Stimuli	1.855*	2.080	.410	-1.342	.580	-.748	1.124	.236
Self-regulatory Strategies	1.626*	1.810	.504	-.289	.143	-1.216	.346	-1.417
Task-Irrelevant Information	.775	-.792	1.206	.097	1.053	-.234	1.315	.771
ML MPOS-COP	-.580	.306	.439	-.101	-.544	.363	-.456	.188
ML RMS-COP	.632	-.593	.282	-.355	.344	-.754	.098	-1.089
ML MPF-COP	-.543	-.401	.651	-.218	.307	-.613	.314	-.504
ML 0-0.1 Hz	1.793*	3.336*	.898	.472	1.967*	3.917*	1.662*	1.910
ML 0.1-1 Hz	1.697*	3.233*	1.720*	2.840	1.707*	3.041*	.610	-.933
ML 1-2.5 Hz	1.744*	3.061*	2.502*	6.116*	1.815*	3.069*	1.287	1.931
ML 2.5-5 Hz	2.398*	5.369*	1.474	2.961*	2.144*	4.442*	1.549*	1.452
AP MPOS-COP	.044	-1.302	.010	-1.180	-.051	-1.116	.223	-.740
AP RMS-COP	1.026	3.244*	1.434	2.807	.430	-.681	.501	-.032
AP MPF-COP	.471	-.246	1.149	2.546	.331	-.791	.628	.409
AP 0-0.1 Hz	1.280	1.623	1.320	1.622	.943	.211	2.095*	4.648*
AP 0.1-1 Hz	.714	.071	.945	.652	1.710*	2.324	.925	.352
AP 1-2.5 Hz	1.443	1.526	.815	.634	1.669*	1.837	.943	-.028
AP 2.5-5 Hz	1.275	.353	1.273	1.207	1.487*	1.514	1.224	.398

Note: EDRs = electrodermal responses; ML = mediolateral; MPOS = mean position; COP = centre of pressure; RMS = root mean square; MPF = mean power frequency; AP = anteroposterior. * indicates significant skewness or kurtosis with $p < 0.001$.

4.2 Descriptive statistics

Mean and standard deviation values for individual characteristics are presented in Table 5. Mean and standard deviation values for all state physiological, psychological, attention focus, and postural control measures across both age groups and all postural threat conditions are presented in Table 6 and Appendix L.

Table 5. Descriptive statistics for individual characteristics

	Young adults				Older adults			
	Mean	SD	Min	Max	Mean	SD	Min	Max
ABC (0-100)	95.98	4.53	82.50	100.00	95.39	4.40	83.10	100.00
MoCA (0-30)	28.96	1.22	26.00	30.00	28.33	1.49	25.00	30.00
STAI (20-80)	36.00	7.45	24.00	54.00	27.41	5.44	20.00	42.00
CMP (5-30)	16.37	4.52	9.00	24.00	13.37	5.81	5.00	23.00
MSC (5-30)	11.85	4.21	5.00	19.00	11.00	5.78	5.00	24.00
DOSPRT (6-42)	30.15	7.55	11.00	41.00	16.19	8.86	6.00	38.00
ERTS (10-40)	18.41	3.61	12.00	26.00	23.56	3.17	15.00	30.00

Note: SD = standard deviation; Min = Minimum; Max = Maximum; ABC = Activity-specific Balance Confidence scale; MoCA = Montreal Cognitive Assessment; STAI = State-Trait Anxiety Inventory; CMP = Conscious Motor Processing; MSC = Movement Self-Consciousness; DOSPRT = Domain Specific Risk-Taking scale; ERTS = Everyday Risk-Taking Scale.

Table 6. Mean and standard deviation values for all state emotional, cognitive, and postural measures.

Dependent Measure	No Threat		Threat _{FIRST}		Threat _{EARLY}		Threat _{REPEATED}	
	YA	OA	YA	OA	YA	OA	YA	OA
EDRs (EDR/min)	6.81 (4.98)	7.48 (4.09)	15.59 (5.01)	13.30 (3.28)	12.59 (4.19)	12.96 (3.18)	8.11 (4.83)	9.41 (3.26)
State Anxiety (%)	3.81 (9.18)	3.46 (6.13)	48.89 (20.91)	43.11 (26.44)	37.96 (20.39)	31.52 (26.30)	19.81 (18.00)	23.30 (22.78)
AF-MP (1-9)	2.56 (1.93)	2.15 (1.06)	4.00 (2.15)	4.26 (2.33)	4.56 (2.10)	4.41 (2.41)	3.44 (2.28)	4.22 (2.82)
AF-TOBJ (1-9)	3.04 (1.93)	2.44 (2.06)	4.22 (2.22)	3.52 (2.46)	3.81 (1.94)	3.41 (2.19)	3.22 (2.03)	3.52 (2.75)
AF-TRS (1-9)	1.34 (0.89)	1.33 (0.68)	4.33 (2.06)	3.33 (2.29)	3.37 (1.55)	3.37 (2.15)	2.26 (1.46)	2.48 (1.93)
AF-SRS (1-9)	1.96 (1.53)	2.37 (1.82)	2.89 (1.55)	3.70 (2.27)	2.52 (1.42)	3.67 (2.06)	2.11 (1.42)	3.37 (2.26)
AF-TII (1-9)	3.93 (2.72)	3.56 (2.71)	2.41 (1.58)	2.18 (1.62)	2.89 (1.67)	2.41 (1.91)	3.70 (2.11)	3.04 (2.46)
ML MPOS (mm)	0.61 (6.01)	-3.42 (10.75)	0.52 (6.35)	-1.50 (7.50)	-1.85 (6.95)	-2.24 (7.62)	1.15 (7.62)	-0.18 (6.51)
ML RMS (mm)	2.87 (1.07)	3.41 (1.27)	3.61 (1.25)	3.93 (1.25)	3.79 (1.54)	4.19 (1.36)	3.81 (1.46)	3.91 (1.36)
ML MPF (Hz)	0.21 (0.09)	0.23 (0.08)	0.30 (0.11)	0.32 (0.15)	0.34 (0.14)	0.38 (0.15)	0.29 (0.11)	0.38 (0.15)
ML 0-0.1 Hz (mm)	44.74 (45.25)	49.28 (48.75)	48.52 (45.25)	45.37 (36.22)	50.02 (45.37)	50.29 (51.79)	49.44 (58.69)	39.53 (43.80)
ML 0.1-1 Hz (mm)	4.74 (5.06)	6.14 (5.41)	7.25 (5.86)	11.05 (11.07)	6.89 (7.29)	11.43 (10.57)	7.46 (6.19)	9.53 (6.87)
ML 1-2.5 Hz (mm)	0.14 (0.15)	0.25 (0.31)	0.39 (0.44)	0.55 (0.75)	0.65 (0.74)	1.18 (1.34)	0.37 (0.43)	0.85 (0.76)
ML 2.5-5 Hz (mm)	0.004 (0.006)	0.008 (0.011)	0.009 (0.010)	0.010 (0.008)	0.021 (0.026)	0.038 (0.043)	0.014 (0.017)	0.038 (0.043)
AP MPOS (mm)	63.94 (42.21)	65.58 (42.21)	65.18 (35.15)	65.88 (39.77)	63.83 (37.55)	65.82 (41.37)	58.77 (39.60)	63.38 (39.77)
AP RMS (mm)	4.87 (1.87)	4.78 (1.62)	5.04 (1.70)	5.62 (1.88)	5.59 (3.02)	5.37 (1.68)	5.40 (2.26)	6.15 (2.04)
AP MPF (Hz)	0.17 (0.07)	0.24 (0.11)	0.19 (0.09)	0.26 (0.13)	0.20 (0.11)	0.27 (0.11)	0.18 (0.09)	0.23 (0.08)
AP 0-0.1 Hz (mm)	83.06 (80.59)	76.91 (54.42)	101.8 (73.89)	96.34 (88.56)	74.90 (57.33)	89.10 (76.08)	108.7 (105.0)	99.09 (116.5)
AP 0.1-1 Hz (mm)	4.98 (4.56)	7.37 (4.44)	7.15 (4.22)	10.80 (6.75)	8.26 (9.42)	13.63 (12.01)	7.01 (4.20)	13.08 (9.05)
AP 1-2.5 Hz (mm)	0.21 (0.32)	0.52 (0.48)	0.35 (0.38)	0.63 (0.41)	0.54 (0.62)	1.09 (1.16)	0.29 (0.25)	0.72 (0.56)
AP 2.5-5 Hz (mm)	0.005 (0.008)	0.014 (0.014)	0.009 (0.010)	0.017 (0.014)	0.019 (0.022)	0.037 (0.034)	0.011 (0.015)	0.033 (0.031)

Note: YA = young adults; OA = older adults; EDRs = electrodermal responses; AF = attention focus to; MP = movement processes; TOBJ = task objectives; TRS = threat-related stimuli; SRS = self-regulatory strategies; TII = task-irrelevant information; ML = mediolateral; MPOS = mean position; RMS = root mean square; MPF = mean power frequency. Negative ML MPOS values represent a leftward COP position shift and positive values represent a rightward COP position shift. Increases in AP MPOS values represent anterior shifts in COP position and decreases represent posterior shifts in COP position.

4.3 Repeated measures ANOVA

Results from the RM-ANOVAs are presented in Table 7.

Table 7. Repeated measures ANOVA statistics.

Measure	Threat			Age			Threat x Age		
	<i>F</i>	<i>p</i>	η_p^2	<i>F</i>	<i>p</i>	η_p^2	<i>F</i>	<i>p</i>	η_p^2
EDRs	78.78	< 0.001	0.60	0.00	0.992	0.00	4.28	0.009	0.08
State Anxiety	92.72	< 0.001	0.64	0.27	0.604	0.01	1.55	0.212	0.03
AF-MP	25.70	< 0.001	0.33	0.06	0.811	0.00	1.96	0.141	0.04
AF-TOBJ	7.19	< 0.001	0.12	0.47	0.498	0.01	1.55	0.204	0.03
AF-TRS	43.50	< 0.001	0.46	0.29	0.594	0.01	2.63	0.062	0.05
AF-SRS	9.75	< 0.001	0.16	4.82	0.033	0.09	1.46	0.235	0.03
AF-TII	10.18	< 0.001	0.16	0.89	0.349	0.02	0.21	0.843	0.00
ML MPOS-COP	2.46	0.065	0.04	1.38	0.245	0.03	1.20	0.313	0.02
ML RMS-COP	10.70	< 0.001	0.17	1.27	0.264	0.02	0.64	0.569	0.01
ML MPF-COP	18.14	< 0.001	0.26	4.03	0.050	0.07	1.62	0.186	0.03
ML 0-0.1 Hz	1.18	0.319	0.02	0.01	0.911	0.00	0.23	0.876	0.00
ML 0.1-1 Hz	9.68	< 0.001	0.16	2.63	0.111	0.05	1.09	0.357	0.02
ML 1-2.5 Hz	35.28	< 0.001	0.40	4.16	0.046	0.07	1.11	0.344	0.02
ML 2.5-5 Hz	53.11	< 0.001	0.50	5.29	0.025	0.09	1.72	0.176	0.03
AP MPOS-COP	4.02	0.013	0.07	0.04	0.836	0.00	0.70	0.532	0.01
AP RMS-COP	3.61	0.020	0.07	0.36	0.550	0.01	1.29	0.282	0.02
AP MPF-COP	2.02	0.113	0.04	12.01	0.001	0.19	0.29	0.834	0.01
AP 0-0.1 Hz	0.49	0.687	0.01	0.00	0.986	0.00	0.62	0.602	0.01
AP 0.1-1 Hz	10.72	< 0.001	0.17	6.10	0.017	0.11	0.23	0.878	0.00
AP 1-2.5 Hz	15.13	< 0.001	0.23	10.00	0.003	0.16	0.32	0.757	0.01
AP 2.5-5 Hz	28.28	< 0.001	0.35	10.06	0.003	0.16	0.60	0.586	0.01

Note: EDRs = electrodermal responses; AF = attention focus to; MP = movement processes; TOBJ = task objectives; TRS = threat-related stimuli; SRS = self-regulatory strategies; TII = task-irrelevant information; ML = mediolateral; MPOS = mean position; COP = centre of pressure; RMS = root mean square; MPF = mean power frequency; AP = anteroposterior.

4.3.1 Electrodermal responses

A significant threat main effect for EDRs was observed ($F_{(2.61, 135.88)} = 78.78, p < 0.001$; Figure 3a). EDRs were significantly greater with first threat exposure ($p < 0.001$; Threat_{FIRST} compared to No Threat). EDRs significantly decreased with early threat exposure ($p < 0.001$; Threat_{EARLY} compared to Threat_{FIRST}) and with repeated threat exposure ($p < 0.001$; Threat_{REPEATED} compared to Threat_{EARLY}). There was no significant age main effect for EDRs ($F_{(1, 52)} = 0.00, p = 0.992$). However, there was a significant interaction effect for EDRs ($F_{(2.61, 135.88)} = 4.28, p = 0.009$; Figure 4), which supersedes the Threat main effect. In young adults, EDRs significantly increased in the Threat_{FIRST} condition compared to No Threat ($p < 0.001$) and significantly decreased in the Threat_{EARLY} compared to Threat_{FIRST} condition ($p < 0.001$). In older adults, EDRs significantly increased in the Threat_{FIRST} condition compared to No Threat ($p < 0.001$) but did not significantly change in the Threat_{EARLY} condition compared to the Threat_{FIRST} condition ($p = 0.558$). EDRs significantly decreased in young ($p < 0.001$) and older ($p < 0.001$) adults with repeated threat exposure.

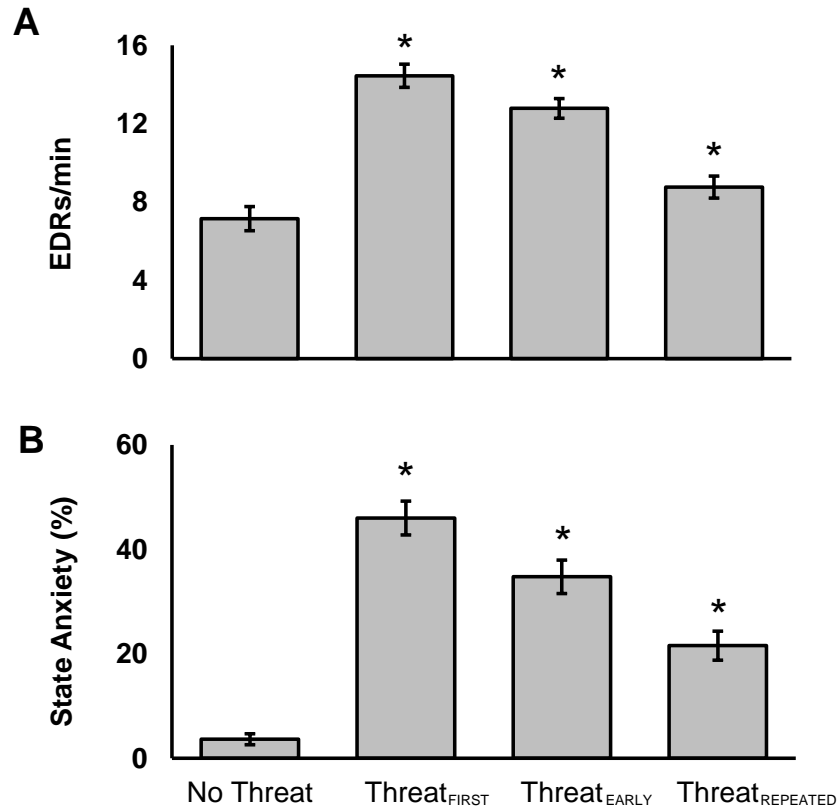


Figure 3. Postural threat main effects for a) electrodermal responses and b) state anxiety. * represents significantly different ($p < 0.016$) than the previous condition.

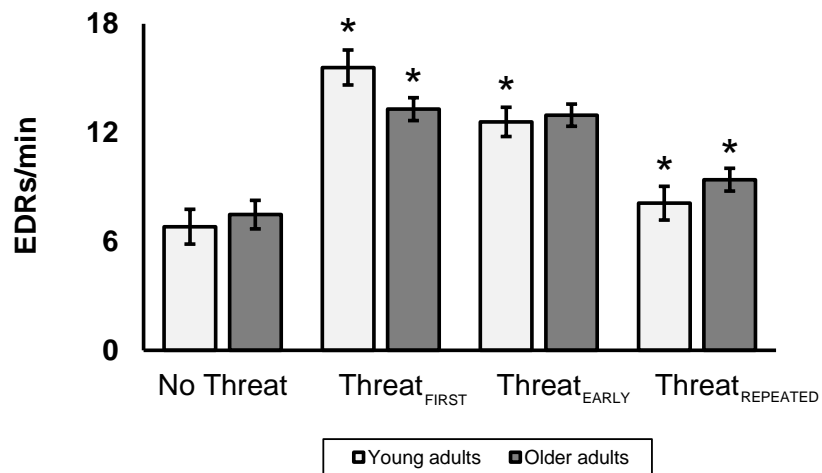


Figure 4. Electrodermal responses for each age group. * represents significantly different ($p < 0.016$) than the previous condition for each age group.

4.3.2 *State anxiety*

There was a significant threat main effect for state anxiety ($F_{(2.45, 127.60)} = 92.72, p < 0.001$; Figure 3b). Participants reported significantly greater state anxiety with first threat exposure ($p < 0.001$; Threat_{FIRST} compared to No Threat). State anxiety significantly decreased with early threat exposure ($p < 0.001$; Threat_{EARLY} compared to Threat_{FIRST}) and repeated threat exposure ($p < 0.001$; Threat_{REPEATED} compared to Threat_{EARLY}). There was no significant age main effect or age x threat interaction effect for state anxiety (Table 7).

4.3.3 *Attention focus*

All attention focus data are presented in Figure 5. A significant threat main effect for attention to movement processes was observed ($F_{(2.20, 114.53)} = 25.70, p < 0.001$; Figure 5a). Participants reported directing significantly more attention to movement processes with first threat exposure ($p < 0.001$; Threat_{FIRST} compared to No Threat). There was no significant difference in attention to movement processes with early threat exposure ($p = 0.052$; Threat_{EARLY} compared to Threat_{FIRST}). Participants reported directing significantly less attention to movement processes with repeated threat exposure ($p = 0.004$; Threat_{REPEATED} compared to Threat_{EARLY}). There was no significant age main effect or age x threat interaction effect for attention to movement processes (Table 7).

A significant threat main effect for attention to task objectives was observed ($F_{(2.69, 139.64)} = 7.19, p < 0.001$; Figure 5b). Participants reported directing significantly more attention to task objectives with first threat exposure ($p < 0.001$; Threat_{FIRST}

compared to No Threat). No significant differences in attention to task objectives were observed with early threat exposure ($p = 0.246$; Threat_{EARLY} compared to Threat_{FIRST}) or with repeated threat exposure ($p = 0.244$; Threat_{REPEATED} compared to Threat_{EARLY}). There was no significant age main effect or age x threat interaction effect for attention to task objectives (Table 7).

A significant threat main effect for attention to threat-related stimuli was observed ($F_{(2.54, 131.81)} = 43.50, p < 0.001$; Figure 5c). Participants reported directing significantly more attention to threat-related stimuli with first threat exposure ($p < 0.001$; Threat_{FIRST} compared to No Threat). There was no significant difference in attention to threat-related stimuli with early threat exposure ($p = 0.027$; Threat_{EARLY} compared to Threat_{FIRST}), however, participants reported directing significantly less attention to threat-related stimuli with repeated threat exposure ($p < 0.001$; Threat_{REPEATED} compared to Threat_{EARLY}). There was no significant age main effect or age x threat interaction effect for attention to threat-related stimuli (Table 7).

A significant threat main effect for attention to self-regulatory strategies was observed ($F_{(2.24, 116.57)} = 9.75, p < 0.001$; Figure 5d). Participants reported directing significantly more attention to self-regulatory strategies with first threat exposure ($p < 0.001$; Threat_{FIRST} compared to No Threat). No significant differences in attention to self-regulatory strategies were observed with early threat exposure ($p = 0.225$; Threat_{EARLY} compared to Threat_{FIRST}) or with repeated threat exposure ($p = 0.022$; Threat_{REPEATED} compared to Threat_{EARLY}). There was a significant age main effect for attention to self-regulatory strategies ($F_{(1, 52)} = 4.82, p = 0.033$). Independent of threat, older adults reported directing significantly more attention to self-regulatory strategies ($M = 3.28, SD$

= 1.79) compared to young adults ($M = 2.37$, $SD = 1.19$). There was no significant age x threat interaction effect observed for attention to self-regulatory strategies (Table 7).

A significant threat main effect for attention to task-irrelevant information was observed ($F_{(2,29, 119.03)} = 10.18$, $p < 0.001$; Figure 5e). Participants reported directing significantly less attention to task-irrelevant information with first threat exposure ($p < 0.001$; Threat_{FIRST} compared to No Threat). No significant differences in attention to task-irrelevant information were observed with early threat exposure ($p = 0.027$; Threat_{EARLY} compared to Threat_{FIRST}), however, participants reported directing significantly more attention to task-irrelevant information with repeated threat exposure ($p = 0.011$; Threat_{REPEATED} compared to Threat_{EARLY}). There was no significant age main effect or age x interaction effect for attention to task-irrelevant information (Table 7).

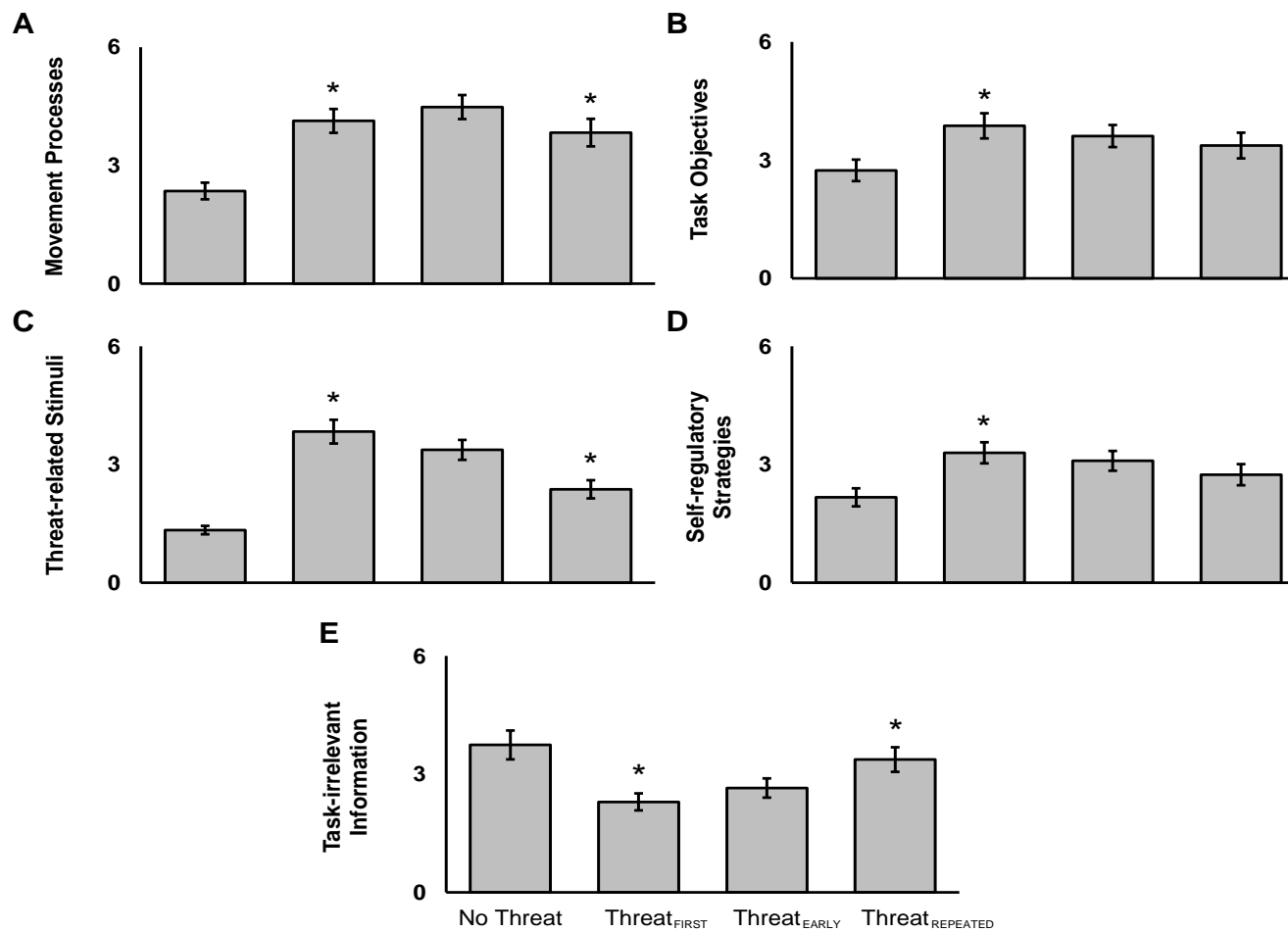


Figure 5. Postural threat main effects for attention focus to a) movement processes, b) task objectives, c) threat-related stimuli, d) self-regulatory strategies, and e) task-irrelevant information. * represents significantly different ($p < 0.016$) than the previous condition.

4.3.4 Postural control

Representative profiles for a young and older adult participant for the No Threat and Threat_{FIRST} conditions are presented in Appendix M.

4.3.4.1 ML postural control

All data from traditional ML COP measures are presented in Figure 6, and all data from ML COP power spectrum analysis are presented in Figure 7.

There was no significant threat main effect, age main effect, or age x threat interaction effect observed for ML MPOS-COP (Figure 6a; Table 7).

RM-ANOVA revealed a significant threat main effect for ML RMS-COP ($F_{(2.59, 134.56)} = 10.70, p < 0.001$; Figure 6b). ML RMS-COP significantly increased with first threat exposure ($p < 0.001$; Threat_{FIRST} compared to No Threat). No significant differences in ML RMS-COP were observed with early threat exposure ($p = 0.132$; Threat_{EARLY} compared to Threat_{FIRST}) or with repeated threat exposure ($p = 0.405$; Threat_{REPEATED} compared to Threat_{EARLY}). There was no significant age main effect or age x threat interaction effect for ML RMS-COP (Table 7).

A significant threat main effect for ML MPF-COP was observed ($F_{(3, 156)} = 18.14, p < 0.001$; Figure 6c). ML MPF-COP significantly increased with first threat exposure ($p < 0.001$; Threat_{FIRST} compared to No Threat). ML MPF-COP also significantly increased with early threat exposure ($p = 0.004$; Threat_{EARLY} compared to Threat_{FIRST}), however, there was no significant difference in ML MPF-COP with repeated threat exposure ($p =$

0.200; Threat_{REPEATED} compared to Threat_{EARLY}). There was no significant age main effect or age x threat interaction effect for ML MPF-COP (Table 7).

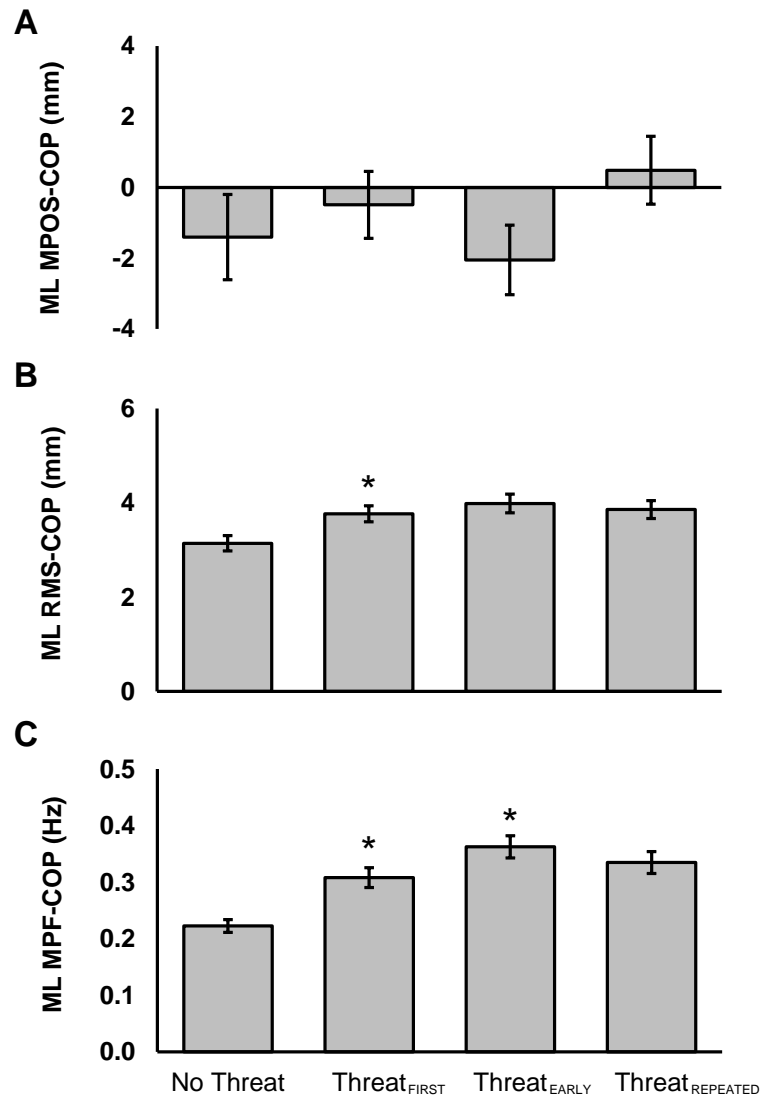


Figure 6. Postural threat main effects for a) ML MPOS-COP, b) ML RMS-COP, and c) ML MPF-COP. * represents significantly different ($p < 0.016$) than the previous condition. Negative ML MPOS-COP values represent leftward COP shift and positive values represent a rightward COP shift.

There was no significant threat main effect, age main effect, or age x threat interaction effect observed for ML COP power within 0-0.1 Hz (Figure 7a; Table 7).

A significant threat main effect for ML COP power within 0.1-1 Hz was observed ($F_{(3, 156)} = 9.68, p < 0.001$; Figure 7b). COP power within 0.1-1 Hz significantly increased with first threat exposure ($p < 0.001$; Threat_{FIRST} compared to No Threat). There was no significant difference in COP power within 0.1-1 Hz with early threat exposure ($p = 0.643$; Threat_{EARLY} compared to Threat_{FIRST}) and with repeated threat exposure ($p = 0.699$; Threat_{REPEATED} compared to Threat_{EARLY}). There was no significant age main effect or age x threat interaction effect for COP power within 0.1-1 Hz (Table 7).

A significant threat main effect for ML COP power within 1-2.5 Hz was observed ($F_{(2.55, 132.69)} = 35.28, p < 0.001$; Figure 7c). ML COP power within 1-2.5 Hz significantly increased with first threat exposure ($p < 0.001$; Threat_{FIRST} compared to No Threat) and with early threat exposure ($p < 0.001$; Threat_{EARLY} compared to Threat_{FIRST}). ML COP power within 1-2.5 Hz significantly decreased with repeated threat exposure ($p = 0.001$; Threat_{REPEATED} compared to Threat_{EARLY}). A significant age main effect for ML COP power within 1-2.5 Hz was observed ($F_{(1, 52)} = 4.16, p = 0.046$). Independent of threat, older adults had significantly greater ML COP power within 1-2.5 Hz ($M = 0.71, SD = 0.61$) compared to young adults ($M = 0.39, SD = 0.40$). There was no significant age x threat interaction effect for ML COP power within 1-2.5 Hz (Table 7).

A significant threat main effect for ML COP power within 2.5-5 Hz was observed ($F_{(2.45, 127.50)} = 53.11, p < 0.001$; Figure 7d). ML COP power within 2.5-5 Hz significantly increased with first threat exposure ($p < 0.001$; Threat_{FIRST} compared to No Threat) and

with early threat exposure ($p < 0.001$; Threat_{EARLY} compared to Threat_{FIRST}). ML COP power within 2.5-5 Hz significantly decreased with repeated threat exposure ($p = 0.008$; Threat_{REPEATED} compared to Threat_{EARLY}). A significant age main effect for ML COP power within 2.5-5 Hz was observed ($F_{(1, 52)} = 5.29, p = 0.025$). Independent of threat, older adults had significantly greater ML COP power within 2.5-5 Hz ($M = 0.023, SD = 0.022$) compared to young adults ($M = 0.012, SD = 0.014$). There was no significant age x threat interaction effect for ML COP power within 2.5-5 Hz (Table 7).

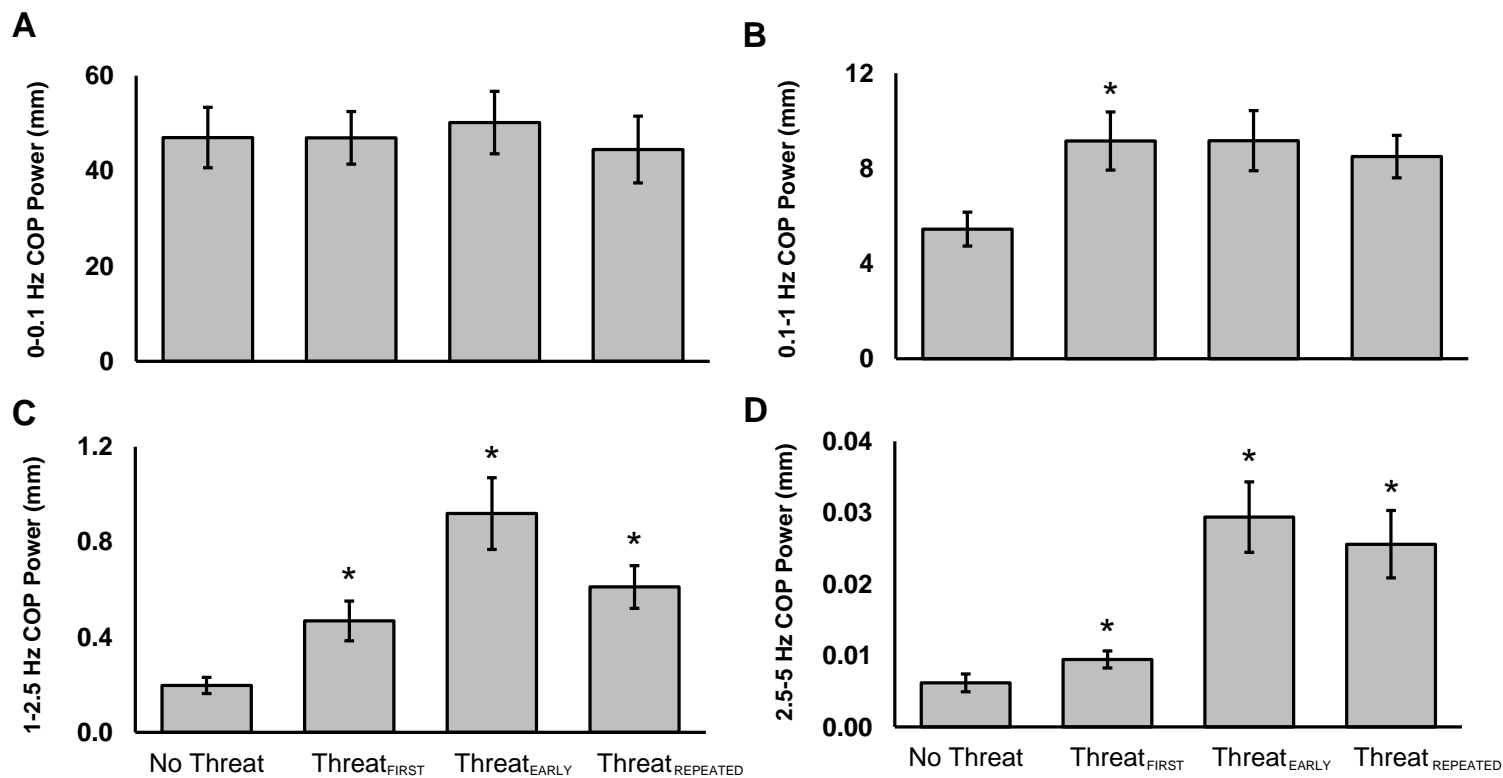


Figure 7. Postural threat main effects for a) low frequency (0-0.1 Hz) ML COP power, b) medium frequency (0.1-1 Hz) ML COP power, c) high frequency (1-2.5 Hz) ML COP power, and d) very high frequency (2.5-5 Hz) ML COP power. * represents significantly different ($p < 0.016$) than the previous condition.

4.3.4.2 AP postural control

All data from traditional AP COP measures are presented in Figure 8, and all data from COP power spectrum analysis are presented in Figure 9.

A significant threat main effect for AP MPOS-COP was observed ($F_{(2.53, 131.44)} = 4.02, p = 0.013$; Figure 8a). There were no significant differences in AP MPOS-COP with first threat exposure ($p = 0.598$; Threat_{FIRST} compared to No Threat) or early threat exposure ($p = 0.471$; Threat_{EARLY} compared to Threat_{FIRST}). However, AP MPOS-COP significantly shifted backwards with repeated threat exposure ($p = 0.010$; Threat_{REPEATED} compared to Threat_{EARLY}). There was no significant age main effect or age x threat interaction effect for AP MPOS-COP (Table 7).

A significant threat main effect for AP RMS-COP was observed ($F_{(2.56, 133.19)} = 3.61, p = 0.020$; Figure 8b). AP RMS-COP significantly increased with first threat exposure ($p = 0.013$; Threat_{FIRST} compared to No Threat) but did not significantly change with early threat exposure ($p = 0.640$; Threat_{EARLY} compared to Threat_{FIRST}) or repeated threat exposure ($p = 0.361$; Threat_{REPEATED} compared to Threat_{EARLY}). There was no significant age main effect or age x threat interaction effect for AP RMS-COP (Table 7).

There were no significant threat main effects, age main effects, or age x threat interaction effects observed for AP MPF-COP (Figure 8c) or AP COP power within 0-0.1 Hz (Figure 9a; Table 7).

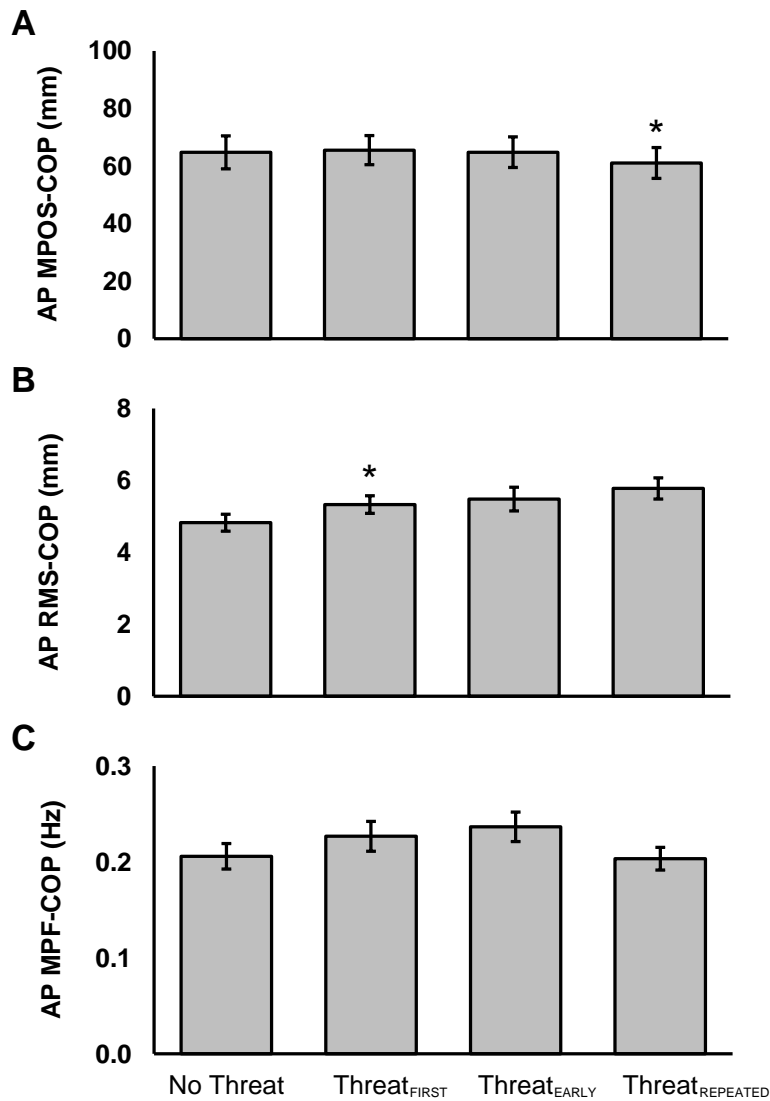


Figure 8. Postural threat main effects for a) AP MPOS-COP, b) AP RMS-COP, and c) AP MPF-COP. * represents significantly different ($p < 0.016$) than the previous condition. Increases in AP MPOS-COP values represent forward COP shifts and decreases in AP MPOS-COP values represent backward COP shifts.

A significant threat main effect for AP COP power within 0.1-1 Hz was observed ($F_{(3, 156)} = 10.72, p < 0.001$; Figure 9b). AP COP power within 0.1-1 Hz significantly increased with first threat exposure ($p < 0.001$; Threat_{FIRST} compared to No Threat). No significant differences in AP COP power within 0.1-1 Hz were observed with early threat exposure ($p = 0.744$; Threat_{EARLY} compared to Threat_{FIRST}) or with repeated threat exposure ($p = 0.860$; Threat_{REPEATED} compared to Threat_{EARLY}). There was a significant age main effect for AP COP power within 0.1-1 Hz ($F_{(1, 52)} = 6.10, p = 0.017$). Independent of threat, older adults had significantly greater AP COP power within 0.1-1 Hz ($M = 11.00, SD = 5.98$) compared to young adults ($M = 7.07, SD = 4.55$). There was no significant age x threat interaction effect (Table 7).

A significant threat main effect for AP COP power within 1-2.5 Hz was observed ($F_{(2.28, 118.44)} = 15.13, p < 0.001$; Figure 9c). AP COP power within 1-2.5 Hz significantly increased with first threat exposure ($p = 0.001$; Threat_{FIRST} compared to No Threat) and with early threat exposure ($p = 0.001$; Threat_{EARLY} compared to Threat_{FIRST}). AP COP power within 1-2.5 Hz significantly decreased with repeated threat exposure ($p < 0.001$; Threat_{REPEATED} compared to Threat_{EARLY}). There was a significant age main effect for AP COP power within 1-2.5 Hz ($F_{(1, 52)} = 10.00, p = 0.003$). Independent of threat, older adults had significantly greater AP COP power within 1-2.5 Hz ($M = 0.716, SD = 0.516$) compared to young adults ($M = 0.364, SD = 0.333$). There was no significant age x threat interaction effect for AP COP power within 1-2.5 Hz (Table 7).

A significant threat main effect for AP COP power within 2.5-5 Hz was observed ($F_{(2.63, 128.07)} = 28.28, p < 0.001$; Figure 9d). AP COP power within 2.5-5 Hz significantly increased with first threat exposure ($p = 0.001$; Threat_{FIRST} compared to No Threat) and

with early threat exposure ($p < 0.001$; Threat_{EARLY} compared to Threat_{FIRST}). AP COP power within 2.5-5 Hz significantly decreased with repeated threat exposure ($p < 0.001$; Threat_{REPEATED} compared to Threat_{EARLY}). There was a significant age main effect for AP COP power within 2.5-5 Hz ($F_{(1, 52)} = 10.06, p = 0.003$). Independent of threat, older adults had significantly greater AP COP power within 2.5-5 Hz ($M = 0.024, SD = 0.019$) compared to young adults ($M = 0.012, SD = 0.010$). There was no significant age x threat interaction effect for AP COP power within 2.5-5 Hz (Table 7).

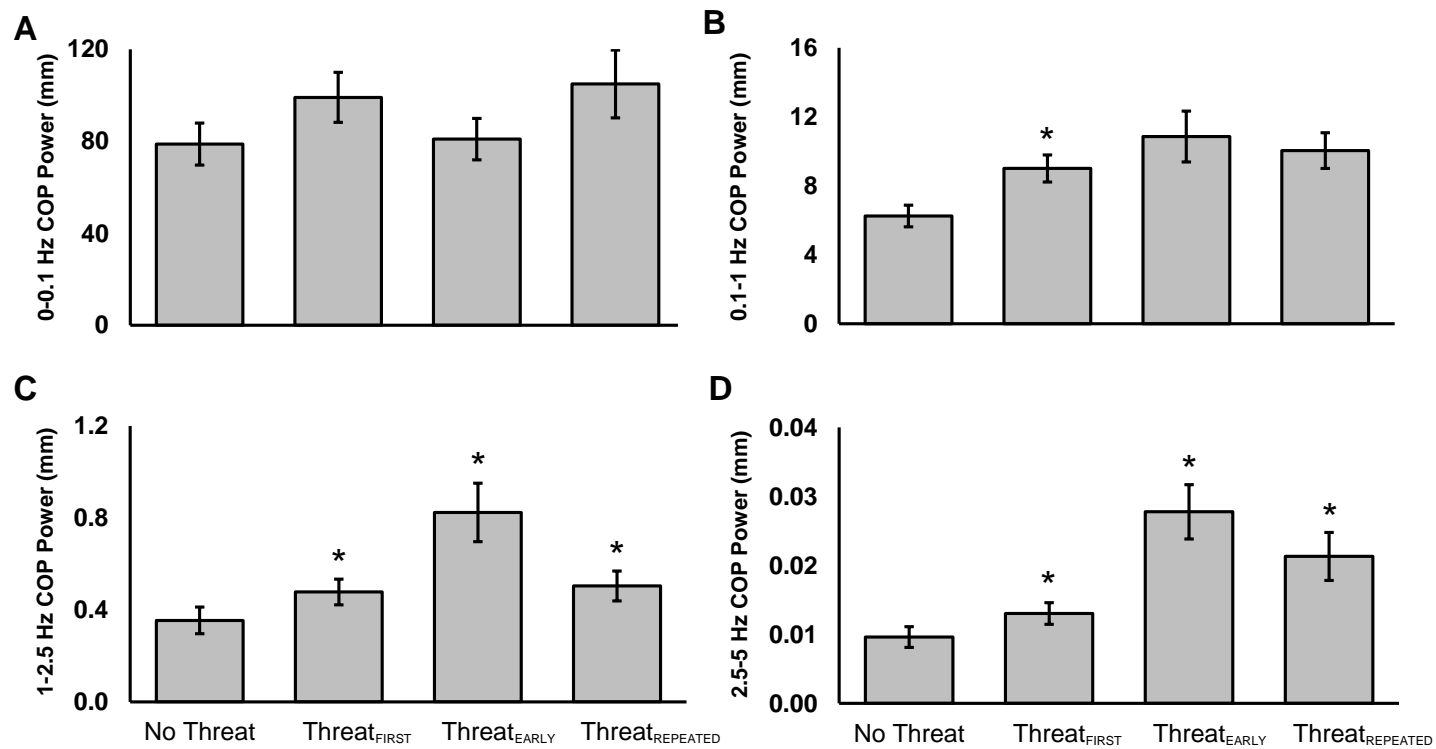


Figure 9. Postural threat main effects for a) low frequency (0-0.1 Hz) AP COP power, b) medium frequency (0.1-1 Hz) AP COP power, c) high frequency (1-2.5 Hz) AP COP power, and d) very high frequency (2.5-5 Hz) AP COP power. * represents significantly different ($p < 0.016$) than the previous condition.

Chapter Five: Discussion

Previous research has shown that postural threat elicits an emotional response, broad changes in attention focus, and changes in postural control in young adults (Johnson et al., 2017; Zaback et al., 2016). A primary aim of this thesis was to determine the extent to which age influences these threat-related responses. Postural threat effects were similar between young and older adults, supporting previous work using height-related threat (Brown et al., 2006; Carpenter et al., 2006; Sturnieks et al., 2016), but not perturbation-related threat (Shaw et al., 2012). This thesis also aimed to explore young and older adults' capacity to adapt threat-related responses with repeated threat exposure. The results of this thesis suggest that healthy young and older adults demonstrate similar patterns of emotional, cognitive, and postural adaptations to repeated threat exposure. Progressive reductions of threat-induced emotional responses occurred with repeated threat exposure, and some threat-induced changes in attention focus did adapt. In addition, COP power spectrum analysis revealed significant reductions in high frequency COP power with repeated exposure in contrast to traditional COP measures which did not adapt.

5.1 First threat exposure

Postural threat elicited an emotional response, characterized by increases in physiological arousal and state anxiety, in young and older adults. This finding supports previous research, which has shown that the threat of a perturbation elicits increases in physiological arousal and increases in self-reported anxiety (Johnson et al., 2017;

Phanthanourak et al., 2016). These responses occurred without the need for participants to experience a perturbation, which supports the efficacy of this threat model for investigating the effects of fall-related emotions on postural control.

Young adults reported directing attention to movement processes, threat-related stimuli, self-regulatory strategies, and task objectives and away from task-irrelevant information when threatened, which supports previous findings except for attention to task objectives, which has either decreased (Zaback et al., 2016) or not changed (Johnson et al., 2017). These broad changes in attention focus support ACT, which suggests that anxious individuals attend to threat-related stimuli and employ alternative processing strategies (e.g., attention to self-regulatory strategies, movement processes) and/or increase cognitive effort to attend to task-relevant information (Eysenck et al., 2007). Greater conscious control of movement has been reported by older adults when threatened with the possibility of a collapsing walkway (Young et al., 2016), however, it was previously unknown if this was the only threat-induced change in attention focus adopted by older adults. Quantification of attention focus in older adults revealed similar threat-induced changes in attention focus as those observed in young adults. Therefore, despite the possibility of greater attentional requirements for postural control (Lajoie et al., 1996; Maylor & Wing, 2000), older adults appear to be able to flexibly allocate attention to movement processes, task objectives, threat-related stimuli, and self-regulatory strategies. It is possible that simple tasks such as quiet standing in anticipation of receiving a perturbation may not challenge cognitive processing efficiency of older adults (Young & Williams, 2015), which may have prevented age-related differences in attention focus from emerging. Therefore, while the threat-induced changes in attention

focus quantified in this study provide some insight into how anxious older adults allocate attention during quiet stance, age-related differences in attention focus may only emerge during the performance of more attention-demanding tasks such as walking (Gage et al., 2003) or performing a concurrent cognitive task (Brown et al., 2002) while threatened.

Participants increased ML RMS-COP and MPF-COP, as well as AP RMS-COP with first threat exposure. This suggests that ML postural control, which is predominantly controlled by hip abductors/adductors and ankle invertors/everters (Winter, Prince, Frank, Powell, & Zabjek, 1996), is influenced by the threat of a lateral perturbation. Specifically, coupled with previous research (Johnson et al., 2017), postural threat may elicit direction-specific increases in MPF-COP and while increases in ML RMS-COP were only observed under the threat of a lateral perturbation, increases in AP RMS-COP were observed regardless of threat direction. Threat-induced changes in AP RMS-COP may be associated with anxiety, which has been shown in previous research (Johnson et al., 2017). Based on this speculation, it would be expected that decreases in AP RMS-COP would occur with repeated threat exposure, which was not observed in this thesis. Increases in ML RMS-COP have been associated with greater stability prior to a postural perturbation (i.e., reduced frequency of stepping in response to a support surface translation; Rajachandrakumar et al., 2018), so this change in postural control may facilitate compensatory stepping responses rather than relate to emotional responses. There was no significant change in ML MPOS-COP with first threat exposure and this thesis did not replicate a threat-induced forward lean that was observed in previous research during the first threat of an AP perturbation (Johnson et al., 2017). Therefore,

adopting a forward or left- or rightward lean may not provide any benefit to stability when faced with the threat of a lateral perturbation.

Young and older adults adopted the same postural control strategy, which supports previous research utilizing increases in surface height to compare threat-induced changes in postural control between young and older adults (Brown et al., 2006; Carpenter et al., 2006; Sturnieks et al., 2016) and refutes previous work using postural perturbations as a postural threat (Shaw et al., 2012). Incongruent findings between studies may have emerged from several methodological differences. For example, Shaw et al. (2012) had participants stand with their eyes closed, which has been shown to significantly influence postural threat effects on postural control (Carpenter et al., 2001a). In addition, Shaw et al. (2012) found significant threat-induced reductions in trunk roll angle and angular velocity in older adults, however, these measures may not be reflected in COP measures (Visser, Carpenter, van der Kooij, & Bloem, 2008). Other methodological differences including stance width (feet together versus feet apart by a foot length), participant instructions (stand as still as possible versus stand quietly), perturbation location (trunk versus support surface), threat direction (AP versus ML), and/or trial duration (30 s versus 60 s) may have prevented similar results between studies. The threat effects observed in older adults from Shaw et al. (2012) occurred perpendicular to the direction of the threat. Although threat effects observed in the current thesis occurred in the same direction as the threat, it remains unknown whether perpendicular threat effects are only observed in response to an AP perturbation threat.

In contrast to MPF-COP, which only increased in the ML direction, participants increased medium, high, and very high frequency COP power in AP and ML directions

with first threat exposure. This strategy has been observed in individuals with pathological anxiety disorders during quiet stance (Holmberg et al., 2009; Krafczyk et al., 1999) and in healthy young adults anticipating a postural threat in the form of a vibratory calf muscle stimulation (Holmberg et al., 2009). Taken together, increases in medium to very high frequency COP power may represent an anxious postural strategy during quiet stance, characterized by increased co-contraction between agonist and antagonist muscle groups in the lower legs (Wuehr et al., 2017). Furthermore, power spectrum analysis of COP may provide a more sensitive measure to detect subtle changes in postural control under conditions of increased postural threat (Singh et al., 2012).

5.2 *Early threat exposure*

With early threat exposure, arousal decreased in young adults but did not change in older adults. Research suggests aging may result in smaller and less frequent EDRs due to fewer active peripheral sweat glands compared to young adults (Catania, Thompson, Michalewski, & Bowman, 1980) and reductions in brain grey matter associated with electrodermal activity (Sequeira & Roy, 1993). Therefore, physiological differences between young and older adults may have created a ceiling for EDRs of older adults. An alternative interpretation of this interaction suggests older adults remained anxious after gaining threat experience, whereas young adults were able to relax with threat experience.

Despite significant reductions in the emotional response to threat with early threat exposure, threat-induced attention focus did not change. Previous research has also

shown that participants do not report significant shifts in threat-induced attention focus with early threat exposure (Johnson et al., 2017). The absence of significant threat-induced changes in traditional COP measures with early threat exposure contrasted previous research (Johnson et al., 2017); this disparity may have resulted from differences in biomechanical control of ML and AP stability (Henry, Fung, & Horak, 1998; Winter et al., 1996), differences in trial duration (i.e., 30 s stance compared to 60 s stance) (Carpenter, Frank, Winter, & Peysar, 2001b), or standing with the expectation that a perturbation may or may not occur during each trial compared to a perturbation that will occur during each trial. Nonetheless, power spectrum analysis revealed significant increases in high and very high frequency COP power in both ML and AP directions. Increased high frequency COP power may result from peripheral sensory feedback modulating postural control in relation to the intensity of the perturbation (Horak et al., 1989). Alternatively, shifts in attention to specific movement processes may have contributed to increases in high frequency COP power (Wuehr et al., 2017). Although overall (mean) attention to movement processes did not significantly change with early threat exposure, attention may have shifted within the broad category of movement processes, which was undetected by the questionnaire used in this study.

5.3 *Repeated threat exposure*

The manipulation of threat exposure was confirmed as repeated threat exposure led to significant reductions in physiological arousal and state anxiety. This finding supports previous research demonstrating decreases in arousal with repeated perturbations (Maki & Whitelaw, 1993) and provides support for this type of repeated

threat exposure as a useful paradigm to further investigate the relationship between threat-related emotional, cognitive, and postural responses.

Research has suggested a reciprocal relationship between anxiety and attentional biases to threat-related stimuli (Van Bockstaele et al., 2014), and experimental cognitive psychology research has explored attention-bias modification, which involves directing attention away from the threat, as a technique used to reduce an emotional response to threat (MacLeod & Clarke, 2015). In this thesis, as the emotional response to threat decreased with gained experience, participants were able to shift attention away from threat-related stimuli. When disengaged from threat-related stimuli, participants reported directing significantly more attention to task-irrelevant information. This reinforces the notion that with repeated exposure, participants felt less threatened and were able to let their attention wander to thoughts unrelated to the balance task, which may have contributed to reductions in threat-induced changes in postural control.

Participants also reported directing significantly less attention to movement processes with repeated threat exposure, which may have contributed to significant reductions in high frequency COP power observed with repeated threat exposure. Directing attention to movement processes can disrupt movement automaticity (Wulf et al., 2001) and result in less efficient postural control (Vuillerme & Nafati, 2007). Research suggests the high frequency postural sway adopted by clinically anxious individuals is associated with an increased attention to movement control (Krafczyk et al., 1999; Wuehr et al., 2017) and this strategy may be normalized when performing more challenging postural tasks (Querner et al., 2000) or when distracting attention using a cognitive dual task (Wuehr et al., 2017). Alternatively, reductions in high frequency COP

power may have resulted from practice-related improvements in postural control; however, since significant reductions in threat-induced emotional responses occurred with repeated threat exposure, changes in postural control with reduced arousal and/or anxiety cannot be ruled out. Furthermore, resolution of pathological anxiety symptoms is associated with return of lower frequency sway (Staab et al., 2013). Follow up comparisons of low frequency COP power between threat conditions was prevented by the absence of a significant threat main effect. Therefore, conclusions cannot be made about whether decreases in high frequency COP power coincided with increases in low frequency COP power.

5.4 Age-related differences

Aging results in many characteristic changes to postural control, including increased postural sway compared to young adults (Laughton et al., 2003; McClenaghan et al., 1996). In this thesis, older adults had significantly greater AP and ML COP power within high and very high frequency components, which has been demonstrated by previous research (Singh et al., 2012). Older adults also reported directing significantly more attention to self-regulatory strategies than young adults. Although these strategies may limit threat-related anxiety (Webb, Miles, & Sheeran, 2012; Wilson, 2008), active distraction from the threat may occupy more available attentional resources and subsequently influence postural control of older adults (Huxhold et al., 2006). Previous research has found associations between threat-induced changes in attention to self-regulatory strategies and threat-induced changes in MPF-COP in young adults (Johnson et al., 2017). Conversely, active distraction has been shown to normalize inadequate

postural control observed in anxious patients (Wuehr et al., 2017). This discrepancy highlights the requirement of future research to systematically investigate this relationship by distracting attention from conscious motor processing and assessing corresponding changes in postural control (i.e., less conscious motor processing being associated with reduced high frequency sway) under conditions of postural threat.

5.5 *Limitations and future directions*

This thesis is not without limitations. First, to reduce the amount of comparisons made, this study did not attempt to determine whether threat-induced responses returned to no threat levels. Thus, conclusions cannot be made about whether there was full adaptation of emotional, cognitive, or postural control measures. Future studies should therefore aim to eliminate the emotional threat response using longer periods of exposure or multiple exposure periods to explore the effects of postural threat re-exposure, which may have important clinical application. Second, items on the attention focus questionnaire used in this thesis represent broad attention focus categories identified by Zaback et al. (2016) and may not be sensitive enough to detect more subtle differences in attention focus. For example, the attention focus category of movement processes captures both conscious control and conscious monitoring of movement, which have been shown to differentially affect performance of certain motor skills (van Ginneken et al., 2017). While a blank space at the bottom of each attention focus questionnaire provided participants with the opportunity to describe changes in attention focus not captured by the questionnaire, no additional information was listed. Moreover, this questionnaire was collected through self-report and may be susceptible to expectation and desirability bias.

Third, the frequency bins used for the power spectrum analysis were selected to isolate low, medium, high, and very high frequency components, but the use of different bins may influence the results of this thesis. Finally, the results of this thesis are only generalizable to healthy young adults and independently-living older adults standing under the threat of in anticipating a ML perturbation. Therefore, future research should explore emotional, cognitive, and postural control adaptations in different populations (e.g., pathologically anxious or fearful individuals, individuals with neurological impairments) and under different postural threat paradigms with greater clinical application (e.g., social evaluative threat; Geh et al., 2011).

5.6 *Implications*

Researchers often average postural responses to platform perturbations across several trials to reduce variability of these measures but disregard the first trial, which potentially represents the most ‘natural’ and ecologically valid response. By averaging data across several trials, researchers also disregard adaptation of postural control over time. Some postural control measures assessed in this thesis (e.g., high and very high COP power) were significantly different across various levels of exposure to the postural threat. Thus, researchers should carefully design experimental protocols to account for first trial effects (Allum et al., 2011) and any adaptation effects that could occur with prolonged exposure to an experimental manipulation such as postural threat.

The results of this thesis provide some understanding of how anxious young and older adults allocate attention focus when threatened with the risk of a postural

perturbation. It has been well established that individuals adopt a more conscious control of posture or movement when threatened, but researchers should consider the influence of other threat-induced changes in attention focus on postural control (i.e., attention to threat-related stimuli, self-regulatory strategies). Furthermore, some of these threat-induced changes in attention focus adapted with repeated threat exposure, which has important implications for design and evaluation of interventions for pathologically anxious or fearful older adults. For example, conscious motor processing has been identified as a significant predictor of fall risk among older adults (Wong et al., 2008). Using cognitive behaviour therapy or using an intervention to improve compensatory stepping responses (Mansfield, Peters, Liu, & Maki, 2007), fearful older adults or older adults at risk of falling may learn to allocate attention away from posture and to task-relevant information, which may contribute to reductions in fall risk.

5.7 *Conclusions*

This thesis was the first to explore emotional, cognitive, and postural adaptations to initial and repeated postural threat exposure in healthy young and older adults. In general, young and older adults demonstrated similar patterns of adaptation to first, early, and repeated threat exposure. Postural threat elicited an emotional response, as well as changes in attention focus and postural control. With early threat exposure, participants decreased the emotional response to threat and increased COP frequency but did not adapt threat-induced changes in attention focus. With repeated threat exposure, participants decreased the emotional response to threat and exhibited adaptation of some threat-induced changes in attention focus. Power spectrum analysis revealed adaptation of

high frequency COP power with repeated exposure and these measures may assist with detecting threat-induced postural control changes. Interventions designed to reduce threat-induced changes in postural control should train individuals using repeated threat exposure and future research should explore the effects of postural threat re-exposure on emotional, cognitive, and postural measures on older fallers and movement-affected populations.

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Appendix A: Brock University Ethics Clearance Certificate



Brock University
 Research Ethics Office
 Tel: 905-688-5550 ext. 3035
 Email: reb@brocku.ca

Bioscience Research Ethics Board

Certificate of Ethics Clearance for Human Participant Research

DATE: April 6, 2017
 PRINCIPAL INVESTIGATOR: TOKUNO, Craig - Kinesiology
 FILE: 14-301 - TOKUNO
 TYPE: Faculty Research STUDENT: Kyle Johnson
 SUPERVISOR: Craig Tokuno
 TITLE: The influence of postural threat on movement control

ETHICS CLEARANCE GRANTED

Type of Clearance: MODIFICATION Expiry Date: 7/31/2017

The Brock University Bioscience Research Ethics Board has reviewed the above named research proposal and considers the procedures, as described by the applicant, to conform to the University's ethical standards and the Tri-Council Policy Statement.

Modification: Addition of second testing site; research personnel; Demographic and Health Questionnaire and two additional questionnaires; and relevant changes on participant materials.

The Tri-Council Policy Statement requires that ongoing research be monitored by, at a minimum, an annual report. Should your project extend beyond the expiry date, you are required to submit a Renewal form before **7/31/2017**. Continued clearance is contingent on timely submission of reports.

To comply with the Tri-Council Policy Statement, you must also submit a final report upon completion of your project. All report forms can be found on the Research Ethics web page at <http://www.brocku.ca/research/policies-and-forms/research-forms>.

In addition, throughout your research, you must report promptly to the REB:

- a) Changes increasing the risk to the participant(s) and/or affecting significantly the conduct of the study;
- b) All adverse and/or unanticipated experiences or events that may have real or potential unfavourable implications for participants;
- c) New information that may adversely affect the safety of the participants or the conduct of the study;
- d) Any changes in your source of funding or new funding to a previously unfunded project.

We wish you success with your research.

Approved:

 Sandra Peters, Chair
 Bioscience Research Ethics Board

Note: Brock University is accountable for the research carried out in its own jurisdiction or under its auspices and may refuse certain research even though the REB has found it ethically acceptable.

If research participants are in the care of a health facility, at a school, or other institution or community organization, it is the responsibility of the Principal Investigator to ensure that the ethical guidelines and clearance of those facilities or institutions are obtained and filed with the REB prior to the initiation of research at that site.

Appendix B: University of British Columbia Ethics Clearance Certificate



The University of British Columbia
Office of Research Ethics
Clinical Research Ethics Board – Room 210, 828 West
10th Avenue, Vancouver, BC V5Z 1L8

ETHICS CERTIFICATE OF EXPEDITED APPROVAL

PRINCIPAL INVESTIGATOR: Mark G Carpenter	INSTITUTION / DEPARTMENT: UBC/Education/School of Kinesiology	UBC CREB NUMBER: H17-01099
INSTITUTION(S) WHERE RESEARCH WILL BE CARRIED OUT:		
Institution		Site
UBC		Vancouver (excludes UBC Hospital)
Other locations where the research will be conducted: N/A		
CO-INVESTIGATOR(S): Martin Zaback Allan Adkin Craig D. Tokuno Kyle J Johnson		
SPONSORING AGENCIES: - Natural Sciences and Engineering Research Council of Canada (NSERC) - "Central and peripheral mechanisms controlling human balance control"		
PROJECT TITLE: The influence of postural threat on movement control		

THE CURRENT UBC CREB APPROVAL FOR THIS STUDY EXPIRES: June 20, 2018

The UBC Clinical Research Ethics Board Chair or Associate Chair, has reviewed the above described research project, including associated documentation noted below, and finds the research project acceptable on ethical grounds for research involving human subjects and hereby grants approval.

This approval applies to research ethics issues only. The approval does not obligate an institution or any of its departments to proceed with activation of the study. The Principal Investigator for the study is responsible for identifying and ensuring that resource impacts from this study on any institution are properly negotiated, and that other institutional policies are followed. The REB assumes that investigators and the coordinating office of all trials continuously review new information for findings that indicate a change should be made to the protocol, consent documents or conduct of the trial and that such changes will be brought to the attention of the REB in a timely manner.

DOCUMENTS INCLUDED IN THIS APPROVAL:			APPROVAL DATE:
Document Name	Version	Date	
Protocol:			June 20, 2017
Protocol - The influence of postural threat on movement control	2	June 19, 2017	
Consent Forms:			
Consent Form - The influence of postural threat on movement control	3	June 19, 2017	
Advertisements:			
Advertisement to Recruit Participants	2	June 19, 2017	
Questionnaire, Questionnaire Cover Letter, Tests:			
State Trait Anxiety Inventory	1	May 30, 2017	
Trait Movement-Specific Reinvestment Scale	1	May 30, 2017	

Domain-Specific Risk-Taking Scale	1	May 30, 2017
Everyday Risk-Taking Scale	1	May 30, 2017
Attention Focus Questionnaire	1	May 30, 2017
Demographic and Health Questionnaire	1	May 30, 2017
Balance Confidence Questionnaire	1	May 30, 2017
Activity-Specific Balance Confidence Scale	1	May 30, 2017
Montreal Cognitive Assessment	7.1	August 18, 2010
State Anxiety Questionnaire	1	May 30, 2017
Other Documents:		
Data Collection Form	1	June 19, 2017
Brock University Ethics Approval Certificate	N/A	May 30, 2017

CERTIFICATION:**In respect of clinical trials:**

1. *The membership of this Research Ethics Board complies with the membership requirements for Research Ethics Boards defined in Division 5 of the Food and Drug Regulations.*
2. *The Research Ethics Board carries out its functions in a manner consistent with Good Clinical Practices.*
3. *This Research Ethics Board has reviewed and approved the clinical trial protocol and informed consent form for the trial which is to be conducted by the qualified investigator named above at the specified clinical trial site. This approval and the views of this Research Ethics Board have been documented in writing.*

The documentation included for the above-named project has been reviewed by the UBC CREB, and the research study, as presented in the documentation, was found to be acceptable on ethical grounds for research involving human subjects and was approved by the UBC CREB.

Approval of the Clinical Research Ethics Board by:
Dr. Stephen Hopton Cann,
Chair

Appendix C: Demographic and Health Questionnaire

Participant Code: _____

Age: _____

Gender: _____

Height: _____

Weight: _____

How many times have you fallen in the past year? _____

Please list the approximate date of the fall, the medical treatment required, and the reason you fell in each case (e.g., uneven surface, going down stairs, etc.).

Have you ever been diagnosed as having any of the following conditions? Please check all that apply.

	Yes	If yes, approximate year of onset?
Heart attack	<input type="checkbox"/>	_____
Angina (chest pain)	<input type="checkbox"/>	_____
Transient ischemic attack	<input type="checkbox"/>	_____
Stroke	<input type="checkbox"/>	_____
Respiratory problems	<input type="checkbox"/>	_____
Diabetes	<input type="checkbox"/>	_____
Cancer	<input type="checkbox"/>	_____
Parkinson's disease	<input type="checkbox"/>	_____
Multiple sclerosis	<input type="checkbox"/>	_____
Other neurological disorders	<input type="checkbox"/>	_____
Rheumatoid Arthritis	<input type="checkbox"/>	_____
Other arthritis	<input type="checkbox"/>	_____
Fracture (< 8 weeks)	<input type="checkbox"/>	_____
Osteoporosis	<input type="checkbox"/>	_____
Joint Replacement	<input type="checkbox"/>	_____
Any other problem (e.g., sensory) that interfere with your balance, walking, or ability to do PA?	<input type="checkbox"/>	_____

Appendix D: Activity-Specific Balance Confidence (ABC) Scale (Powell & Myers,
1995)

Appendix E: State-Trait Anxiety Inventory (STAI; Spielberger et al., 1983)

Directions: A number of statements which people have used to describe themselves are given below. Read each statement and then place the appropriate number to the right of the statement to indicate how you *generally* feel (i.e., on a regular basis)

1= Almost Never

2= Sometimes

3= Often

4= Almost Always

1. I feel pleasant _____
2. I feel nervous and restless _____
3. I feel satisfied with myself _____
4. I wish I could be as happy as others seem to be _____
5. I feel like a failure _____
6. I feel rested _____
7. I am "calm, cool, and collected" _____
8. I feel that difficulties are piling up such that I cannot overcome them _____
9. I worry too much over something that really doesn't matter _____
10. I am happy _____
11. I have disturbing thoughts _____
12. I lack self-confidence. _____
13. I feel secure _____
14. I make decisions easily _____
15. I feel inadequate _____
16. I am content _____
17. Some unimportant thought runs through my mind and bothers me _____
18. I take disappointments so keenly that I can't put them out of my mind _____
19. I am a steady person _____
20. I get in a state of tension or turmoil as I think over my recent concerns and failures _____

Appendix F: Movement-Specific Reinvestment Scale (MSRS; Masters et al., 2005)

Directions: Below are a number of statements about your movements. The possible answers go from 'strongly agree' to 'strongly disagree'. There are no right or wrong answers so circle the answer that best describes how you feel for each question.

1. I rarely forget the times when my movements have failed me, however slight the failure.

strongly disagree	moderately disagree	weakly disagree	weakly agree	moderately agree	strongly agree
----------------------	------------------------	--------------------	-----------------	---------------------	-------------------

2. I'm always trying to figure out why my actions failed.

strongly disagree	moderately disagree	weakly disagree	weakly agree	moderately agree	strongly agree
----------------------	------------------------	--------------------	-----------------	---------------------	-------------------

3. I reflect about my movement a lot.

strongly disagree	moderately disagree	weakly disagree	weakly agree	moderately agree	strongly agree
----------------------	------------------------	--------------------	-----------------	---------------------	-------------------

4. I am always trying to think about my movements when I carry them out.

strongly disagree	moderately disagree	weakly disagree	weakly agree	moderately agree	strongly agree
----------------------	------------------------	--------------------	-----------------	---------------------	-------------------

5. I'm self-conscious about the way I look when I am moving.

strongly disagree	moderately disagree	weakly disagree	weakly agree	moderately agree	strongly agree
----------------------	------------------------	--------------------	-----------------	---------------------	-------------------

6. I sometimes have the feeling that I'm watching myself alone.

strongly disagree	moderately disagree	weakly disagree	weakly agree	moderately agree	strongly agree
----------------------	------------------------	--------------------	-----------------	---------------------	-------------------

7. I'm aware of the way my mind and body works when I am carrying out a movement.

strongly disagree	moderately disagree	weakly disagree	weakly agree	moderately agree	strongly agree
----------------------	------------------------	--------------------	-----------------	---------------------	-------------------

8. I'm concerned about my style of moving.

strongly disagree	moderately disagree	weakly disagree	weakly agree	moderately agree	strongly agree
----------------------	------------------------	--------------------	-----------------	---------------------	-------------------

9. If I see my reflection in a shop window, I will examine my movements.

strongly disagree	moderately disagree	weakly disagree	weakly agree	moderately agree	strongly agree
----------------------	------------------------	--------------------	-----------------	---------------------	-------------------

10. I am concerned about what people think about me when I am moving.

strongly disagree	moderately disagree	weakly disagree	weakly agree	moderately agree	strongly agree
----------------------	------------------------	--------------------	-----------------	---------------------	-------------------

Appendix G: Everyday Risk-Taking Scale (ERTS; Butler et al., 2015)

Please indicate how often you perform the following activities.

- | | 1 | 2 | 3 | 4 | |
|-----|--|--------|--------------|-------|-------|
| | Always | Mostly | Occasionally | Never | |
| 1. | Do you sit down to put on your shoes and socks? | | | | _____ |
| 2. | Do you hold on to the handrail when you walk down stairs if one is available? | | | | _____ |
| 3. | Do you hold on to the handrail when you walk up stairs? | | | | _____ |
| 4. | Would you catch a bus if you had to stand? | | | | _____ |
| 5. | At traffic lights, do you start crossing after the DO NOT WALK sign starts flashing? | | | | _____ |
| 6. | Would you cross against the lights to catch a bus if you might miss it? | | | | _____ |
| 7. | Would you run to catch a bus or cross the road if you had to? | | | | _____ |
| 8. | Would you climb up on furniture to reach high shelves or change a light bulb? | | | | _____ |
| 9. | Do you use escalators in shopping centres? | | | | _____ |
| 10. | Do you turn the light on at night when going from one room to another? | | | | _____ |

Appendix H: Domain-Specific Risk-Taking Scale (DOSPERT; Blais & Weber, 2006)

For each of the following statements, please indicate the likelihood that you would engage in the described activity or behaviour if you were to find yourself in that situation. Provide a rating from “*Extremely Unlikely*” to “*Extremely Likely*” using the following scale:

1	2	3	4	5	6	7
extremely unlikely	moderately unlikely	somewhat unlikely	not sure	somewhat likely	moderately likely	extremely likely

1. Admitting that your tastes are different from those of a friend _____
2. Going camping in the wilderness _____
3. Betting a day’s income at the horse races _____
4. Investing 10% of your annual income in a moderate growth mutual fund _____
5. Drinking heavily at a social event _____
6. Taking some questionable deductions on your income tax return _____
7. Disagreeing with an authority figure on a major issue _____
8. Betting a day’s income at a high-stake poker game _____
9. Having an affair with a married man/woman _____
10. Passing off somebody else’s work as your own _____
11. Going down a ski run that is beyond your ability _____
12. Investing 5% of your annual income in a very speculative stock _____
13. Going whitewater rafting at high water in the spring _____
14. Betting a day’s income on the outcome of a sporting event _____
15. Engaging in unprotected sex _____
16. Revealing a friend’s secret to someone else _____
17. Driving a car without wearing a seatbelt _____
18. Investing 10% of your annual income in a new business venture _____
19. Taking a skydiving class _____
20. Riding a motorcycle without a helmet _____
21. Choosing a career that you truly enjoy over a more secure one _____
22. Speaking your mind about an unpopular issue in a meeting at work _____
23. Sunbathing without sunscreen _____
24. Bungee jumping off a tall bridge _____
25. Piloting a small plane _____
26. Walking home alone at night in a unsafe area of town _____
27. Moving to a city far away from a your extended family _____
28. Starting a new career in your mid-thirties _____
29. Leaving your young children alone at home while running an errand _____
30. Not returning a wallet you found that contains \$200 _____

Appendix I: Protocol Outline

Condition	Trial	Perturbation	Direction	Time (s)	Notes
Practice	1	N	N/A	60	Questionnaires
No Threat	1	N	N/A	60	Questionnaires

-----PLATFORM DEMONSTRATION (L & R)-----

Condition	Trial	Perturbation	Direction	Time (s)	Notes
Threat _{FIRST}	1	Y	L	62	Questionnaires
	2	Y	R	15	
	3	Y	L	45	
Threat _{EARLY}	4	Y	R	62	Questionnaires
	5	Y	L	5	
	6	Y	L	55	
	7	Y	R	30	
	8	Y	L	15	
	9	Y	R	62	
	10	Y	R	55	
	11	Y	L	5	
	12	Y	R	45	
	13	Y	L	30	
	14	Y	R	62	Questionnaires
	15	Y	L	15	
	16	Y	R	55	
	17	Y	R	5	
	18	Y	L	30	
	19	Y	L	62	
	20	Y	R	30	
	21	Y	L	5	
	22	Y	R	45	
	23	Y	R	15	
Threat _{REPEATED}	24	Y	L	62	Questionnaires

Condition	Trial	Perturbation	Direction	Time (s)	Notes
No Threat	2	N	N/A	60	Questionnaires

Appendix J: State Anxiety Questionnaire

Using the following scale, please rate how worried you were when performing the balance task (e.g., worried about losing my balance, worried about performing the task incorrectly, etc.):

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

Not at all worried	Moderately worried	Very worried
-----------------------	-----------------------	-----------------

Using the following scale, please rate how physically anxious you felt during the balance task (e.g., tense, nervous, heart racing, stomach sinking, etc.):

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

I did not feel anxious at all	I felt moderately anxious	I felt very anxious
----------------------------------	------------------------------	------------------------

Using the following scale, please rate how difficult it was for you to remain focused on doing what you were asked to do (i.e., was your concentration disrupted by any intrusive thoughts such as the possibility of falling, performing poorly, etc.):

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

Not at all difficult	Moderately difficult	Very difficult
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Appendix K: Attention Focus Questionnaire

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

Trying to consciously monitor or control specific parts of your movement (e.g., pressure under your feet; ankle, leg, trunk, arm or head movement; how much you were moving; how much you were leaning; contractions of your muscles, etc.)

1	2	3	4	5	6	7	8	9
Not at all		Slightly		Moderately		Quite a bit		Very much so

Concentrating on the specific instructions provided to you about the task objectives (e.g., to keep your arms at your sides, to maintain focus on the visual target, etc.)

1	2	3	4	5	6	7	8	9
Not at all		Slightly		Moderately		Quite a bit		Very much so

Feelings of anxiety or worry (e.g., concern about the possibility or consequences of falling or failing at the task, etc.)

1	2	3	4	5	6	7	8	9
Not at all		Slightly		Moderately		Quite a bit		Very much so

Coping strategies to help remain confident, calm, and/or focused (e.g., regulated breathing, purposeful distraction, positive/relaxing thoughts, etc.)

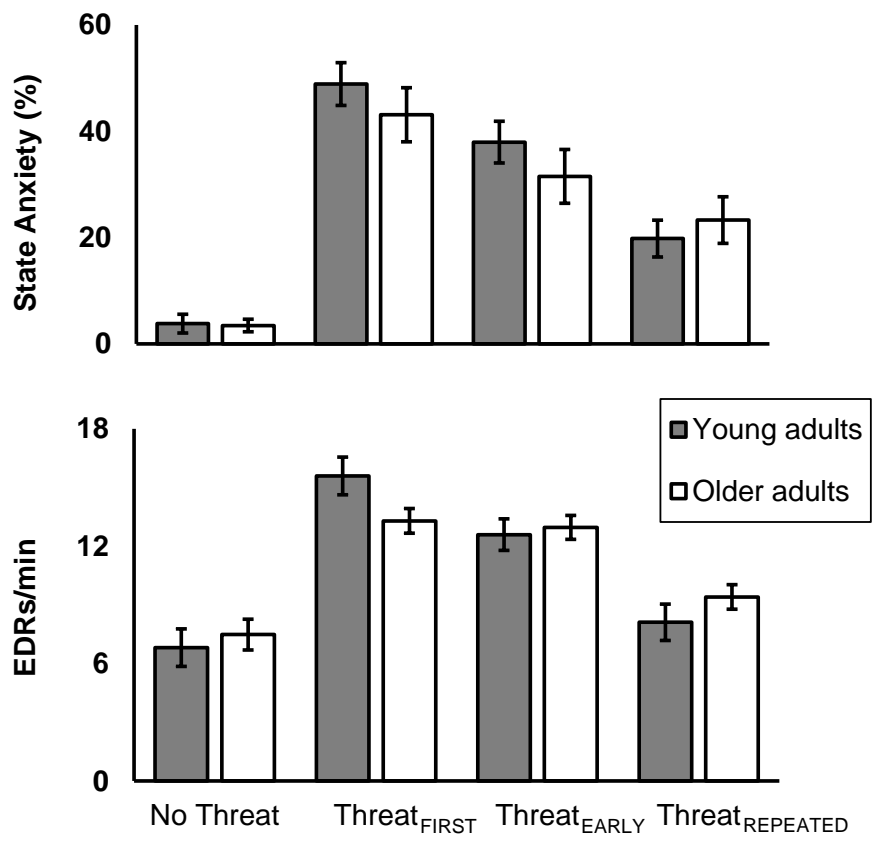
1	2	3	4	5	6	7	8	9
Not at all		Slightly		Moderately		Quite a bit		Very much so

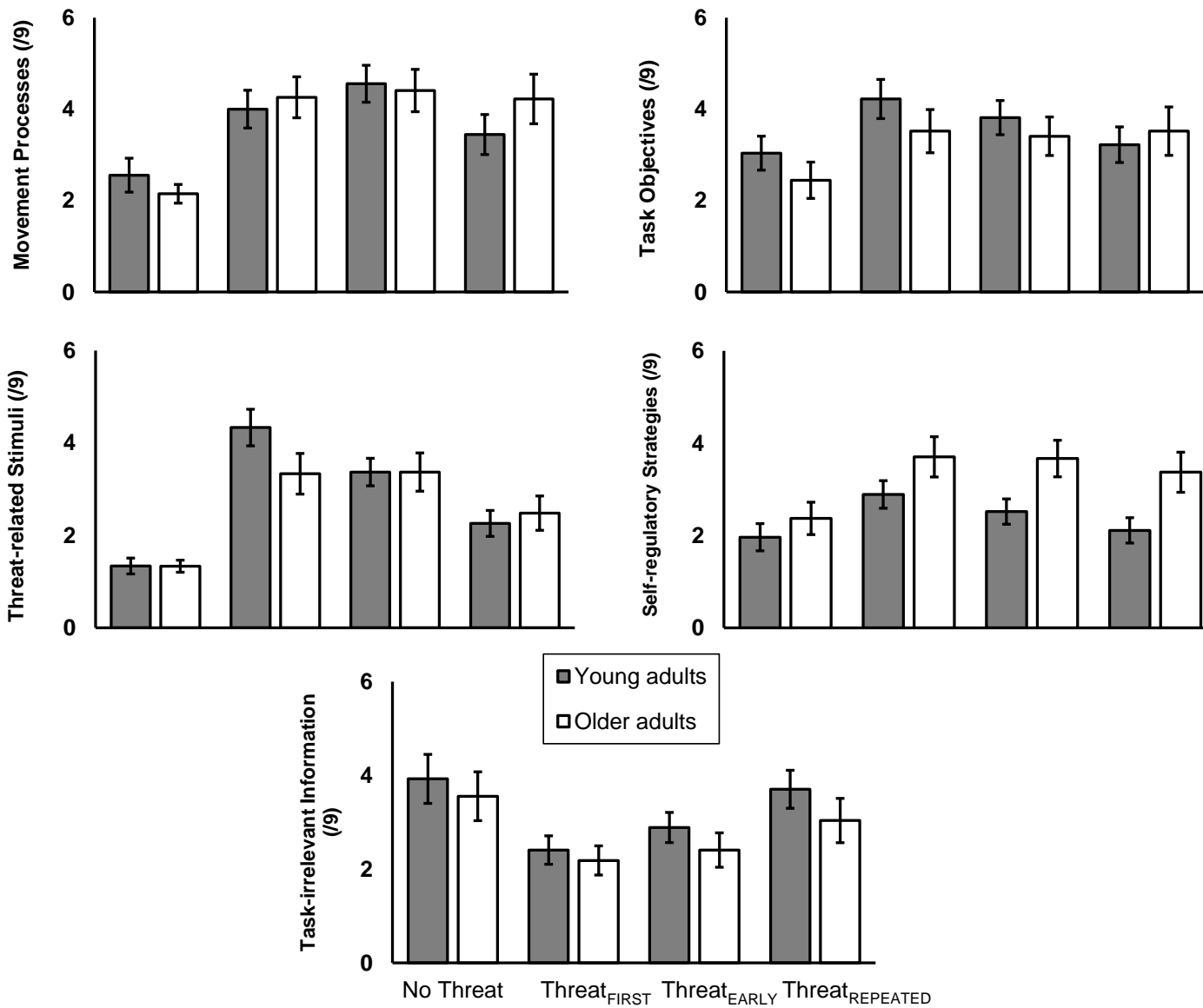
Thoughts unrelated to balance task (e.g., plans for after study, events from yesterday, trivial environmental distractions, etc.)

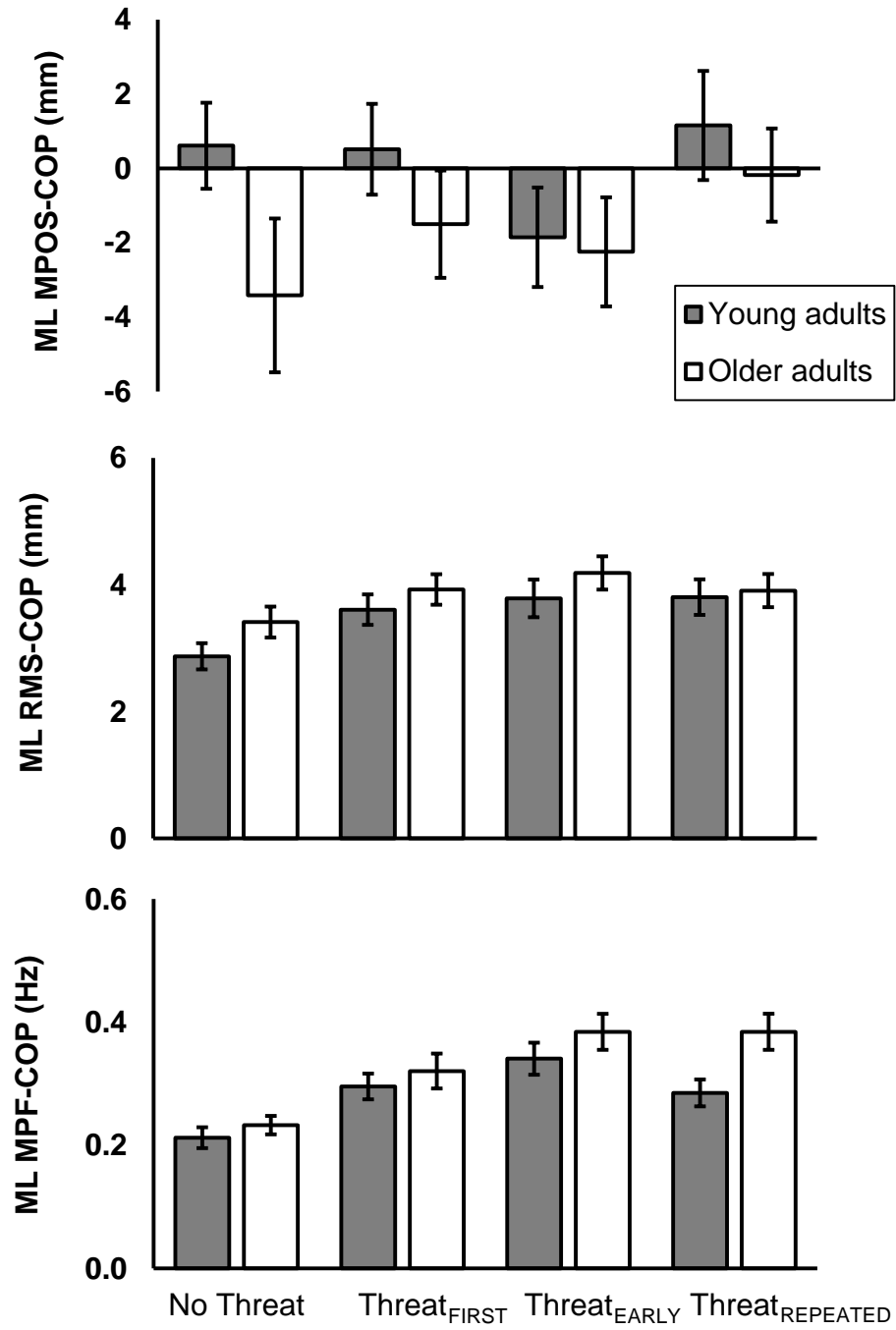
1	2	3	4	5	6	7	8	9
Not at all		Slightly		Moderately		Quite a bit		Very much so

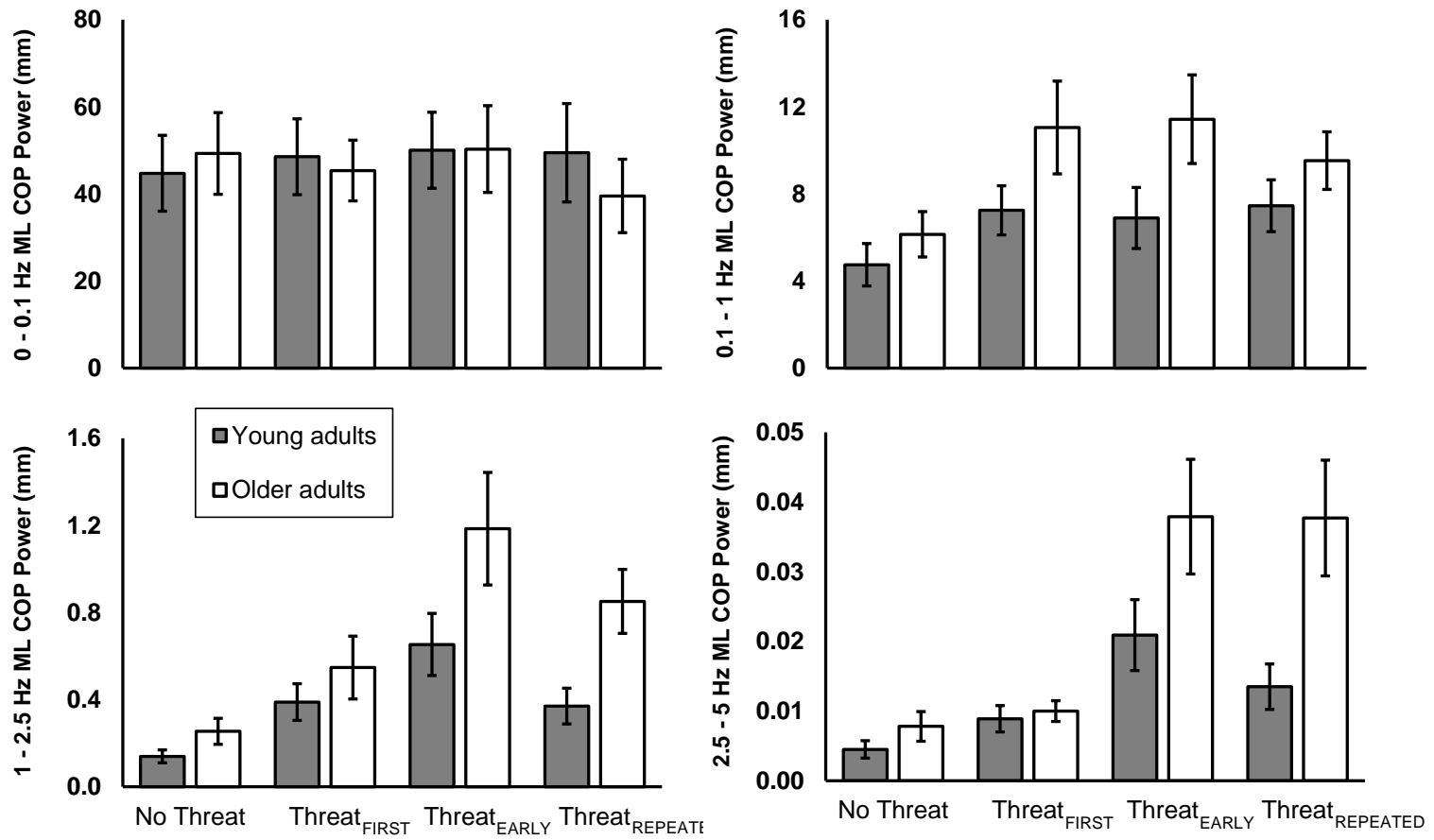
Was there anything else that you focused on or thought about when doing the balance task?

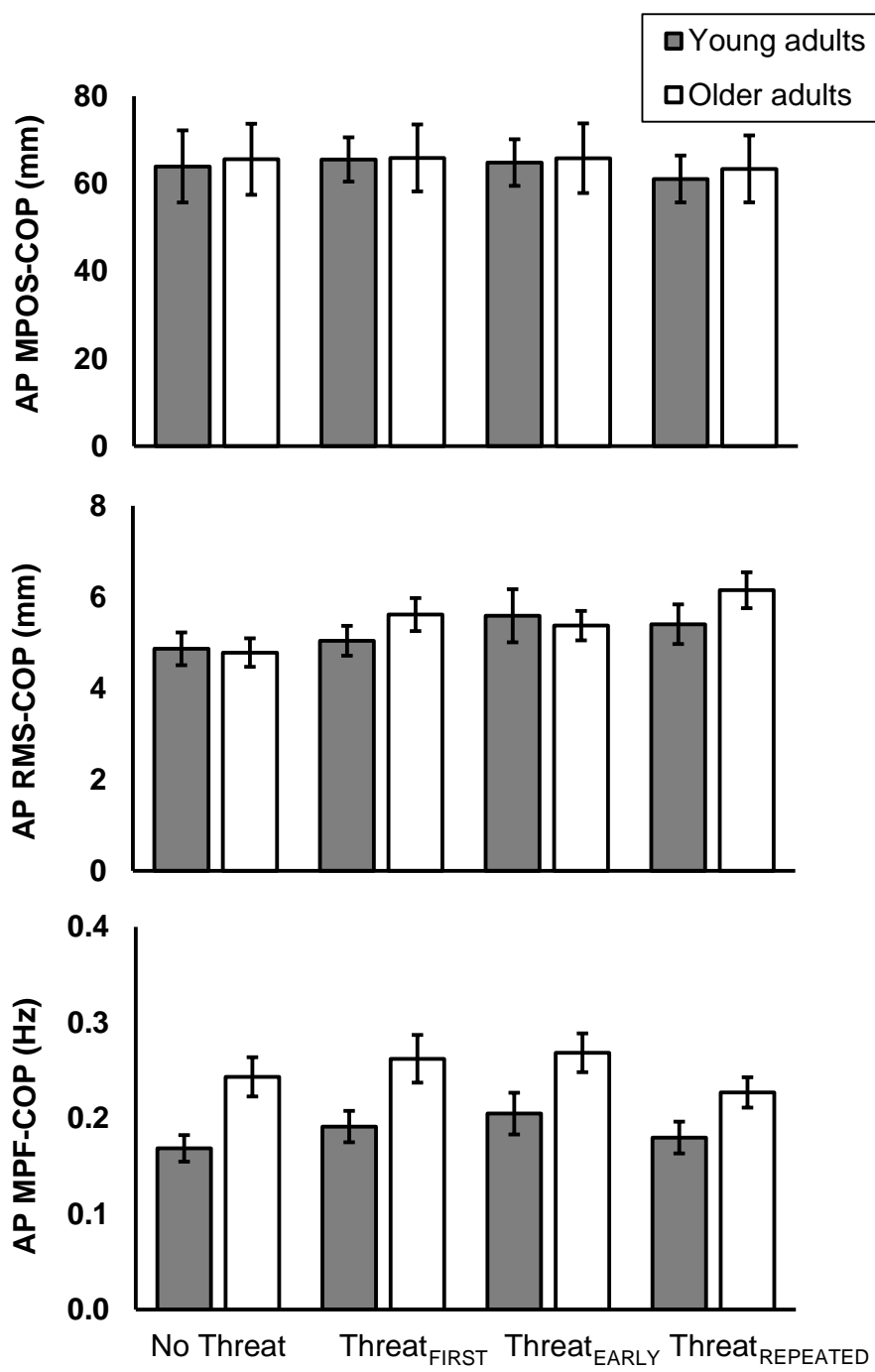
Appendix L: Data for young and older adults by threat condition

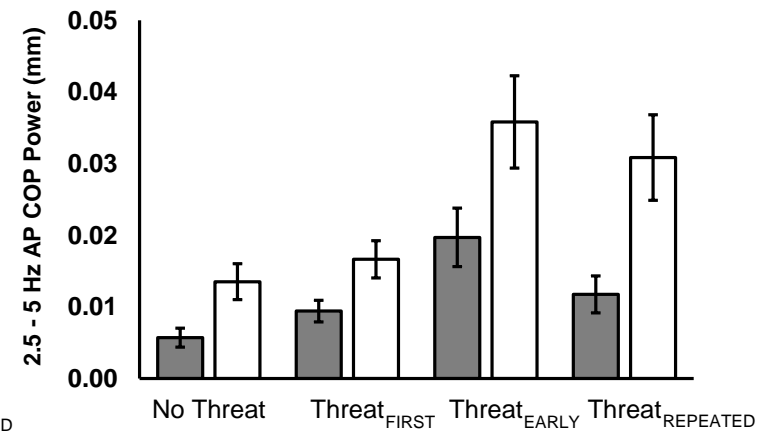
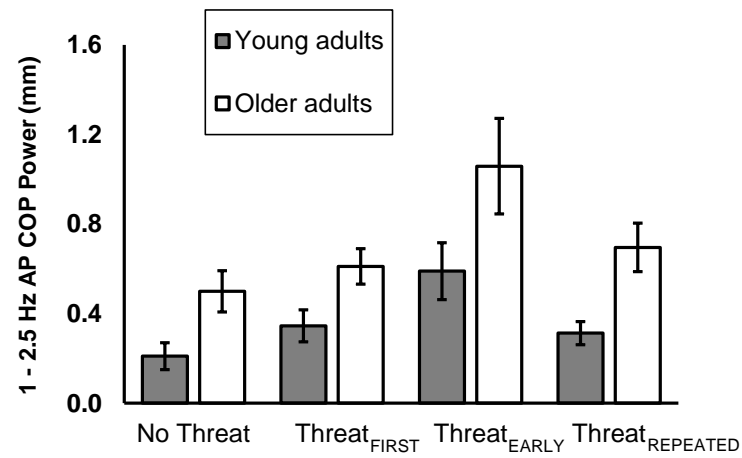
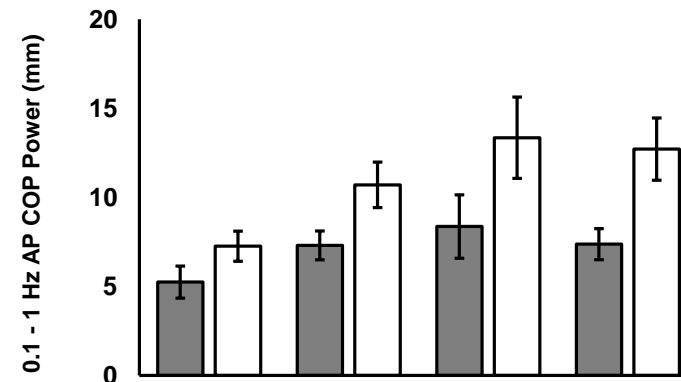
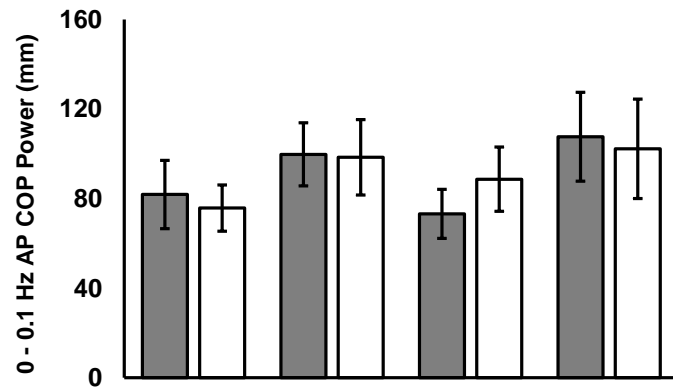












Appendix M: Representative COP data of initial threat effect

