The effects of postural threat on sample entropy

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Abstract

The objectives of this thesis were to 1) explore the effects of postural threat on sample entropy, a measure interpreted to reflect the attentional investment in postural control, and to 2) examine the relationships between threat-related changes in physiological arousal, perceived anxiety, attention focus, conventional postural control measures, and sample entropy. A secondary data analysis was conducted on a combined data set derived from two published studies; each study used the postural perturbation threat model which allowed for a comparison between No Threat and Threat conditions. Young adults ($N = 105$) stood without (No Threat) and with (Threat) the expectation of receiving a temporally and directionally unpredictable support surface translation in the forward or backward direction. Mean electrodermal activity and anterior-posterior centre of pressure mean position, root mean square, mean power frequency, power within low (0–0.05 Hz), medium (0.5–1.8 Hz), and high frequency (1.8–5 Hz) components, and sample entropy were calculated for each trial. Anxiety and attention focus to movement processes, task objectives, threat-related stimuli, self-regulatory strategies, and task-irrelevant information were rated after each trial. The results of the thesis showed that postural threat had a significant effect on sample entropy; higher values were reported in the Threat compared to No Threat condition. However, threat-related changes in physiological arousal, perceived anxiety, and attention focus were not significantly related to changes in sample entropy. Threat-related changes in sample entropy were related to changes in sway amplitude and frequency. The results of this thesis suggest a shift to a more automatic control of posture when threatened despite evidence of increased attention to postural control.

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Chapter One: Literature Review

1.1 Postural control

Postural control is a key requirement for the safe performance of many motor-related activities (Horak, 2006). Postural control can be defined as a complex sensorimotor process that involves the integration of sensory information from the visual, vestibular, and somatosensory systems to produce appropriate motor responses for upright stance (Horak, 2006; Winter, 1995). The central nervous system (CNS) coordinates sensorimotor strategies to stabilize the body's centre of mass (COM; position on the body in which the total body mass is equally distributed) over the supporting base through changes in the centre of pressure (COP), which corresponds to the point of application of the ground reaction force vector. To control the vertical projection of the COM over the base of support (BOS; area of the body in contact with the supporting surface; Winter, 1995), the CNS uses anticipatory and/or reactive strategies (Horak, 2006; Maki & McIlroy, 1997). These strategies contribute to whole-body control in static conditions (e.g., quiet two-legged stance) or when experiencing instability, either self-initiated or externally evoked (Horak, 2006). Therefore, the sensory information from the perceptual-motor system, environment, and performance task constraints affect appropriate task-specific performance (Huxham, Goldie, & Patla, 2001; Shumway-Cook & Woollacott, 2000). Considering the adaptability of the CNS, the integration of visual, vestibular, and somatosensory information changes in response to task constraints to achieve control in static and dynamic conditions (Horak & Macpherson, 1996; Shumway-Cook & Woollacott, 2000).

1.2 Emotional contributions

Fear of falling, and other fall-related psychological concerns have been shown to contribute to changes in postural control (Hadjistavropoulos, Delbaere, & Fitzgerald, 2011; Payette, Belanger, Leveille, & Grenier, 2016; Staab, Balaban, & Furman, 2013; Sturnieks, Delbaere, Brodie, & Lord, 2016; Young & Williams, 2015). For example, comparisons found increased sway variability during quiet standing in self-reported fearful older adults compared to non-fearful older adults (Maki, Holliday, & Topper, 1991). Research has also shown that neurophysiological substrates responsible for processing specific emotions, such as fear and anxiety, can explain the relationship between fall-related emotions and postural control (Balaban, 2002; Balaban & Thayer, 2001; Staab et al., 2013). Anxiety is an aversive emotional state in response to threatening circumstances and uncertainty as to the expectancy of threat (Bishop, 2007; Dimitriev, Saperova, & Dimitriev, 2016; Eysenck, Derakshan, Santos, & Calvo, 2007; Friedman, 2007). Postural control changes such as increased sway variability and sway velocity have been seen among those diagnosed with pathological anxiety disorders or those high-trait anxious (Redfern, Furman, & Jacob, 2007; Stambolieva & Angov, 2010). These emotional contributions are supported through integrated neurophysiological substrates responsible for autonomic control, vestibulo-autonomic interactions, and anxiety (Balaban, 2002; Balaban & Thayer, 2001; Staab et al., 2013).

Research has studied the relationship between threat-related changes in emotions and postural control. For example, the International Affective Picture System (e.g., IAPS; Lang, Bradley, & Cuthbert, 1999) has been used to explore the neural correlates underlying the processing of emotional or neutral pictures (Azevedo et al., 2005; Facchinetti, Imbiriba, Azevedo, Vargas, & Volchan, 2006; Mastria, Ferrari, & Codispoti, 2017; Soares et al., 2015). Healthy young adults passively viewing mutilation pictures on a stabilometric platform demonstrated a decreased amplitude and increased frequency of sway (Azevedo et al., 2005; Facchinetti et al., 2006). Studies using social evaluative threat, which is evoked by an evaluative audience or social comparison, have also examined the effects of emotions on postural control. For example, an arithmetic task and social evaluative threat resulted in decreased amplitude when provided with a negative performance evaluation (Doumas, Morsanyi, & Young, 2018). Evaluation by an 'expert' throughout the completion of a task has shown to affect older adults compared to tasks without an expert evaluator. Significant increases in amplitude and frequency were observed during two-legged stance with eyes closed while being assessed by an evaluator (Geh, Beauchamp, Crocker, & Carpenter, 2011). Taken together, these studies provide evidence of a relationship between emotions and postural control.

Another experimental approach that can be used to examine the effects of emotions on postural control is to increase the likelihood, or perceived consequences of instability associated with postural threat. This thesis will review the 1) surface height threat model and 2) postural perturbation (anticipation) threat model that have been used to examine the direct effects of emotions on postural control.

1.3 Postural threat

1.3.1 Surface height threat model

Researchers have manipulated the height of the surface on which participants stand to induce postural threat and increase the perceived consequences associated with instability (Adkin & Carpenter, 2018). The surface height model has been used to compare postural control in less threatening (e.g., standing on the ground) and more threatening conditions (e.g., standing on an elevated platform positioned 3.2-m above ground). Experimentally manipulating the surface height has been effective in providing researchers with an opportunity to directly examine the effects of emotions on postural control (Adkin & Carpenter, 2018). Research has shown that height-related postural threat is associated with increased physiological arousal and blood pressure (Adkin, Frank, Carpenter, & Peysar, 2002; Brown, Polych, & Doan, 2006; Carpenter, Adkin, Brawley, & Frank, 2006; Cleworth & Carpenter, 2016; Cleworth, Horslen, & Carpenter, 2012; Davis, Campbell, Adkin, & Carpenter, 2009; Huffman, Horslen, Carpenter, & Adkin, 2009; Sturnieks et al., 2016; Zaback, Cleworth, Carpenter, & Adkin, 2015; Zaback, Adkin, & Carpenter, 2019), and higher levels of self-reported state anxiety and fear of falling (Adkin et al., 2002; Carpenter et al., 2006; Cleworth & Carpenter, 2016; Cleworth et al., 2012; Davis et al., 2009; Hauck, Carpenter, & Frank, 2008; Huffman et al., 2009; Zaback et al., 2015; 2019). These measures provide evidence that the surface height threat model evokes state-related changes in emotions.

Research has also shown postural control changes in static (Adkin, Frank, Carpenter, & Peysar, 2000; Brown et al., 2006; Carpenter, Frank, & Silcher, 1999; Carpenter, Frank, Silcher, Peysar, 2001; Carpenter et al., 2006; Cleworth & Carpenter, 2016; Cleworth et al., 2012; Davis et al., 2009; Hauck et al., 2008; Huffman et al., 2009; Sturnieks et al., 2016; Zaback et al., 2019), anticipatory (Adkin et al., 2002; Gendre, Yiou, Gélat, Honeine, & Deroche, 2016; Zaback et al., 2015), and reactive (Brown & Frank, 1997; Carpenter, Frank, Adkin, Paton, & Allum, 2004) conditions of height-related threat. These results provide converging evidence for the use of the surface height model to investigate the relationship between emotions and postural control.

Quiet standing has been the most commonly studied postural task when using the surface height threat model. Ground reaction forces and moments applied to the supporting surface of the force plate represent quantitative parameters in the analysis of postural control during quiet standing (Duarte & Freitas, 2010; Koltermann, Gerber, Beck, & Beck, 2018; Mansfield & Inness, 2015; Palmieri, Ingersoll, Stone, & Krause, 2002; Scorza et al., 2018). The vector sum of the resultant ground reaction forces represents the net neuromuscular response of the CNS in controlling the displacements of the COM through the generation of ankle torques applied in the anterior-posterior (A-P) plane and lateral weight shifts in the medial-lateral (M-L) plane (Carpenter et al., 2001; Carpenter, Murnaghan, & Inglis, 2010; Gage, Winter, Frank, & Adkin, 2004; Santos, Kanekar, & Aruin, 2010; Sienko et al., 2010; Winter, 1995). Force plates provide position and frequency-based summary measures that describe various quantitative parameters such as mean position (MPOS-COP), root-mean-square (RMS-COP) amplitude, and mean power frequency (MPF-COP) that are derived from variations in COP displacement (Palmieri et al., 2002). These summary measures have been traditionally used by researchers to examine changes in standing postural control under conditions of threat (Adkin & Carpenter, 2018).

When tasked to stand quietly at, or close to the edge of an elevated surface height, healthy younger (Adkin et al., 2000; Brown et al., 2006; Carpenter et al., 1999; 2001; 2006; Cleworth et al., 2012; Davis et al., 2009; Hauck et al., 2008; Huffman et al., 2009; Sturnieks et al., 2016; Zaback et al., 2015; 2019) and older adults (Brown et al., 2006; Carpenter et al., 2006; Sturnieks et al., 2016) lean further away from the edge and adopt a postural control strategy characterized by decreased amplitude and increased frequency of COP displacements. These changes in postural control serve to constrain the forward displacement of the COM (Brown et al., 2006; Carpenter et al., 1999; 2001; Zaback et al., 2019; Zaback, Luu, Adkin, & Carpenter, 2021). The CNS exacts passive control over the displacement of the COM through increased amplitudes of activity in the agonist and antagonist muscles acting around the ankle joint (Brown et al., 2006; Carpenter et al., 1999). Results have suggested a decreased sway variability and increased sway frequency to reflect ankle muscle stiffness in response to postural threat. An ankle stiffening strategy is coupled with muscle coactivity of the ankle plantarflexors and dorsiflexors to control the body's COM as it structurally rotates around the ankle joint (Brown et al., 2006; Carpenter et al., 1999; Zaback et al., 2021). The adoption of an ankle stiffening strategy while standing at height allows control over the forward movement of the body's COM without imposing change to body orientation in the way of a compensatory step (Brown et al., 2006). This was confirmed by increased co-contraction of lower leg muscles and constrained COM displacements under height-related threat (Carpenter et al., 2001). Further evaluation has revealed changes in higher frequency (> 0.5 Hz) COP displacements and SOL-TA co-contraction. Zaback et al. (2019) examined frequency bands where COP significantly differed between conditions of threat and determined that increases in MPF-COP are due to decreases in lower frequency (≤ 0.05 Hz) and increases in higher frequency (> 0.5 Hz) COP. Significant postural control changes in static conditions of height-related threat are examined in Table 1.

Table 1. Effects of height-related threat on standing postural control

Study	Population	Maximum Threat	Sampling Duration	A-P MPOS-COP	A-P RMS-COP	A-P MPF-COP
Adkin et al. (2000)	62 YA	1.6 m	120 s	Posterior lean	Decreased	Increased
Brown et al. (2006)	15 YA/OA	1.4 m	15 s	Posterior lean	Decreased	Increased
Carpenter et al. (1999)	28 YA	0.81 m	120 s	Posterior lean	Decreased	Increased
Carpenter et al. (2001)	8 YA	0.81 m	120 s	Posterior lean	Decreased	Increased
Carpenter et al. (2006)	14 YA/OA	1.6 m	120 s	Posterior lean	Decreased	Increased
Davis et al. (2009)	36 YA	3.2 m	60 s	Posterior lean	Decreased	Increased
Hauck et al. (2008)	31 YA	1.4 m	60 s	Posterior lean	Decreased	Increased
Huffman et al. (2009)	48 YA	3.2 m	60 s	Posterior lean	No change	Increased
Sturnieks et al. (2016)	9 YA/48 OA	0.65 m	30 s	Posterior lean	Decreased	Increased
Zaback et al. (2015)	82 YA	3.2 m	60 s	Posterior lean	Decreased	Increased
Zaback et al. (2019)	68 YA	3.2 m	120 s	Posterior lean	Decreased	Increased

Note: Significant anterior-posterior (A-P) centre of pressure (COP) mean position (MPOS), root mean square (RMS), and mean power frequency (MPF) measures in young (YA) and older (OA) adults are reported. Adapted from Adkin and Carpenter (2018).

Research has consistently reported threat-related postural changes standing at surface heights. Young and healthy older adults lean further away from the edge of the surface, and demonstrate decreased amplitude and increased frequency when threatened (Adkin et al., 2000; Brown et al., 2006; Carpenter et al., 1999; 2001; 2006; Cleworth et al., 2012; Davis et al., 2009;

Hauck et al., 2008; Sturnieks et al., 2016; Zaback et al., 2015; 2019). Threat-related changes in amplitude (Davis et al., 2009; Nakahara, Takemori, & Tsuruoka, 2000; Simeonov & Hsiao, 2001; Zaback et al., 2015), or no significant change (Pasman, Murnaghan, Bloem, & Carpenter, 2011; Huffman et al., 2009) in the amplitude of sway have been reported as exceptions to these results. For example, standing at extreme surface heights (> 9-m high; Nakahara et al., 2000; Simeonov & Hsiao, 2001) has revealed significant increases in sway amplitude. A three-way interaction for height, surface firmness, and visual reference reported increased A-P sway (101%) in conditions without close visual reference on deformable surfaces (Simeonov & Hsiao, 2001). Research has also shown increased amplitude in self-reported fearful groups (Davis et al., 2009), and participants more prone to trait conscious motor processing (Zaback et al., 2015).

Research has also examined threat-related changes in anticipatory (Adkin et al., 2002; Gendre et al., 2016; Zaback et al., 2015) and reactive postural control (Brown & Frank, 1997; Carpenter et al., 2004), and gait (Brown, Sleik, Polych, & Gage, 2002; McKenzie & Brown, 2004). For example, in whole-body movement towards the edge of an elevated surface, such as the task of rising to toes, the peak amplitude and velocity of anticipatory postural adjustments were reduced while threatened (Adkin et al., 2002). Reductions in COM displacement and a significantly shorter latency to peak COM velocity has also been observed following a forward push to the upper trunk (Brown & Frank, 1997). Furthermore, unexpected perturbations reduced COM displacement and angular displacements of the leg, pelvis, and trunk (Carpenter et al., 2004). Slower gait velocity and shorter stride lengths have also been observed using the surface height threat model (Brown et al., 2002), with reduced limb velocity, trail limb velocity, and whole body COM velocity in obstacle negotiation tasks (McKenzie & Brown, 2004).

1.3.2 Postural perturbation (anticipation) threat model

Postural threat has been manipulated by altering the expectation of receiving an unpredictable perturbation. This model can be used to compare quiet standing behaviour in non-threatening (i.e., standing with no possibility of a perturbation) and threatening conditions (i.e., standing with the possibility of a perturbation). The type of perturbation has varied from a push or a pull to the upper body (Shaw, Stefanyk, Frank, Jog, & Adkin, 2012), or a support surface translation (Johnson, Watson, Tokuno, Carpenter, & Adkin, 2020; Johnson, Zaback, Tokuno, Carpenter, & Adkin, 2019; 2019b; Phanthanourak, Cleworth, Adkin, Carpenter, & Tokuno, 2016) or rotation (Horslen, Murnaghan, Inglis, Chua, & Carpenter, 2013). The threat of receiving a postural perturbation significantly increases physiological arousal and self-reported state anxiety, which supports the use of the model as an alternative approach to surface height threat, to investigate the emotional contributions on postural control (Johnson et al., 2019; 2019b; 2020; Shaw et al., 2012).

Research has shown increased angular displacement and angular velocity of trunk sway in the roll and pitch directions while standing with, compared to without the expectation of receiving a perturbation to the upper trunk in healthy young adults (Shaw et al., 2012). Threat-related changes in quiet standing such as increased amplitude and frequency of COP displacements, and a significant forward lean has been seen in anticipation of an A-P support surface perturbation (Johnson et al., 2019; 2020). Threat-related increases in the amplitude and frequency of COP displacements have also been observed when anticipating a support surface perturbation occurring in the left or rightward direction (Johnson et al., 2019). Significant effects of perturbation threat on standing postural control are summarized in Table 2. Recent evaluation of threat-related changes in postural control has revealed no change in the low frequency (0–0.05

Hz), but increases in the medium (0.5–1.8 Hz) and high frequency (1.8–5 Hz) components of COP displacements when threatened (Johnson et al., 2019b; 2020).

Table 2. Effects of support surface perturbation threat on standing postural control

Study	Population	Direction of Threat	Peak Acceleration	MPOS-COP	RMS-COP	MPF-COP
Johnson et al. (2019)	80 YA	A-P	1.7 m/s^2	Forward lean	Increased	Increased
Johnson et al. (2019b)	27 YA/OA	M-L	1.4 m/s^2	No effect	Increased	Increased
Johnson et al. (2020)	25 YA	A-P	1.7 m/s^2	Forward lean	Increased	Increased

Note: Significant anterior-posterior (A-P) and medial-lateral (M-L) centre of pressure (COP) mean position, mean power frequency (MPF), and root mean square (RMS) measures in young (YA) and older (OA) adults are reported. COP measures were calculated in the A-P direction (Johnson et al., 2019; 2020) and M-L direction (Johnson et al., 2019b).

1.3.3 Threat-related changes in standing postural control: role of threat context

Research has shown a consistent strategy in standing postural control under conditions of height-related threat (Table 1). Consistent changes in standing postural control have also been shown while standing with the threat of a support surface perturbation (Table 2). When comparing changes in postural control between height and perturbation-related threat, some postural changes seem to be specific to the context of the threat while other postural changes are consistent across threat contexts. For example, threat-related changes in leaning and amplitude are context-dependent, while changes in frequency are consistent across different types of threat (Adkin & Carpenter, 2018; Johnson et al., 2019; 2019b; 2020; Zaback et al., 2019). Increased frequency (i.e., MPF-COP, COP $Freq_{MED}$, and COP $Freq_{HIGH}$) has been consistently reported between No Threat and Threat conditions (Table 3). Significant increases in spectral power at higher frequencies has also been consistent across threat contexts (Johnson et al., 2019b; 2020;

Zaback et al., 2019). Height-related threat showed that changes in MPF-COP were the result of decreases in low frequency (≤ 0.05 Hz) and increases in higher frequency (> 0.5 Hz) components (Zaback et al., 2019). It is therefore possible that some threat-related postural changes are primarily dependent on the context of the postural threat. For example, increased amplitude prior to a perturbation has been shown to preserve stability in the A-P direction (Rajachandrakumar, Mann, Schinkel-Ivy, & Mansfield, 2018). Increased amplitude and frequency of COP displacements, and leaning further forward can be considered an appropriate strategy in response to a perturbation-related threat as it has been shown to counteract forward and backward body sway and promote compensatory stepping (Maki & Whitelaw, 1993; Welch & Ting, 2014). Contrary to the postural perturbation threat model, decreased amplitude and increased frequency, as well as leaning further away from the edge of the surface can constrain the body's COM under conditions of height-related threat (Adkin et al., 2000; Brown et al., 2006; Carpenter et al., 1999; 2001; 2006; Davis et al., 2009; Huffman et al., 2009; Sturnieks et al., 2016; Zaback et al., 2015; 2019).

Table 3. Effects of threat on anterior-posterior (A-P) and medial-lateral (M-L) COP power within low, medium, and high frequencies

Study	Population	Type of Threat	MPF-COP	COP $Freq_{LOW}$	COP $Freq_{MED}$	COP $Freq_{HIGH}$
Johnson et al. (2019b)	27 YA/OA	Perturbation	Increased	No effect	Increased	Increased
Johnson et al. (2020)	25 YA	Perturbation	Increased	No effect	Increased	Increased
Zaback et al. (2019)	68 YA	Height	Increased	Decreased	Increased	Increased

Note: Significant anterior-posterior (A-P) and medial-lateral (M-L) centre of pressure (COP) mean power frequency (MPF) and COP power within ranges of 0-0.05 Hz (COP $Freq_{LOW}$) 0.5–1.8 Hz (COP $Freq_{MED}$), and 1.8−5 Hz (COP $Freq_{HIGH}$) in young (YA) and older (OA) adults are reported. COP measures were calculated in the A-P direction (Johnson et al., 2019; 2020) and M-L direction (Johnson et al., 2019b).

1.4 Mechanisms underlying threat-related changes in postural control

Research has previously documented state-related physiological and psychological changes associated with postural threat. State-related changes in physiological arousal and anxiety (Adkin et al., 2002; Brown et al., 2006; Carpenter et al., 2006; Davis et al., 2009; Hauck et al., 2008; Huffman et al., 2009; Johnson et al., 2019; 2019b; 2020; Sturnieks et al., 2016; Zaback et al., 2015; 2019), and ratings of stability and balance-related confidence (Hauck et al., 2008; Huffman et al., 2009) have been consistently reported. These state changes have been shown to contribute to threat-related changes in postural control. For example, increased confidence (i.e., task-specific balance efficacy) was significantly associated with decreased COP frequency and increased one-leg stance duration (Hauck et al., 2008). State-changes in conscious motor processing and movement self-consciousness, and self-reported perceptions of anxiety (i.e., worry-related and somatic anxiety subscales) were associated with leaning further away from the edge of an elevated surface (Huffman et al., 2009). Research has also shown increases in proprioceptive (Davis et al., 2011; Horslen et al., 2013; Horslen, Dakin, Inglis, Blouin, &

Carpenter, 2014; Horslen, Zaback, Inglis, Blouin, & Carpenter, 2018) and vestibular-evoked reflex gains (Naranjo, Allum, Inglis, & Carpenter, 2015; Naranjo et al., 2016; 2017), which has been known to actively modulate muscle spindle sensitivity to stretch. This has been assessed indirectly through changes in soleus tendon-tap reflex (t-reflex) and Hoffmann (H-) reflex (Horslen et al., 2014). Stretch reflexes, evoked with Achilles tendon taps, increased in amplitude when standing on an elevated surface (Horslen et al., 2013). Research has shown that increased sensory gain contributes to participants perceiving themselves to be swaying at larger amplitudes than actually exhibited. For example, leaning amplitude decreased under height-related threat and participants perceived themselves to be at a further position relative to their actual position (Cleworth, Inglis, & Carpenter, 2018). An altered perception could be associated with increases in conscious motor processing (Cleworth & Carpenter, 2016). Therefore, a combination of neurophysiological modifications and changes in attention to movement could contribute to threat-related changes in postural control (Adkin & Carpenter, 2018).

1.4.1 Threat-related changes in attention focus

There are significant threat-related changes in attention focus. Postural threat changes the focus of attention, and has the potential to contribute to threat-related changes in postural control (Huffman et al., 2009; Johnson et al., 2019; 2019b; 2020; Zaback et al., 2015; Zaback, Carpenter, & Adkin, 2016). Research has shown increased movement specific reinvestment; a propensity to focus attention internally to consciously process relatively automated movements under conditions of postural threat (Huffman et al., 2009; Zaback et al., 2015). The propensity for movement reinvestment can be measured using the Movement Specific Reinvestment Scale (MSRS), which evaluates two subscales of reinvestment, conscious motor processing (CMP) and movement self-consciousness (MSC; Masters & Maxwell, 2008). CMP reflects a tendency to consciously control movement mechanics, whereas MSC reflects concern over movement style (Masters, Eves, & Maxwell, 2005). Younger adults were observed when standing under conditions of height-related threat. For example, state-changes in CMP and MSC were reported at two different surface heights: ground level (LOW) and 3.2-m above ground level (HIGH). Increases in state-related movement reinvestment were associated with leaning further away from the edge of the support surface (Huffman et al., 2009). Trait movement reinvestment also contributes to threat-related changes in postural control. For example, increased trait CMP was significantly associated with increased COP amplitude when standing under conditions of height-related threat (Zaback et al., 2015).

The prioritization of postural control, and subsequent performance of secondary cognitive tasks in conditions of postural threat has been quantified in younger and older adults (Brown et al., 2002; Gage, Sleik, Polych, McKenzie, & Brown, 2003). A prioritization index was calculated to quantify the relationship between cognition and postural task performance in testing positions presenting a threat to posture. Task priority was tested standing in two surface height positions (e.g., low and high) and stance conditions (e.g., middle of the support surface and edge of the support surface) while performing a secondary task. Performance on the Brooks' Spatial Letter task showed that the prioritization of postural control can be preserved when threatened. For example, young adults prioritized cognitive and postural task performance by significantly reducing COP area while standing at the edge of the support surface. However, older adults prioritized postural control over secondary cognitive task performance (Brown et al., 2002). Performing a cognitive task in conditions of postural threat can provide further explanation for the known age-dependent differences compromising attentional processing, and subsequent task performance during walking tasks (Brown et al., 2002; Gage et al., 2003). When tasked to walk at a self-determined speed responding to an unpredictable auditory stimulus, the prioritization of postural control can be preserved under conditions of height-related threat. Task priority was tested depending on the width constraints of the walkway (e.g., 1.5-m and 6-m) and the height of the walking surface (e.g., 0-m and 6-m). Interpreted by response time to a probe reaction time task, younger and older adults prioritized postural task performance. Slower verbal response times were reported, which has been interpreted as an increase in the amount of attention invested in the primary task of walking (Gage et al., 2003). These results suggest that participants may alter their cognitive strategy and reallocate attention towards conscious control of posture under threatening conditions (Gage et al., 2003). These results have been supported by research showing broad changes in attention focus, including directing more attention to movement, in response to both height- and perturbation-related threat (Adkin & Carpenter, 2018).

Threat-related changes in attention focus have been consistently reported. Attention focus has been categorized using an open-ended question (i.e., “What did you think about or direct your attention toward during the balance task?”) with follow-up interviews to assess the reallocation of attention under conditions of height-related postural threat. Based on participant responses, five attention focus categories were defined including movement processes, task objectives, threat-related stimuli, self-regulatory strategies, and task-irrelevant information (Zaback et al., 2016). When standing at height, participants self-report increasing attention towards movement processes, threat-related stimuli, and self-regulatory strategies, and decreasing attention to task objectives and task-irrelevant information (Zaback et al., 2016; 2019). Research has shown threat-related changes in attention focus associated with threat-related changes in postural control. For example, increases in attention towards movement processes accounted for increases in frequency (i.e., MPF-COP) of COP displacements. Increases in attention towards self-regulatory strategies between No Threat and Threat conditions was associated with decreases in COP amplitude (Zaback et al., 2016). Standing under repeated exposure to high threat also showed that attention to movement processes was a significant predictor for high frequency (> 0.5 Hz) COP (Zaback et al., 2019).

Threat-related changes in attention focus have also been reported using the postural perturbation (anticipation) threat model. When threatened, participants self-report increasing attention towards movement processes, threat-related stimuli, and self-regulatory strategies, and decreasing attention to task-irrelevant information. Threat-related changes in attention to task objectives has either increased (Johnson et al., 2019b; 2020), or has shown no significant changes (Johnson et al., 2019). For example, increased attention towards movement processes was associated with increased amplitude and leaning. Furthermore, increased attention towards self-regulatory strategies between No Threat and Threat conditions was associated with increased frequency (Johnson et al., 2019). While performing a concurrent cognitive task, decreases in attention to self-regulatory strategies accounted for decreases in medium frequency (0.59–1.82 Hz) components when threatened. While not confirmed statistically, threat-related changes in attention towards movement processes and high frequency (1.83–5 Hz) COP were attenuated by a cognitive distractor task (Johnson et al., 2020). Research has shown inconsistent relationships between psychological (e.g., increased attention towards movement processes) and physiological responses (e.g., increased blood pressure) and threat-related changes in postural control (Table 4). Participants' self-reported psychological state could be confounded by the context of the threat, or the psychometric properties (i.e., reliability and validity) of questionnaire scales. For example, the attention focus questionnaire is potentially susceptible to response bias (Zaback et al., 2016).

Table 4. Relationships between threat-related changes in psychological, physiological, and postural control measures

Study	Threat	Postural control measures	Trait, and State Psychological and Attention measures
Carpenter et al., 2006	Height	↑ A-P RMS-COP	↑ Blood pressure (mmHg)
		↑ M-L RMS-COP ↑ A-P MPF-COP	↑ State anxiety ↓ Balance efficacy
Davis et al., 2009	Height	↑ A-P RMS-COP	↑ Fear of falling (%)
		↑ A-P MPF-COP	↑ Fear of falling (%)
Hauck et al., 2008	Height	↑ A-P RMS-COP ↓ A-P MPF-COP	↑ Perceived stability (sum) ↑ Balance confidence (%)
Huffman et al., 2009	Height	↓ A-P MPOS-COP	↑ State CMP (sum)
			↑ State MSC (sum)
			↑ Perceived anxiety (sum)
			↓ Perceived stability (sum)
		↑ A-P MPF-COP	↓ Balance confidence (%)
Zaback et al., 2015	Height	↓ A-P MPOS-COP	↓ Physical risk-taking (sum) ↑ Trait CMP (sum)
		↑ A-P RMS-COP	↑ Physical risk-taking (sum)
			↑ Trait CMP (sum)
		↓ A-P RMS-COP	↑ Trait MSC (sum)
		↑ A-P MPF-COP	↓ Physical risk-taking (sum)
Zaback et al., 2016	Height	↓ A-P RMS-COP	↓ Att. MP
			↑ Att. SRS
		↑ A-P MPF-COP	↑ Att. MP
Johnson et al., 2019	Perturbation	↑ A-P MPOS-COP	↑ Att. MP*
		↑ A-P RMS-COP	↑ Perceived anxiety (sum)
		↑ A-P MPF-COP	↑ Att. SRS*

Note: A-P = anterior-posterior; RMS = root mean square; COP = centre of pressure; M-L = medial-lateral; MPF = mean power frequency; MPOS = mean position; CMP = conscious motor processing; MSC = motor self-consciousness; MP = movement processes; SRS = self-regulatory strategies. ↑ represents an increase, ↓ represents a decrease. For A-P MPOS-COP, a ↑ represents a forward lean and a ↓ represents a backward lean. * relationship was identified after perturbation experience.

1.5 Exploring the relationship between emotions, attention focus, and postural control

Specific associations between threat-related changes in emotions, attention focus, and postural control have been identified. However, these associations are inconsistent and require further examination. Recently, different approaches have been used to examine these relationships including repeated exposure to threat and distraction. For example, repeated exposure to height has been associated with threat-related changes in attention focus and postural control. While repeatedly exposed to a surface height threat (i.e., five consecutive two-minute standing trials), participants increased attention towards task-irrelevant information and decreased attention towards movement processes and threat-related stimuli. Specifically, changes in attention towards movement processes and threat-related stimuli remained elevated above low threat values, whereas attention towards task-irrelevant information returned to those values. Threat-related changes in postural control such as high frequency (> 1.83 Hz) COP and ankle muscle co-contraction showed adaptation across repeated exposures to HIGH (3.2-m) threat. Attention to movement processes has been shown as a significant predictor of change for high frequency (> 1.83 Hz) COP. There are also specific threat-related changes in postural control that are less prone to adaptation such as amplitude and mean position (Zaback et al., 2019).

Threat-related changes in attention focus and postural control have also been examined across repeated exposures to the threat of perturbation. Participants completed 24 trials standing with the expectation that the support surface could translate in the left or rightward direction at any time during each trial (Threat). Participants increased attention towards task-irrelevant information and decreased attention towards movement processes and threat-related stimuli between $\text{Threat}_{\text{EARLY}}$ (i.e., early threat experience) and $\text{Threat}_{\text{LATE}}$ conditions (i.e., late threat experience). Changes in attention to task objectives and self-regulatory strategies did not significantly adapt. Participants also decreased frequency (i.e., MPF-COP and COP Freq_{MED})

across repeated threat exposures. Conversely, threat-related changes in amplitude and high frequency (> 1.83 Hz) COP were not associated with adaptation. However, relationships between threat-related changes in attention focus and postural control were not examined in this study (Johnson et al., 2019b).

Further research has examined the effects of distraction on threat-related changes in attention focus and postural control. Participants completed three distractor task conditions: Letter Sequence, Number Sequence, and No Distractor Task to determine if distracting attention has the potential to attenuate threat-related changes in postural control. For example, participants counted the occurrence of a pre-selected letter in an auditory sequence of letters presented at 2 second intervals. In the Threat compared to No Threat condition, attention to self-regulatory strategies decreased in the Letter Sequence condition. Participants also showed decreases in medium frequency (0.5–1.8 Hz) COP when standing and concurrently performing a distractor task under conditions of postural threat. While unconfirmed statistically, threat-related changes in attention to movement processes and higher frequency (1.8–5 Hz) COP were attenuated with distraction (Johnson et al., 2020).

1.6 Linear measures of postural control

Quiet standing has been commonly studied in the surface height and postural perturbation threat model. Centre-of-pressure (COP) and frequency-domain measures (i.e., power spectrum of the COP) recorded from quiet standing trials have been compared in No Threat and Threat conditions. More recently, non-linear measurements have been used to complement COP summary measures under conditions of height-related threat. Static posturography uses force plate instrumentation to evaluate the COP, which corresponds to the point of application of the ground reaction force vector (Lafond, Corriveau, Hébert, & Prince, 2004; Maurer & Peterka, 2005; Moghadam et al., 2011; Winter, 1995). Force plates provide position and frequency-based summary measures that describe various quantitative parameters in the A-P and M-L directions (Bernard et al., 2013). Force plate posturography quantifies the displacement of the COP, with parameters including mean position (MPOS-COP), root-mean-square (RMS-COP) amplitude, RMS velocity, and mean power frequency (MPF-COP; Baratto, Morasso, Re, & Spada, 2002; Cavanaugh, Guskiewicz, & Stergiou, 2005; Giovanini, Silva, Manffra, & Nievola, 2017; Lafond et al., 2004; Palmieri et al., 2002; Schilling et al., 2009). Frequency-domain measures also evaluate frequency content or pre-determined frequency bands (Hansen et al., 2017; Maurer & Peterka, 2005; Paillard & Noé, 2015; Prieto, Myklebust, Hoffmann, Lovett, & Myklebust, 1996). For example, the power spectrum of the COP is contained within frequency bands: low, medium, and high (Laboissière et al., 2015; Singh, Taylor, Madigan, & Nussbaum, 2012). Frequency-domain measures characterize the area or shape of the Power Spectral Density (PSD) profile (Laboissière et al., 2015; Maurer & Peterka, 2005; Palmieri et al., 2002). A Fast Fourier Transform (FFT) evaluates the amount of power in pre-determined frequency bands (Laboissière et al., 2015; Singh et al., 2012). For example, the FFT algorithm estimated the power of the signal distributed over different frequencies (bandwidth 0.1-8 Hz) in patients with phobic postural vertigo (i.e., PPV). Significant increases in spectral power at higher frequencies (3.53–8 Hz) were seen in patients compared to controls (Krafczyk, Schlamp, Dieterich, Haberhauer, & Brandt, 1999). The distribution of frequencies in the power spectrum were also examined under postural threat conditions (Johnson et al., 2019b; 2020; Zaback et al., 2019). The distribution of spectral power concentrated at higher frequencies were observed in healthy young adults standing in Threat compared to No Threat conditions. Significant increases in medium (0.5–1.8 Hz) and high frequencies (1.8–5 Hz) were seen prior to a support surface perturbation (Johnson et al., 2019). Research has suggested that higher frequency (> 0.1 Hz) corresponds to an anxious control of posture (Holmberg, Tjernström, Karlberg, Fransson, & Magnusson, 2009). Therefore, the distribution of frequencies along the power spectrum can be used to evaluate threat-related changes in postural control.

1.6.1 Non-linear measures of postural control

Researchers have considered whether linear measures of postural control should be supplemented with non-linear measures. For example, linear and non-linear measurements have evaluated fall-related psychological concerns and anxiety under height-related threat (Ellmers, Kal, & Young, 2020; Stins, Roerdink, & Beek, 2011). Entropy-based measures and stabilogram diffusion analysis (SDA) were calculated from the COP signal to evaluate associated changes in postural control. Asymptomatic older adults completed standing conditions: Baseline (ground level), Threat (standing at a surface height of 0.6 m), and Threat-Distraction. Relationships between fall-related anxiety, conscious processing of balance, and distorted perceptions of instability were explored. Ellmers et al. (2020) hypothesized that non-linear measurements would provide a comprehensive measure of COP, for example, increases in sample entropy (i.e., less consciously processed balance) and short-term diffusion coefficients were shown standing at a surface height of 0.6-m. Linear (e.g., amplitude and frequency) and non-linear measurements showed similar results. Sample entropy significantly increased; coinciding with increases in medium (0.5–1.8 Hz) and high frequencies (1.8–5 Hz; Ellmers et al., 2020). Research has also shown contradictory results in younger adults standing at a surface height of 1-m. No significant differences in amplitude and MPF-COP were observed between height and baseline conditions. Stins and colleagues (2011) hypothesized that sample entropy would decrease (i.e., greater consciously processed balance) but no such effect was found. Due to the inconsistent results in the surface height threat model, further evaluation is required to explore linear and non-linear measurements.

1.6.2 Entropy-based measures

Linear postural measurements are unable to reliably represent the structure of variability of the COP signal (Kędziorek & Błażkiewicz, 2020; Kirchner, Schubert, Schmidtbleicher, & Haas, 2012; Ladislao & Fioretti, 2007; Liau et al., 2019; Turnock & Layne, 2009). Measures that assume linearity are not sensitive enough to capture temporal patterns in the COP signal (Ladislao & Fioretti, 2007; Liau et al., 2019; Turnock & Layne, 2009). Therefore, non-linear measurements have been used to evaluate changes in the COP signal that are not captured by linear measures (Hansen et al., 2017; Kędziorek & Błażkiewicz, 2020; Roerdink et al., 2006). Non-linear measurements include the largest Lyapunov exponent and Hurst exponent, recurrence quantification analysis (RQA), as well as fractal dimension (FD) and entropy-based (Kędziorek & Błażkiewicz, 2020; Uiga, Capio, Ryu, Wilson, & Masters, 2018). Researchers have used non-linear measures of postural control to supplement linear measures (Turnock & Layne, 2009). For example, entropy-based measures (e.g., approximate entropy and sample entropy) have been used to evaluate the regularity or predictability of the COP signal (Pincus, 1991; Richman & Moorman, 2000). Approximate entropy (ApEn) quantifies the conditional probability of pattern reproducibility in the signal (Hansen et al., 2017; Kaffashi, Foglyano, Wilson, & Loparo, 2008; Pincus, 1991). By quantifying the probability that relatively short time-series are repeated as a logarithmic function, ApEn produces a unit-less value between 0 and 2 (Turnock & Layne, 2009). A zero value corresponds to a time-series containing repeated patterns (e.g. a periodic signal), whereas a value equal to 2 corresponds to a completely random pattern (Cavanaugh et al., 2005; Delgado-Bonal & Marshak, 2019). The ApEn algorithm counts self-matches in the estimates of the conditional probability to prevent computing the natural logarithm of zero, therefore producing a biased measure (Delgado-Bonal & Marshak, 2019; Kaffashi et al., 2008; Sokunbi, 2014). To reduce this bias, sample entropy was introduced to eliminate self-matches and shows relative consistency over approximate entropy.

1.6.3 Sample entropy

Sample entropy is the negative natural logarithm of the conditional probability that two similar sequences with the same amount of data points remain similar when another data point is added, where self-matches are not included in calculating the probability (Richman & Moorman, 2000). Lower sample entropy values correspond to a high frequency of similarity in a time-series (i.e., more repeating patterns) whereas higher sample entropy values correspond to a low frequency of similarity (Bhavsar et al., 2018; Delgado-Bonal, Marshak, Yang, & Holdaway, 2020; Yamagata, Ikezoe, Kamiya, Masaki, & Ichihashi, 2017). Sample entropy is calculated using the following formula (Richman & Moorman, 2000):

$$\text{SampEn}\ (m, r, N) = -\log\left(\frac{\text{A}}{\text{B}}\right)$$

where, *m* is the length of the sequences to be compared, *r* is the tolerance value for accepting matches, *N* is the length of the data, and *A/B* are defined as follow:

$$A = \left\{\frac{(n-m-1)(n-m)}{2}\right\} A^m(r), \text{ and } B = \left\{\frac{(n-m-1)(n-m)}{2}\right\} B^m(r)$$

where, $A^m(r)$ is the probability that sequences match for $m + 1$ points, and $B^m(r)$ is the probability that sequences match for *m* points. Sample entropy thus follows from log(A/B), with lower sample entropy values arising from a high probability of repeated sequences in the time-series. It is recommended that parameter *r* is set between 0.1 and 0.25 times the standard deviation (SD) of the data. Choosing a smaller *r* value can lead to an increased number of self-matches and choosing a larger *r* value can avoid significant noise contributions (Kaffashi et al., 2008). It is also recommended that *m* is set at 2 or 3. By choosing an *m* of 2, for example, the algorithm compares two sequences of $m = 2$ consecutive data points (Kuznetsov, Bonnette, & Riley, 2013). Researchers compared patients with and without vestibular dysfunction in a virtual reality assessment, and showed that sample entropy was consistent across $m = 2$ and $m = 3$. Within the assessment, patients observed virtual reality scenes, while standing on a stable or a compliant surface. A consistent significant main effect of surface was reported across the two different *m* values (Lubetzky, Harel, & Lubetzky, 2018). Appropriate lengths of time-series have also been recommended, for example, lengths equal to or greater than $N = 60$-s (Kuznetsov et al., 2013; Yentes et al., 2013). Montesinos and colleagues (2018) studied whether sample entropy could discriminate between experimental populations across $N = 600$ and $N = 1200$ (30-s and 60-s, respectively). Young adults and older adults with and without falls in the last year completed four conditions: eyes open on a rigid surface, eyes open on a foam surface, eyes closed on a rigid surface, and eyes closed on a foam surface. No significant differences were observed between longer and shorter lengths. Sample entropy was able to discriminate between two different populations (i.e., young and older adults), however, only certain parameter combinations showed significant differences between similar populations (i.e., older adults with and without falls in the last 12 months). Differences were observed in the A-P direction with longer time-series of length $N = 1200$ (equivalent to 60-s). Researchers have recommended consistency when comparing sample entropy, even in those with similar populations and testing conditions (Montesinos, Castaldo, & Pecchia, 2018).

1.6.4 Interpretation of sample entropy

Sample entropy provides a measure of automaticity – for which higher values correspond to more automatic (i.e., less consciously processed) control (Drozdova-Statkevičienė, Česnaitienė, Pukėnas, Levin, & Masiulis, 2018). There is speculation that automaticity, which is characteristic of attention, is significantly correlated to entropy-based measures (Rhea, Diekfuss, Fairbrother, & Raisbeck, 2019). Theories claim postural control to be automatic and require minimal attention, emphasizing the continuum on which sample entropy can be described (Figure 1). For example, Roerdink et al. (2011) reported significant decreases in sample entropy in patients recovering from stroke compared to healthy controls, and increases during the course of rehabilitation. Interpreted as attentional investments in postural control; a significant increase in sample entropy corresponded to a decrease in attention (Roerdink et al., 2006). Similarly, Rhea and colleagues (2019) compared whether focusing internally or externally could contribute to changes in the structure and magnitude (SD) of postural control. In the internal focus conditions, young and older adults were instructed to focus on keeping their feet level and in the external focus condition, to focus on keeping the floor level when performing a static balance task. Sample entropy significantly increased when instructed to focus externally, with no main effect of age. Results also showed no differences in SD (Rhea et al., 2019). These results were theoretically significant to the interpretation of the relationship between sample entropy and attention (Roerdink et al., 2006). Expected to be influenced by threat, a corresponding decrease in sample entropy was theoretically predicted (Roerdink, Hlavackova, & Vuillerme, 2011; Figure 1, Panel E).

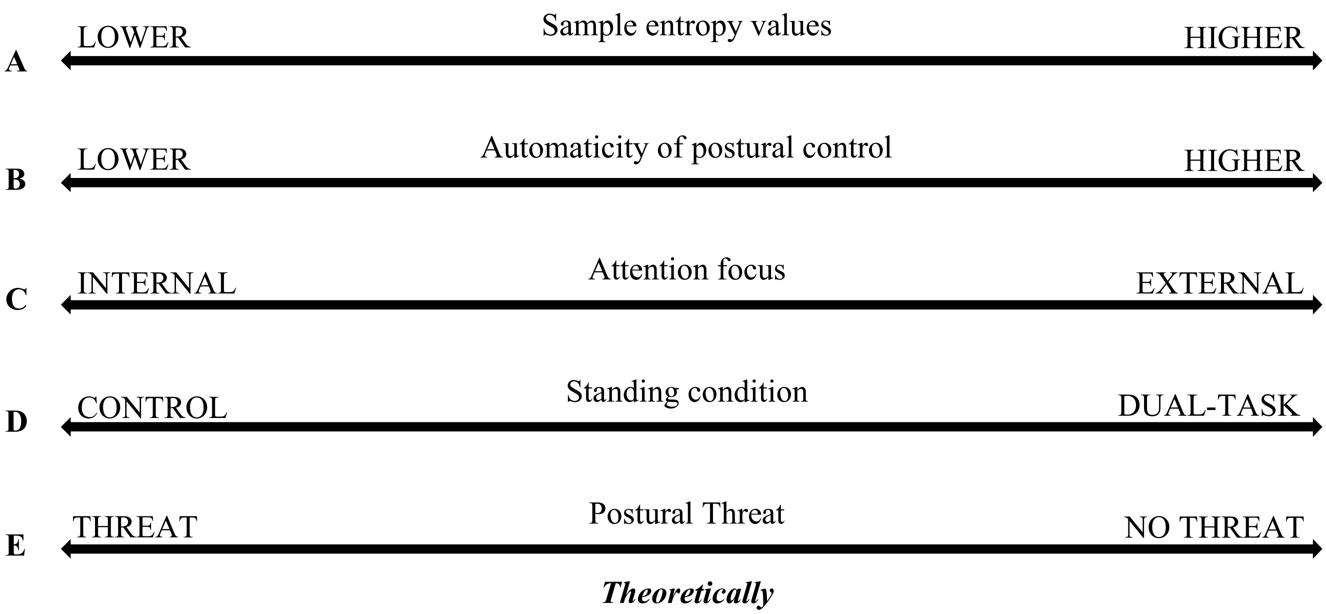

Figure 1. Schematic overview of the parallel continuum between sample entropy and the amount of attention invested in posture, with low automaticity of control positioned on the left and high automaticity positioned on the right. Adapted from Roerdink et al. (2011).

Theoretical claims were further corroborated by the results of Huffman et al. (2009). For example, state-changes in conscious motor processing and movement self-consciousness were reported at two different surface heights: ground level (LOW) and 3.2-m above ground level (HIGH). Furthermore, increases in conscious motor processing and movement self-consciousness were associated with leaning further away from the edge of the surface. Results confirmed a relationship between threat-related changes in attention and MPOS-COP. However, relationships between attention and other measures of postural control were not identified (Huffman et al., 2009). Changes in postural control were more directly related to attention than others, and were therefore not indicative of the amount of attention invested in posture. For a more comprehensive measure of attention, linear and non-linear measurements should be examined. Potvin-Desrochers and colleagues (2017) studied the performance of concurrent cognitive tasks on COP and entropy-based measures; continuous tasks significantly increased sample entropy compared to control and discrete tasks (Figure 1, Panel C). Young and older adults counted the occurrence of a pre-selected number in an auditory sequence of numbers presented at 3 second intervals. Continuous tasks provided fewer opportunities to consciously process balance, supportive of the interpretation of the relationship between sample entropy and attention (Potvin-Desrochers, Richer, & Lajoie, 2017). Studies have validated sample entropy as a measure of automaticity in dual-task conditions (e.g., simple reaction time and go/ no-go reaction time tasks), however, further evidence is desired. For example, theoretical interpretations of entropy-based measures have been evaluated under height-related threat. No significant differences in sample entropy were observed between height conditions; a surface height of 1-m may not have been perceived as threatening for healthy young adults. Subjective anxiety scores were not reported, so it is unknown if anxiety was actually experienced (Stins et al., 2011). Conversely, Ellmers et al. (2020) showed a significant increase in sample entropy; coinciding with significant increases in medium (0.5–1.8 Hz) and high frequencies (1.8–5 Hz). Results also showed that while conscious processing of balance can influence perceived instability, this was not the sole mechanism underpinning (distorted) threat-related perceptions of instability. That is, the position on the continuum could progressively shift right when standing at a surface height of 0.6-m. It's possible that sample entropy is not only susceptible to change through attention focus. Entropy-based measures should therefore be complemented with linear measurements to evaluate threat-related changes in attention focus and postural control.

1.7 Attention focus in non-threatening contexts

1.7.1 Effects of attention focus instructions on postural control

Attention focus has been extensively studied within the constrained-action hypothesis (McNevin, Shea, & Wulf, 2003; Wulf, McNevin, & Shea, 2001; Wulf, Mercer, McNevin, & Guadagnoli, 2004). The hypothesis states that an internal focus of attention results in conscious control, such that the system constrains, or interferes with automatic (i.e., non-conscious) control processes (Wulf, 2013). An external focus results in automatic control, unconstrained by the conscious interference in the control processes associated with a variety of tasks (McNevin et al., 2003; Wulf, 2007; Wulf et al., 2001; 2004). Evidence supporting automaticity with an external focus has been shown in terms of higher frequency control (Becker, Georges, & Aiken, 2019; Kal, van der Kamp, & Houdijk, 2013; Lohse, Sherwood, & Healy, 2010; Porter, Makaruk, & Starzak, 2016; Vaz, Avelar, & Resende, 2019), and lower probe reaction times to a secondary task (Wulf et al., 2001). Thus, instructions to an internal focus of attention and an external focus of attention, or no focus instructions have been studied. Uninstructed control participants have been shown to perform comparably to internally focused participants. Such significance has also been expected in sample entropy studies (i.e., external focus > internal focus and no instructions). Rhea et al. (2019) compared sample entropy with internal focus instructions (i.e., instructed to focus on keeping their feet level), external focus instructions (i.e., instructed to focus on keeping the floor level), or no focus instructions (i.e., control). Sample entropy significantly increased between the control and external focus condition, compared to no changes between the control and internal focus condition, nor between the internal focus and external focus conditions (Rhea et al., 2019). This supports the constrained-action hypothesis as an internal focus of attention interferes with automatic (i.e., non-conscious) control processes (Wulf, 2013). Similarly, Vuillerme and Nafati (2007) compared conditions with an internal focus of attention, or no specific instructions. Significant increases in amplitude and frequency of

COP–COG_v motions (i.e., difference between COP and centre of gravity), and slower probe reaction times to a secondary task were seen with an internal focus instructions compared to no focus instruction. The results provide support for the constrained action hypothesis as an internal focus of attention results in consciously processed control, in which it corresponds to the automaticity-of-control continuum (Figure 1, Panel C).

Higher automaticity with external focus instructions has been seen within a variety of tasks, for example, on a stability platform supported by two freely rotating axles. Becker and Hung (2020) compared sample entropy with internal focus instructions, external focus instructions, or holistic focus instructions (i.e., focus on feeling calm and stable). Sample entropy increased significantly in the external focus condition compared to the internal and holistic focus conditions. The standard deviation of the platform angle also decreased in the external focus condition, but was confounded by a focus x order interaction (Becker & Hung, 2020). Therefore, external focus instructions resulted in automatic control, unconstrained by the conscious interference in the control processes. Diekfuss et al. (2019) also compared sample entropy in performance of a multi-directional wobble board task with internal focus instructions, external focus instructions, or no focus instructions. Results showed that the mean and standard deviation of board velocity decreased in the external focus condition compared to the internal focus and control condition. No significant differences were seen in sample entropy, contrary to the results of Becker and Hung (2020) that showed significant increases in sample entropy with external focus instructions. These differences could be due to between-subject variability, for example, as seen in comparisons between experts and non-experts. Participant characteristics (i.e., expertise) were compared standing with eyes open and closed (i.e., an internal focus of attention), and in secondary task (i.e., an external focus of attention) conditions. Sample entropy significantly increased in experts compared to non-experts, and in eyes open compared to eyes closed conditions. Sample entropy also increased in the secondary task condition compared to the single task condition, thus showing increased automatic control in dual-task conditions. Therefore, attention focus can vary along the continuum (Stins, Michielsen, Roerdink, & Beek, 2009; Figure 1, Panel C), and can be affected by participant characteristics (i.e., expertise). The results provide support in that sample entropy increases in dual-task conditions, with values showing pathology and expertise, or controls situation in the center of the continuum (Figure 1, Panel D).

1.7.2 Effects of distraction on postural control

Support of automaticity with external focus instructions started from between-subject comparisons, in which sample entropy was compared between controls and experts (Stins et al., 2009; Vuillerme & Nougier, 2004), or between controls and patients (Roerdink et al., 2006). Sample entropy was then confirmed from within-subject comparison, or dual-task conditions. A dual-task assesses secondary task loading on primary motor task performance (Kal et al., 2013). That is, a secondary task is expected to interfere with the performance of a consciously controlled task, but should not, or to a lesser extent, interfere with the performance of an automatized task (Kal et al., 2013; Krajenbrink, van Abswoude, Vermeulen, van Cappellen, & Steenbergen, 2018). For example, sample entropy was compared in combinations of eyes open and closed, and in secondary task conditions. Sample entropy significantly increased in the eyes open compared to eyes closed condition, and in the secondary task compared to single task condition. Results also showed no main effect of task for sample entropy (Donker, Roerdink, Greven, & Beek, 2007). Therefore, uncertainty continued about how internal focus instructions, or external focus instructions cause differences in tasks. The performance of a short-term digit-span memory task significantly decreased amplitude and increased sway frequency compared to the control condition (Nafati & Vuillerme, 2011). Similarly, sample entropy increased, and sway area and variability decreased in continuous task (e.g., equation and number sequence tasks) conditions compared to control and discrete task (e.g., simple reaction time and go/ no-go reaction time tasks) conditions (Potvin-Desrochers et al., 2017). Changes in variability and mean velocity have also been compared between internal focus instructions, external focus instructions, and no focus instructions (Polskaia, Richer, Dionne, & Lajoie, 2015). Specifically, the continuous task condition decreased variability and increased frequency compared to the internal focus and external focus conditions (Richer, Polskaia, & Lajoie, 2017). Sample entropy significantly increased in the external focus and dual-task (e.g., DNS; double-number sequence) condition compared to the control condition in the M-L direction. Sample entropy only increased in the dual-task (e.g., SNS; single-number sequence) condition compared to the control condition in the A-P direction (Richer & Lajoie, 2020). The results support the constrained action hypothesis as an external focus of attention results in automaticity, unconstrained by the interference caused by conscious control.

These results are significant to the expectation of sample entropy decreasing in Threat compared to No Threat conditions. This is expected if conscious control and attention focus to balance (i.e., internal) increase when threatened.

Chapter Two: Rationale, Purpose, and Hypotheses

2.1 Rationale

Research has extensively studied the relationship between emotions (i.e., fear and anxiety) and postural control (Balaban & Thayer, 2001; Hadjistavropoulos et al., 2011; Staab et al., 2013; Young & Williams, 2015). For example, the effects of fall-related emotions on postural control in response to threat have been studied in healthy younger and older adults. Postural threat has been primarily assessed in a series of studies increasing the height of the surface at which participants stand in high, compared to low conditions. Research has reported changes in postural control characterized by decreased amplitude and increased frequency of COP displacements (Adkin & Carpenter, 2018). Similar to the surface height threat model, the threat of a support surface perturbation has been used as an alternative approach to study the effects of fall-related emotions on postural control. Threat-related changes in postural control are characterized by increased amplitude and frequency of COP displacements in anticipation of an A-P support surface perturbation (Johnson et al., 2019; 2020). Research has shown threat-related changes in leaning and amplitude are context-dependent, while changes in frequency (i.e., COP $Freq_{HIGH}$) are consistent across different types of threat (Johnson et al., 2019; 2019b; Zaback et al., 2019).

Threat-related postural changes are accompanied by changes in proprioceptive and vestibular-evoked reflex gains (Horslen et al., 2013; Naranjo et al., 2015), as well as changes in attention. Postural threat changes the focus of attention in quiet standing (Huffman et al., 2009; Johnson et al., 2019; 2019b; Zaback et al., 2016; 2019) and gait (Ellmers & Young, 2018; Young, Olonilua, Masters, Dimitriadis, & Williams, 2016). For example, participants self-report increasing attention towards movement processes, threat-related stimuli, and self-regulatory strategies, and decreasing attention to task objectives and task-irrelevant information (Johnson et al., 2019; Zaback et al., 2016). These threat-related changes in attention have been associated with threat-related changes in postural control. For example, attention to movement processes has been associated with increases in amplitude while standing with the threat of a support surface perturbation (Johnson et al., 2019). Similarly, changes in attention to movement processes has accounted for decreases in amplitude and increases in frequency under conditions of height-related threat (Zaback et al., 2016). While there are some changes consistent across threat contexts, complementing conventional summary statistics with non-linear analysis should be considered when examining threat-related changes in attention focus and postural control.

Non-linear measures have been used to assess the predictability of a considered time-series. Sample entropy is the negative natural logarithm of the conditional probability that two similar sequences with the same amount of data points remain similar when another data point is added (Richman & Moorman, 2000). Lower sample entropy values correspond to a high frequency of similarity in a time-series whereas higher sample entropy values correspond to a low frequency of similarity (Bhavsar et al., 2018; Delgado-Bonal et al., 2020; Yamagata et al., 2017). Theories claim that sample entropy can quantify the amount of attention invested in the control of posture (Roerdink et al., 2011). Interpreted as attentional investments in postural control; a significant increase in sample entropy corresponds to a decrease in attention (Roerdink et al., 2006). Therefore, a relationship between sample entropy and the amount of attention invested in postural control was proposed. Expected to be influenced by threat, a corresponding decrease in sample entropy was theoretically predicted (Roerdink et al., 2011). Contrary to theoretical claims, state-changes in conscious motor processing were reported under conditions of height-related threat. Results confirmed a direct relationship between threat-related changes in attention and MPOS-COP. However, relationships between attention and other threat-related changes in postural control (i.e., RMS-COP, MPF-COP) were not identified (Huffman et al., 2009). Changes in postural control were more directly related to attention than others, and was therefore not indicative of the amount of attention invested in posture. Furthermore, no significant differences in sample entropy have been reported in healthy young adults standing at a surface height of 1-m; this may not have been perceived as threatening (Stins et al., 2011). Research has also reported a corresponding change in sample entropy in asymptomatic older adults standing at a surface height of 0.6-m. A significant increase in sample entropy coincided with significant increases in medium (0.5–1.8 Hz) and high frequency (1.8–5 Hz) components (Ellmers et al., 2020). Therefore, sample entropy should be examined under conditions of postural threat and the analysis should be completed with summary statistics quantifying postural control.

Complementing conventional summary statistics with non-linear analysis that examine threat-related changes in attention focus and postural control may provide insight into the effects of attention focus on standing postural control strategies. It should be determined whether sample entropy – which quantifies the amount of attention invested in posture – changes under postural threat conditions. It should also be determined if changes in postural control, particularly high frequency (>1.8 Hz) COP, can be consistent with changes in attention focus. Sample entropy should then be calculated to support the relationship between threat-related changes in attention focus and postural control. Specifically, if changes in attention towards movement processes in the Threat compared to No Threat condition correlate to changes in sample entropy. Increases in attention towards movement processes should provide cause to explore sample entropy (Johnson et al., 2019; 2019b; 2020; Zaback et al., 2016; 2019).

2.2 Purpose

The primary purpose of this thesis was to investigate the effects of postural threat on sample entropy. A secondary purpose of this thesis was to examine the relationships between threat-related changes in physiological arousal, perceived anxiety, attention focus, conventional COP summary measures, and sample entropy. This thesis involved secondary data analyses that combined data sets from two published studies; each study used the postural perturbation threat model which allowed for a comparison between No Threat and Threat conditions (Johnson et al., 2019; 2020). Apart from the combined data set, a novel component of this thesis was the calculation of sample entropy which had not been previously examined in these two studies.

2.3 Hypotheses

A significant decrease in sample entropy was expected in the Threat compared to No Threat condition. Theoretically, a decrease in sample entropy thought to reflect less automaticity should result as increased conscious motor processing and movement self-consciousness (Huffman et al., 2009), and attention focus to movement processes have been reported when threatened (Johnson et al., 2019; 2020). As conscious motor processing increased compared to No Threat conditions, it was expected that sample entropy would decrease when standing with the expectation of receiving a postural perturbation. Alternatively, research has reported no significant differences in sample entropy in healthy young adults standing at a surface height of 1-m (Stins et al., 2011), while a significant increase in sample entropy has been reported in asymptomatic older adults standing at a surface height of 0.6-m (Ellmers et al., 2020). Thus, significant increases in sample entropy in the Threat compared to No Threat condition may result due to a shift to a more automatic control of posture supported by observations of threat-related neurophysiological changes (i.e., proprioceptive and vestibular-evoked reflex gains).

Based on the previous hypothesis, it was also expected that threat-related changes in attention focus to movement processes would be significantly associated with threat-related changes in sample entropy. For example, it was expected that larger increases in attention to movement processes would significantly account for larger decreases in sample entropy.

Chapter Three: Methods Overview and Secondary Data Analysis Approach

3.0 Overview of Methods

A secondary data analysis was conducted for this thesis. All procedures were approved by the Brock University Bioscience Research Ethics Board (19-356; Appendix A). Data was obtained from two published studies that quantified threat-related changes in physiological arousal, perceived anxiety, attention focus, and postural control (Johnson et al. 2019; 2020). The two studies used the same postural perturbation threat model; standing with or without the expectation of receiving a perturbation (i.e., A-P support surface translation; perturbation characteristics: displacement = 0.25 m, peak velocity = 0.9 m/s, peak acceleration = 1.7 m/s^2). Although the procedures differed slightly between the two studies, there was always a No Threat condition (i.e., one trial performed prior to any threat/perturbation experience) and Threat condition (i.e., one trial performed after experience with the threat/perturbation) that could be used for comparison. The data collection approach and dependent measures taken were also similar between the two studies. However, a significant difference between the two studies was the duration of the quiet standing trial with or without the expectation of receiving a postural perturbation (i.e., 60-s versus 30-s). As significant changes in sample entropy under combinations of N = 60-s and N = 30-s have been observed (Lubetzky et al., 2018; Montesinos et al., 2018), a preliminary analysis was conducted to examine parameter value N on sample entropy using the 60-s quiet standing No Threat trials from the Johnson et al. (2020) study. Sample entropy in the A-P direction (i.e., the direction of the threat) was compared between the 60-s and shortened 30-s quiet standing trials (i.e., early 30-s and late 30-s of the standing trial). The trials were separated into 30-s durations as this was the trial duration used in the Johnson et al. (2019) study. The results of the analysis revealed significant differences in sample entropy between the 60-s duration and the early 30-s duration, showing that A-P sample entropy needed to be examined using data obtained from equivalent trial durations. Therefore, the decision was made to combine the data sets from the two studies and compare A-P sample entropy between a No Threat and Threat condition calculated over 30-s durations. Thus, the early 30-s standing trials from the Johnson et al. (2020) study were combined with the 30-s standing trials from the Johnson et al. (2019) study. After presenting the results of this preliminary analysis, the remainder of the thesis will focus on the combined data set.

3.1 Effects of trial duration on sample entropy

3.1.1 Participants

Data from 25 healthy young adults (13 females, 12 males; mean ± standard deviation (SD) age = 22.4 ± 2.4 years) was obtained from the study, "The Effects of Distraction on Threat-Related Changes in Standing Balance Control" (Johnson et al., 2020). This data set was used to examine the effect of trial duration on sample entropy.

3.1.2 Procedure

Participants stood with no expectation of receiving a postural perturbation (No Threat) and with the expectation of receiving a postural perturbation (Threat). The perturbation was a temporally and directionally unpredictable support surface translation in the anterior or posterior direction (displacement = 0.25 m, peak velocity = 0.9 m/s, peak acceleration = 1.7 m/s^2). Participants completed No Threat and Threat trials under three distractor task conditions: Control (i.e., no task), Letter Sequence, and Number Sequence. The distractor task conditions were excluded from this statistical analysis. An outline of the Control condition is presented in Table 5; the Control condition was always completed first in the Johnson et al. (2020) study.

Participants completed one 60-s quiet standing trial with no possibility of receiving a perturbation. This trial served as practice to address first trial effects on postural control (Adkin et al., 2000) and to prime the state questionnaires. Participants then completed a block of four trials consisting of a No Threat trial and three randomized Threat trials. In each No Threat trial, participants stood for 60-s with no expectation of receiving a postural perturbation. In each Threat trial, participants stood with the expectation of receiving a postural perturbation. The perturbation was delivered at any time period during the completion of the trial, from after 5-s of quiet standing to 60-s of quiet standing. The No Threat trial was selected for this statistical analysis and separated to compare 60-s, 30-s (early), and 30-s (late) durations.

3.2 Dependent measures

3.2.1 Sample entropy

Ground reaction forces were collected at a sampling rate of 100 Hz and low-pass filtered offline using a second order Butterworth filter with a cut-off frequency of 10 Hz (Payton & Bartlett, 2008). Sample entropy was then calculated in the A-P direction (i.e., the direction of the threat) from customized scripts presented by Richman and Moorman (2000):

$$\text{SampEn}\,(m, r, N) = -\log\left(\frac{\text{A}}{\text{B}}\right)$$

where, m is the length of the sequences to be compared, r is the tolerance value for accepting matches, N is the length of the data, and A/B are defined as follows:

$$A = \left\{\frac{(n-m-1)(n-m)}{2}\right\} A^m(r), \text{ and } B = \left\{\frac{(n-m-1)(n-m)}{2}\right\} B^m(r)$$

where, $A^m(r)$ is the probability that sequences match for m + 1 points, and $B^m(r)$ is the probability that sequences match for m points. Parameter values were set to $m = 2$ and $r =$

0.15*SD. There is no established consensus on parameter selection. Parameter settings for postural control studies are commonly set to $m = 2$ or 3, and r between 0.1 and 0.25*SD (Pincus, 1991, Richman & Moorman, 2000). A separate analysis calculated sample entropy in combinations of $m = (2, 3)$ and $r = (0.15, 0.25)$. Sample entropy was consistent in different parameter value combinations. Differences in parameters were observed in Ellmers et al. (2020) and Stins et al. (2011) where m was set at 3, and r was set at 0.01 and 0.04*SD, respectively.

3.3 Statistical analysis

3.3.1 Descriptive statistics

Descriptive statistics were calculated for sample entropy in the No Threat condition. Assumptions of normality were confirmed prior to statistical analysis. A one-way repeated measures ANOVA with a within-subject factor of trial duration (60-s, 30-s early, and 30-s late) was conducted for sample entropy. If Mauchly's test statistic was significant, the Greenhouse-Geisser correction was used. Where significant main effects of trial duration were found, pairwise comparisons with Bonferroni correction were performed to determine significant differences between pairs of trial duration. Comparisons were considered statistically significant at $p < 0.05$.

3.4 Results

3.4.1 Data screening and statistical assumptions

Sample entropy values were screened for univariate outliers. To screen for univariate outliers, values were converted to standardized z-scores. Converted z-scores greater or less than $\pm$ 3.29 were considered an outlier, and any value fitting this criterion was replaced by a value $\pm$ 3 standard deviations of the mean in the direction it was previously outlying. Following replacements for each outlying value, data was re-screened, and any new outlying values were replaced using this procedure until there were no remaining outliers (Tabachnick & Fidell, 2013). No outlying values were identified in this analysis.

3.4.2 Normality

Normality was assessed for all values by examining the skewness and kurtosis statistic (Hopkins & Weeks, 1990; Tabachnick & Fidell, 2013). Each skewness and kurtosis statistic was converted to standardized z-scores by dividing each value by its own standard error. Values greater or less than ± 3.29 were considered significantly skewed or kurtotic at $p < 0.001$ (Field, 2018; Tabachnick & Fidell, 2013). No values were identified as significantly skewed or kurtotic.

3.4.3 Sphericity

The assumption of sphericity was assessed using Mauchly's test of sphericity (Field, 2018). Greenhouse-Geisser corrections were used if the assumption of sphericity was violated (Field, 2018; Tabachnick & Fidell, 2013).

3.4.4 Sample entropy

A significant main effect of trial duration was observed for sample entropy ($F_{(1,33)} = 3.89$, $p < .05$; Figure 2). Sample entropy significantly increased in the 30-s early (0.09 ± 0.01) duration compared to the 60-s (0.07 ± 0.01) and 30-s late (0.08 ± 0.01) duration. Follow-up comparisons revealed significant differences between the 60-s and 30-s early ($p = 0.02$) trial duration. There were no significant differences between the 60-s and 30-s late ($p = 0.07$) trial duration or between the 30-s early and 30-s late ($p = 1.00$) trial duration.

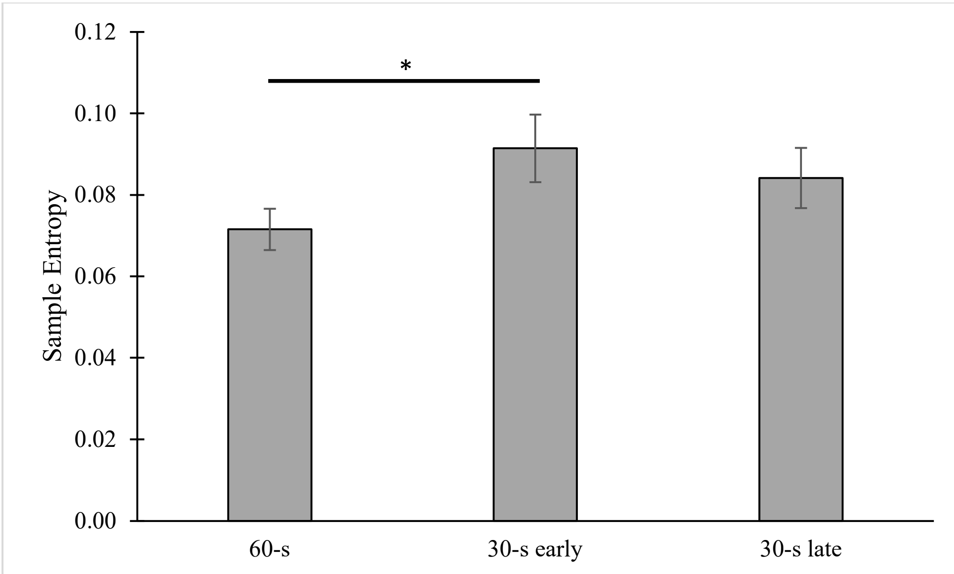

Figure 2. Main effect of trial duration on sample entropy. * represents a significant difference (p < .05).

Sample entropy was calculated under combinations of *N* = 60-s, 30-s (early), and 30-s (late). Changing parameter value *N* confirmed that there should be consistencies in time-series length. Data from the study titled, “The Effects of Distraction on Threat-Related Changes in Standing Balance Control” should be shortened to a time-series of length *N* = 30-s (early) for comparison (Johnson et al., 2020).

Chapter Four: Methods

4.0 Effects of postural threat on sample entropy

4.1 Participants

Data collected from the Biomechanics and Motor Control Laboratory at Brock University was combined to create a data set of 105 healthy young adults (63 females, 42 males; mean ± SD age = 21.8 ± 2.8 years). Data from 25 healthy young adults was obtained from the study "The Effects of Distraction on Threat-Related Changes in Standing Balance Control" (Johnson et al., 2020) and data from 80 healthy young adults was obtained from the study "Exploring the Relationship Between Threat-Related Changes in Anxiety, Attention Focus, and Postural Control" (Johnson et al., 2019). Participants in these studies provided written informed consent prior to the start of experimental procedures in accordance with the Brock University Biosciences Research Ethics Board.

4.2 Procedure

The following are common procedures that were used across the two studies. Any differences between the two studies are noted. Prior to the start of the experimental procedures, a demographic and health questionnaire was administered to each participant and anthropometric measures (e.g., height, weight, foot length, and heel to ankle length) were recorded (Appendix B). Then, participants completed a randomly presented series of questionnaires to assess trait anxiety, movement reinvestment, and physical risk-taking.

Trait anxiety was assessed using the trait form of the State-Trait Anxiety Inventory (STAI; Spielberger, Gorsuch, Lushene, Vagg, & Jacobs, 1983; Appendix C). The questionnaire comprises a 20-item self-report scale that targets how respondents "generally feel" (e.g., "I feel satisfied with myself"; "I lack self-confidence"). Responses were rated on a 4-point Likert scale ranging from 1 ("Almost never") to 4 ("Almost always") on how frequently respondents generally feel about a statement. Total scores ranged from 20 to 80 with higher scores representing greater trait anxiety.

Trait movement reinvestment was assessed using the Movement Specific Reinvestment Scale (MSRS; Masters et al., 2005; Appendix D). The questionnaire comprises two 5-item subscales of movement reinvestment: conscious motor processing (CMP; e.g., "I am aware of the way my body works when I am carrying out a movement") and movement self-consciousness (MSC; e.g., "I am self-conscious about the way I look when I am moving"). Responses were rated on a 6-point Likert scale ranging from 1 ("Strongly disagree") to 6 ("Strongly agree") on how respondents generally feel about a statement. Total scores for each subscale ranged from 5 to 30 with higher scores representing greater CMP and MSC, respectively.

Risk-tasking was assessed using the Domain-Specific Risk-Taking Scale (DOSPERT; Blais & Weber, 2006; Appendix E). The questionnaire comprises a 30-item self-report scale that targets respondents' behavioural intentions across five content domains (ethical, social, health and safety, financial, and recreational). Responses were rated on a 7-point Likert scale ranging from 1 ("Extremely unlikely") to 7 ("Extremely likely") on the likelihood to participate in the described activity or behaviour. Only six items related to the recreational domain (e.g., "Piloting a small plane"; "Going camping in the wilderness") were assessed with higher scores representing greater risk-tasking behaviour.

4.3 Experimental configuration

Participants stood on a force plate (OR6-7, AMTI, Watertown, MA, USA) surrounded by a wooden platform (0.9m x 1.6m) fitted flush with its surface. The force plate and platform were secured to a motorized 4.3-m linear positioning stage (H2W Technologies Inc., Valencia, CA, USA). Participants were instructed to stand with bare-feet, in a stance width equal to their foot length, with arms at their side, and their gaze fixed on an eye-level target located on the wall 4-m away. Participants' stance width was kept consistent across all conditions by outlining the feet with tape (Carpenter et al., 1999). Throughout the experiment, a spotter was positioned beside the platform and participants wore a harness that was attached to a track secured along the ceiling. The procedure was the same for all participants included in the combined data set.

4.4 Postural threat manipulation

In the Johnson and colleagues (2019) study, participants stood with no expectation of receiving a postural perturbation (No Threat), with the expectation of receiving a postural perturbation prior to gaining experience with the perturbation ($\text{Threat}_{\text{noexp}}$), and with the expectation of receiving a postural perturbation after having gained experience with the perturbation ($\text{Threat}_{\text{exp}}$). The perturbation was a temporally and directionally unpredictable support surface translation in the anterior or posterior direction (displacement = 0.25 m, peak velocity = 0.9 m/s, peak acceleration = 1.7 m/s^2). Perturbation direction was randomized within the experimental protocol.

4.5 Experimental protocol

Participants stood quietly under three threat conditions: No Threat, $\text{Threat}_{\text{noexp}}$, and $\text{Threat}_{\text{exp}}$. First threat exposures were not analyzed in the Johnson and colleagues (2020) study. Participants experienced the perturbation prior to completing the 60-s Threat trial. As such, No

Threat (i.e., one trial performed prior to any threat/perturbation experience) and $Threat_{exp}$ conditions (i.e., one trial performed after experience with the threat/perturbation) were compared in this thesis. The $Threat_{noexp}$ conditions were excluded from statistical analysis. Table 5 highlights the similarities and differences between the two protocols.

Participants completed one 30-s quiet standing trial with no possibility of receiving a perturbation in the Johnson and colleagues (2019) study. This trial served as practice to address first trial effects on postural control (Adkin et al., 2000) and to prime the state questionnaires. Participants then completed a No Threat trial before continuing with $Threat_{noexp}$ and $Threat_{exp}$ trials. In each No Threat trial, participants stood for 30-s with no expectation of receiving a postural perturbation. In each Threat trial, participants stood with the expectation of receiving a postural perturbation; however, on the first Threat trial ($Threat_{noexp}$), the platform did not translate. On the subsequent two Threat trials, the perturbation was delivered after 10-s and 15-s of quiet standing. These trials were excluded from statistical analysis; they were only completed to give participants experience with the perturbation and to ensure temporal unpredictability of the perturbation. On the final Threat trial ($Threat_{exp}$), participants stood with the expectation of receiving a postural perturbation; however, the platform did not translate. A second No Threat trial was completed after the Threat conditions.

Table 5: Outline of the similarities and differences between the experimental protocols

Study	Condition	Duration	Expectation of Perturbation	Delivery of Perturbation
Johnson et al. (2019)	**No Threat**	30-s	No	No
	Threat_{noexp}	30-s	Yes	No
	Threat	10-s	Yes	Yes
	Threat	15-s	Yes	Yes
	Threat_{exp}	30-s	Yes	No
	No Threat	30-s	No	No
Johnson et al. (2020)	**No Threat**	60-s	No	No
	Threat_{noexp}	5-s	Yes	Yes
	Threat	30-s	Yes	Yes
	Threat_{exp}	60-s	Yes	Yes

Note: The No Threat and Threat_{exp} conditions were used for comparison in this thesis.

Data was collapsed between the two secondary datasets. The completed 30-s quiet standing trials (Johnson et al., 2019) were selected for statistical analysis and combined with 30-s (early) standing trials (Johnson et al., 2020). The No Threat conditions were compared to the Threat_{exp} conditions.

4.6 Dependent measures

4.6.1 Physiological arousal

To estimate changes in physiological arousal, electrodermal activity (EDA) was recorded using a constant voltage of 0.5 V to two silver–silver chloride (Ag/AgCl) electrodes (EL-507, BIOPAC Systems Inc., USA) placed on thenar and hypothenar eminences of the non-dominant hand (Boucsein, 2012). Prior to electrode placement, a skin preparation gel was applied to the palmar recording sites (NuPrep, Weaver and Company, USA). Electrodermal activity was A/D sampled at 1000 Hz (Micro1401, CED, Cambridge, UK) and recorded using Spike2 software (CED, Cambridge, UK). A custom script that calculated mean EDA for the 30-s trial was used (MATLAB R2020a, MathWorks, USA).

4.6.2 Perceived anxiety

Perceptions of anxiety were recorded from a self-report questionnaire. The questionnaire was administered to evaluate worry-related anxiety and somatic anxiety (Appendix F). Responses were rated on a scale ranging from 1 ("I was not at all worried") to 100 ("I was very worried") on how respondents generally felt from the start to the end of the standing trial (or the time prior to platform translation). Responses to the question "How physically anxious did you feel when performing the balance task?" were rating on a scale ranging from 1 ("I did not feel anxious at all") to 100 ("I felt very anxious") to represent somatic anxiety. Perceived anxiety was calculated by summing the scores of the worry-related and somatic subscales. In the Johnson and colleagues (2020) study, responses were rated on a scale ranging from 1 ("I was not at all worried") to 9 ("I was very worried"). Thus, worry-related and somatic anxiety scores were converted to a percent of maximum possible score (POMP; Cohen, Cohen, Aiken, & West, 1999). Of note, worry-related and somatic anxiety were reported across 30-s standing trials (Johnson et al., 2019) and 60-s standing trials (Johnson et al., 2020).

4.6.3 Attention focus

A questionnaire was administered to evaluate attention focus (Appendix G) with the following statement preceding each question, "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:'' (1) movement processes, (2) task objectives, (3) threat-related stimuli, (4) self-regulatory strategies, and (5) task-irrelevant information. Responses were rated on a 9-point Likert scale ranging from 1 (“Not at all”) to 9 (“Very much so”) on how respondents directed their attention from the start to the end of the standing trial, or the time prior to platform translation (Zaback et al., 2016). Of note, attention focus responses were rated across 30-s standing trials (Johnson et al., 2019) and 60-s standing trials (Johnson et al., 2020).

4.6.4 Postural control

Ground reaction forces and moments from the force plate were collected at a sampling rate of 100 Hz and low-pass filtered offline using a second order Butterworth filter with a cut-off frequency of 10 Hz (Payton & Bartlett, 2008). Force plates provided position and frequency based summary measures describing various quantitative parameters such as mean position (MPOS-COP), root-mean-square (RMS-COP) amplitude, and mean power frequency (MPF-COP) in the A-P direction. MPOS-COP was calculated to provide an estimate of leaning when referenced to participants’ ankle joints. MPOS-COP was subtracted from the COP signal to remove bias prior to calculating amplitude and frequency (Duarte & Freitas, 2010; Palmieri et al., 2002). A custom script transformed data from time to frequency based (MATLAB R2020a, MathWorks, USA). MPF-COP was calculated to estimate the average frequency contained within a power spectrum following Fast Fourier Transform (FFT; Beckham, Suchomel, & Mizuguchi, 2014). The Fast Fourier Transform was then performed on equal length, non-overlapping data segments and converted to power spectra (Reynolds, 2010). Power spectrum analysis was used to determine the average power contained within specific frequency bands: 0–0.05 Hz (low frequency), 0.5–1.8 Hz (medium frequency), and 1.8–5 Hz (high frequency; Zaback et al., 2019).

4.6.5 Sample entropy

Sample entropy is the negative natural logarithm of the conditional probability that two similar sequences with the same amount of data points remain similar when another data point is added. Sample entropy was calculated from customized scripts presented by Richman and Moorman (2000):

$$\text{SampEn}\ (m, r, N) = -\log\left(\frac{\mathrm{A}}{\mathrm{B}}\right)$$

where, *m* is the length of the sequences to be compared, *r* is the tolerance value for accepting matches, *N* is the length of the data, and *A/B* are defined as follows:

$$A = \left\{\frac{(n-m-1)(n-m)}{2}\right\} A^m(r), \text{ and } B = \left\{\frac{(n-m-1)(n-m)}{2}\right\} B^m(r)$$

where, $A^m(r)$ is the probability that sequences match for m + 1 points, and $B^m(r)$ is the probability that sequences match for m points. Parameter values were set to $m = 2$ and $r = 0.15*SD$. There is no established consensus on parameter selection. Parameter settings for postural control studies are commonly set to $m = 2$ or 3, and *r* between 0.1 and 0.25*SD (Pincus, 1991, Richman & Moorman, 2000). A separate analysis calculated sample entropy in combinations of $m = (2, 3)$ and $r = (0.15, 0.25)$. Sample entropy was consistent in different parameter value combinations. Differences in parameters were observed in Ellmers et al. (2020) and Stins et al. (2011) where *m* was set at 3, and *r* was set at 0.01 and 0.04*SD, respectively.

4.7 Statistical analysis

4.7.1 Descriptive statistics

Descriptive statistics were calculated for demographic (e.g., age, height, weight) and personality traits (e.g., STAI, MSRS, DOSPERT), as well as for physiological arousal, perceived anxiety, attention focus, and postural control measures across all postural threat conditions.

4.7.2 Repeated measures ANOVA: Effects of postural threat

Separate within-subject repeated measures ANOVA were conducted for each dependent variable. Differences in physiological arousal, perceived anxiety, attention focus, and postural control measures were examined between No Threat and Threat conditions. The assumption of normality was confirmed prior to the statistical analysis. Non-normal variables (EDA, RMS, MPF, COP $Freq_{LOW}$, COP $Freq_{MED}$, COP $Freq_{HIGH}$) were corrected using logarithmic transformations, which calculated the base 10 logarithm of each value of the non-normal dependent variable. Statistical significant was set at $p < 0.05$.

4.7.3 Associations between threat-related changes in emotions, attention focus, and postural control

To examine correlations between threat-related changes in physiological arousal, perceived anxiety, attention focus, and postural control, change scores between No Threat and Threat conditions were calculated for each dependent variable. Bivariate correlations between change scores were conducted to detect significant collinearity (Table 9); no variables were considered to be highly related ($r > 0.80$).

Multiple linear regressions were conducted to determine if threat-related changes in physiological arousal, perceived anxiety, and attention focus contribute to threat-related changes in postural control. Change scores between No Threat and Threat conditions were calculated for each dependent variable. If significant effects of postural threat were found, variables were entered into each regression model. Seven multiple linear regressions were conducted with physiological arousal, perceived anxiety, and attention to movement processes, task objectives, threat-related stimuli, self-regulatory strategies, and task-irrelevant information as the predictor variables and MPOS-COP, RMS-COP, MPF-COP, COP $Freq_{LOW}$, COP $Freq_{MED}$, COP $Freq_{HIGH}$, and sample entropy as the dependent variables. Statistical significant was set at $p < 0.05$.

Chapter Five: Results

5.0 Results

5.1 Data screening and statistical assumptions

All variables were screened for univariate outliers. To screen for univariate outliers, data for these variables were converted to standardized z-scores. Converted z-scores greater or less than ± 3.29 were considered an outlier, and any variable fitting this criterion was replaced by a value ± 3 standard deviations of the mean in the direction it was previously outlying. Following replacements for each outlying variable, data was re-screened, and any new outlying variables were replaced using this procedure until there were no remaining outliers (Tabachnick & Fidell, 2013). One physiological arousal value was consistently identified as an outlier and was excluded from the analysis. Values were also excluded where data was missing (i.e., five physiological arousal values were excluded). However, the number of values were considered sufficient to conduct the analysis.

5.1.2 Normality

Normality was assessed for all variables by examining the skewness and kurtosis statistic (Hopkins & Weeks, 1990; Tabachnick & Fidell, 2013). Each skewness and kurtosis statistic was converted to standardized z-scores by dividing each value by its own standard error. Values greater or less than ± 3.29 were considered significantly skewed or kurtotic at $p < 0.001$ (Field, 2018; Tabachnick & Fidell, 2013). While some variables violated the assumption of normality, transformations were not considered necessary on those self-report variables as they reflect participants' true perceptions. A log10 transformation was conducted on significantly skewed or kurtotic COP variables prior to statistical analyses to correct for violations. Skewness and kurtosis statistics are summarized in Table 6.

Table 6: Skewness and kurtosis statistics for all physiological arousal, perceived anxiety, attention focus, and postural control measures.

	No Threat		Threat	
	Skewness	Kurtosis	Skewness	Kurtosis
EDA	**0.978**	0.621	**0.866**	0.396
ANX	**1.526**	**1.557**	-0.243	-0.886
MP	0.103	-1.158	-0.726	-0.317
TO	-0.164	-1.143	-0.329	-0.776
TRS	**1.436**	**1.644**	-0.249	-0.938
SRS	0.769	-0.248	-0.249	-0.938
TII	0.571	-0.596	**1.491**	**1.551**
MPOS-COP	-0.221	0.374	-0.336	0.360
RMS-COP	**0.860**	1.020	**0.973**	1.238
MPF-COP	0.531	0.177	**1.211**	**2.217**
COP $Freq_{LOW}$	**1.549**	**1.787**	**1.734**	**2.527**
COP $Freq_{MED}$	0.738	0.130	**1.445**	**1.678**
COP $Freq_{HIGH}$	**1.317**	1.324	**1.613**	**2.143**
SampEn	0.738	0.217	0.773	0.235

Note: EDA = electrodermal activity; ANX = self-reported anxiety; MP = movement processes; TO = task objectives; TRS = threat-related stimuli; SRS = self-regulatory strategies; TII = task-irrelevant information; MPOS = mean position; COP = centre of pressure; RMS = root mean square; MPF = mean power frequency; $Freq_{LOW}$ = low frequency (0–0.05 Hz); $Freq_{MED}$ = medium frequency (0.5–1.8 Hz); $Freq_{HIGH}$ = high frequency (1.8–5 Hz); SampEn = sample entropy. Bold font indicates significant skewness or kurtosis at $p < 0.001$.

5.2 Descriptive statistics

Descriptive statistics for participant characteristics are summarized in Table 7. Descriptive statistics for physiological arousal, perceived anxiety, attention focus, and postural control in each threat condition are summarized in Table 8.

Table 7: Mean and standard deviation (SD) values for participant characteristics.

	Mean	SD	Min	Max
Age (years)	21.84	2.85	18	31
Height (m)	1.71	0.09	1.52	1.95
Weight (kg)	71.67	13.62	46.26	120.98
STAI (20-80)	36.71	9.1	21	64
MSRS-CMP (5-30)	19.11	4.53	5	29
MSRS-MSC (5-30)	15.88	5.44	6	29
DOSPERT (6-42)	24.52	8.76	6	42

Note: STAI = state-trait anxiety inventory (scale range: 20-80); MSRS = movement specific reinvestment scale; CMP = conscious motor processing (scale range: 5-30); MSC = movement self-consciousness (scale range: 5-30); DOSPERT = domain specific risk-taking scale (recreational domain scale range: 6-42).

Table 8: Mean and standard error (SE) values for all physiological, psychological, attention focus, and postural control measures

	No Threat	Threat
Physiological & Psychological Measures		
EDA	15.81 (0.67)	18.97 (0.75)
ANX	14.26 (1.84)	56.11 (2.60)
Attention Focus Measures		
AF-MP	4.79 (0.24)	6.73 (0.20)
AF-TO	5.40 (0.29)	5.91 (0.22)
AF-TRS	2.17 (0.14)	5.42 (0.23)
AF-SRS	3.56 (0.22)	4.77 (0.22)
AF-TII	3.60 (0.21)	2.29 (0.17)
Postural Control Measures		
MPOS-COP	40.61 (1.97)	49.98 (2.09)
RMS-COP	4.55 (0.17)	5.41 (0.20)
MPF-COP	0.26 (0.01)	0.41 (0.02)
COP $Freq_{LOW}$	99.61 (9.92)	114.76 (11.50)
COP $Freq_{MED}$	0.65 (0.03)	2.09 (0.15)
COP $Freq_{HIGH}$	0.02 (0.002)	0.09 (0.008)
SampEn	0.09 (0.004)	0.13 (0.01)

Note: EDA = electrodermal activity; ANX = self-reported anxiety; AF = attention focus; MP = movement processes; TO = task objectives; TRS = threat-related stimuli; SRS = self-regulatory strategies; TII = task-irrelevant information; MPOS = mean position; COP = centre of pressure; RMS = root mean square; MPF = mean power frequency; $Freq_{LOW}$ = low frequency (0–0.05 Hz); $Freq_{MED}$ = medium frequency (0.5–1.8 Hz); $Freq_{HIGH}$ = high frequency (1.8–5 Hz); SampEn = sample entropy.

5.3 *Physiological and psychological measures*

Significant main effects of threat were observed for EDA ($F_{(1,98)} = 85.64$, $p < 0.001$) and perceived anxiety ($F_{(1,104)} = 258.52$, $p < 0.001$). Electrodermal activity was significantly higher in the Threat (18.97 ± 0.75) compared to No Threat (15.81 ± 0.67) condition (Figure 3A), and perceptions of anxiety were significantly higher in the Threat (56.12 ± 2.59) compared to No Threat (14.26 ± 1.84) condition (Figure 3B).

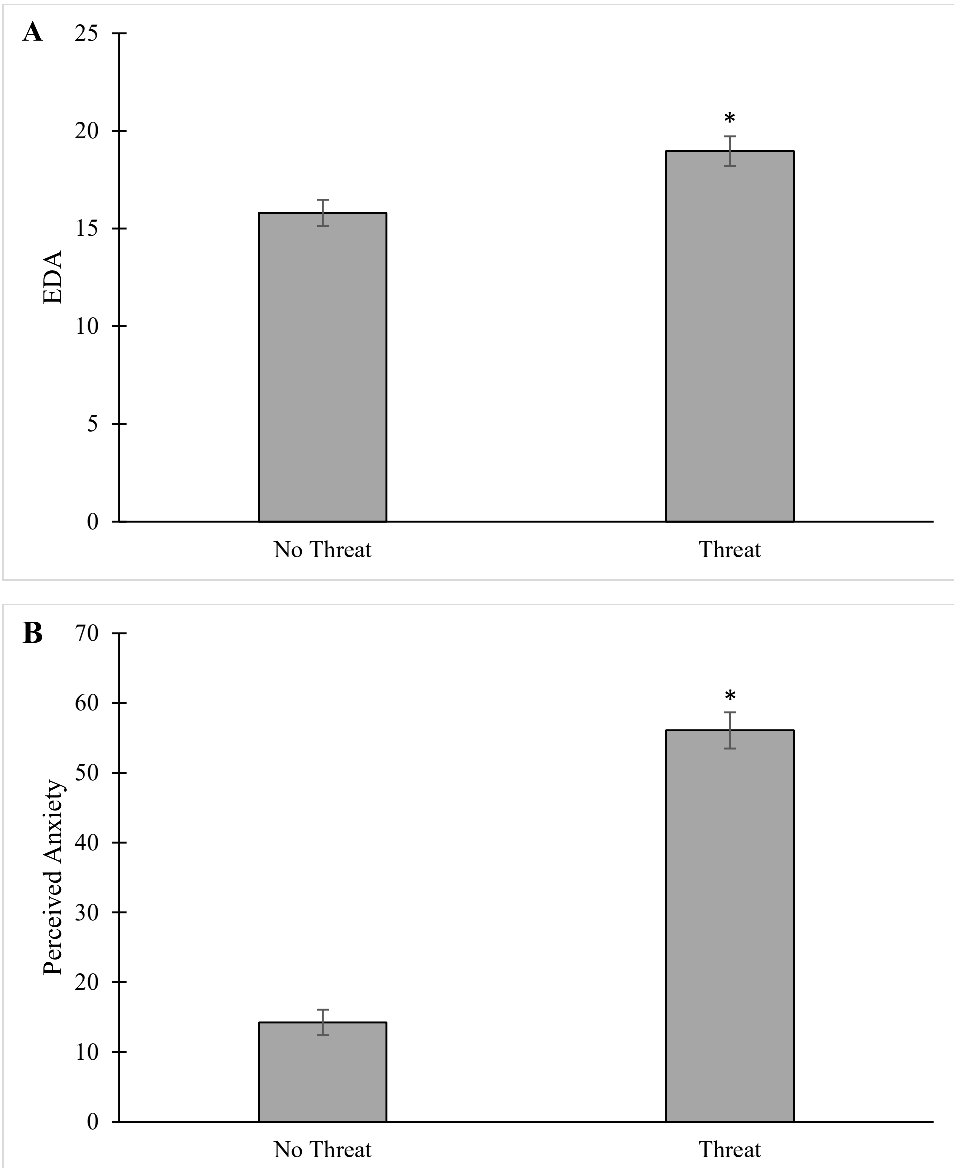

Figure 3. Threat main effects for physiological (A) and psychological measures (B) * represents a significant difference (p < 0.05).

5.4 Attention focus measures

A significant main effect of threat was observed for attention to movement processes ($F_{(1,104)} = 73.65$, $p < 0.001$), task objectives ($F_{(1,104)} = 6.06$, $p = 0.015$), threat-related stimuli

($F_{(1,104)} = 242.18$, $p < 0.001$), self-regulatory strategies ($F_{(1,104)} = 27.69$, $p < 0.001$), and task-irrelevant information ($F_{(1,104)} = 38.29$, $p < 0.001$). Participants reported directing significantly more attention towards movement processes, task objectives, threat-related stimuli, and self-regulatory strategies, and significantly less attention to task-irrelevant information (Figure 4; Table 7).

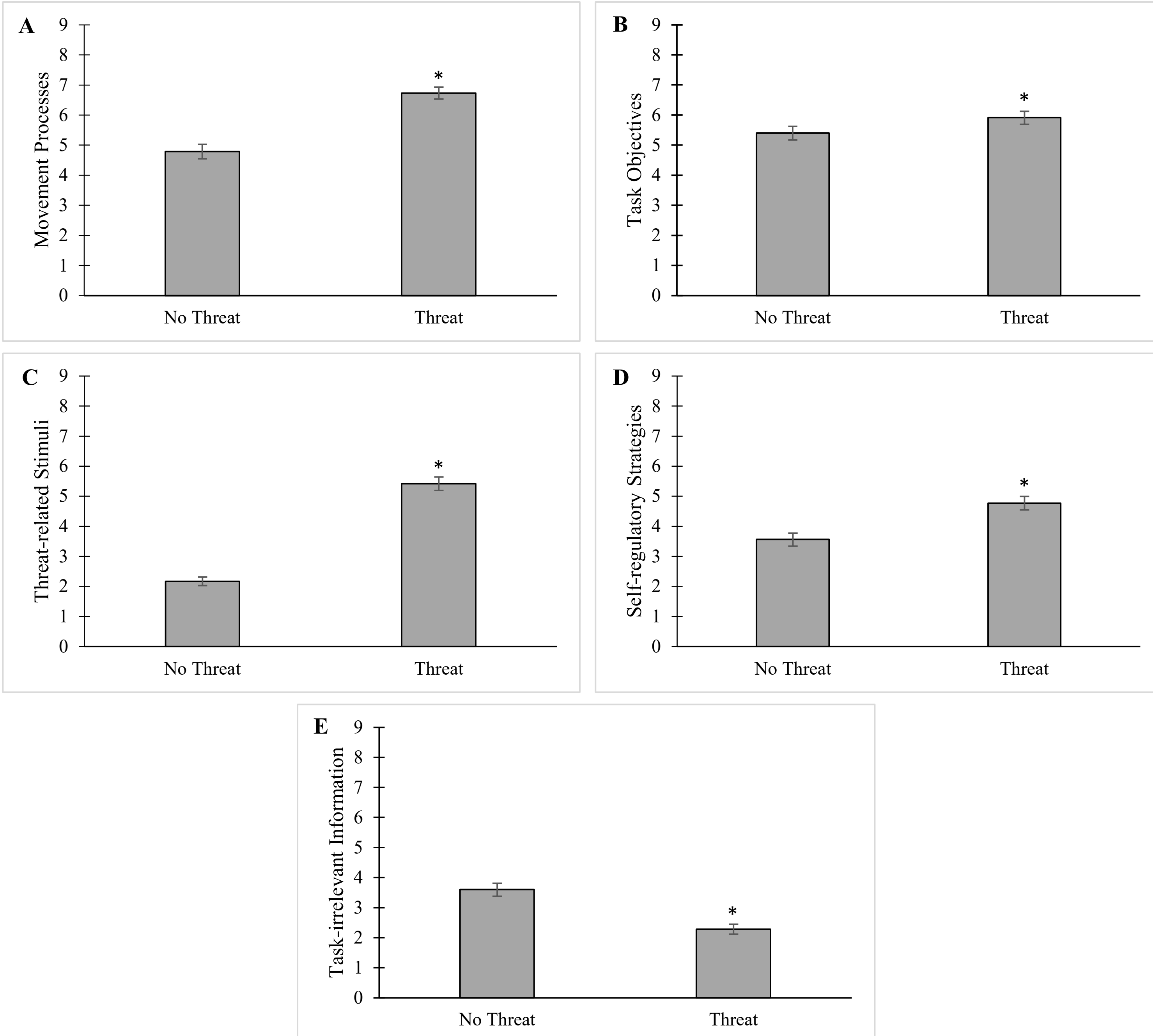

Figure 4. Threat main effects for attention to movement processes (A), task objectives (B), threat-related stimuli (C), self-regulatory strategies (D), and task-irrelevant information (E). * represents a significant difference ($p < 0.05$) from the No Threat condition.

5.5 Postural control measures

A significant main effect of threat was observed for MPOS-COP ($F_{(1,104)} = 53.00$, $p < 0.001$), RMS-COP ($F_{(1,104)} = 15.62$, $p < 0.001$), and MPF−COP ($F_{(1,104)} = 68.90$, $p < 0.001$). Participants leaned significantly further forward, and had significantly higher amplitude and frequency of COP displacements in the Threat compared to No Threat condition (Figure 5; Table 7).

There was no significant main effect of threat for COP $Freq_{LOW}$ ($F_{(1,104)} = 1.05$, $p = 0.31$). However, a significant main effect of threat was observed for COP $Freq_{MED}$ ($F_{(1,104)} = 228.55$, $p < 0.001$) and COP $Freq_{HIGH}$ ($F_{(1,104)} = 150.95$, $p < 0.001$). COP $Freq_{MED}$ and COP $Freq_{HIGH}$ were significantly higher in the Threat compared to No Threat condition (Figure 6; Table 7).

A significant main effect of threat was observed for sample entropy ($F_{(1,104)} = 40.50$, $p < 0.001$). Sample entropy was significantly higher in the Threat compared to No Threat condition (Figure 7; Table 7).

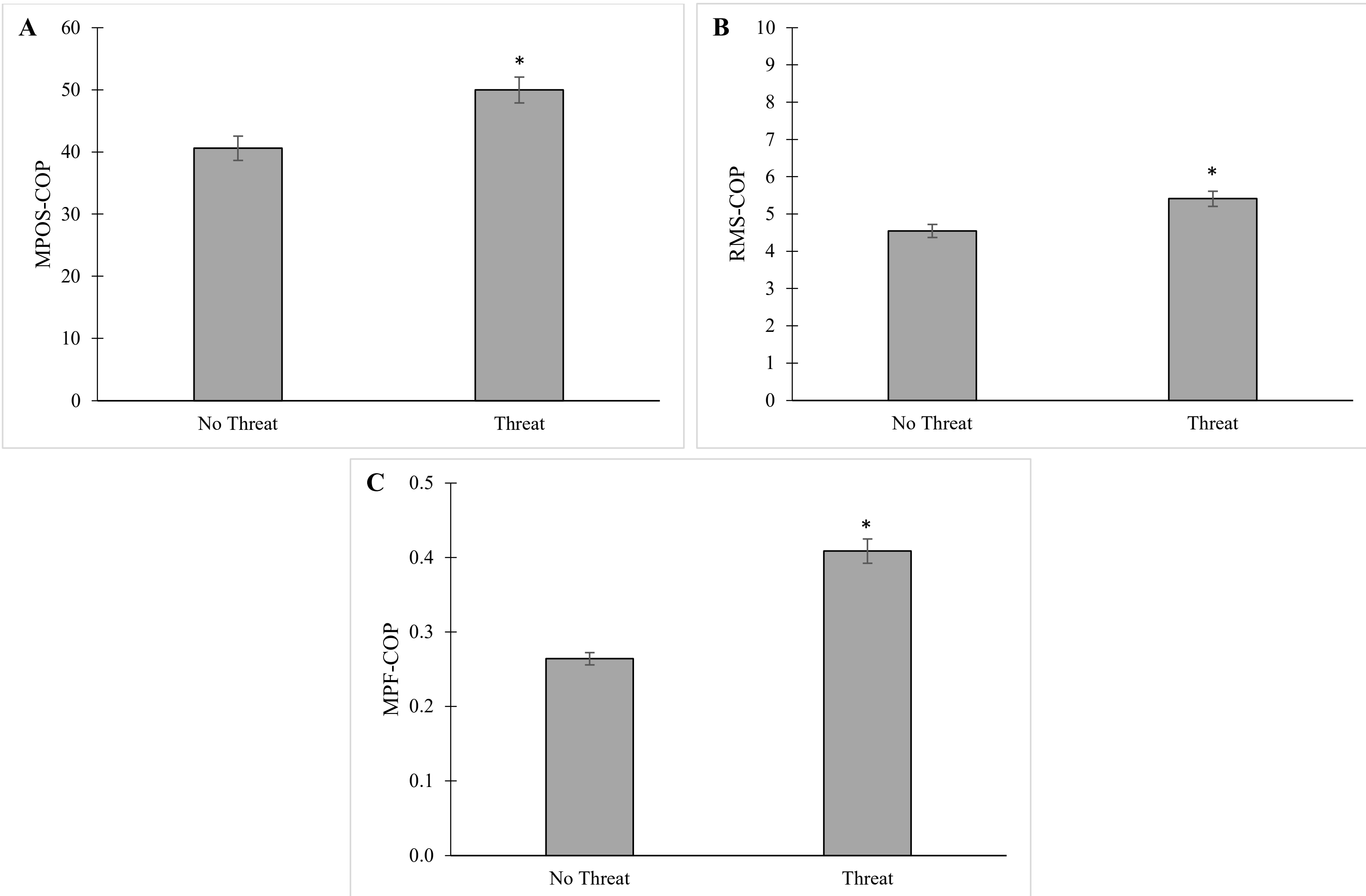

Figure 5. Threat main effects for MPOS-COP (A), RMS-COP (B), and MPF-COP (C). * represents a significant difference ($p < 0.05$) from the No Threat condition.

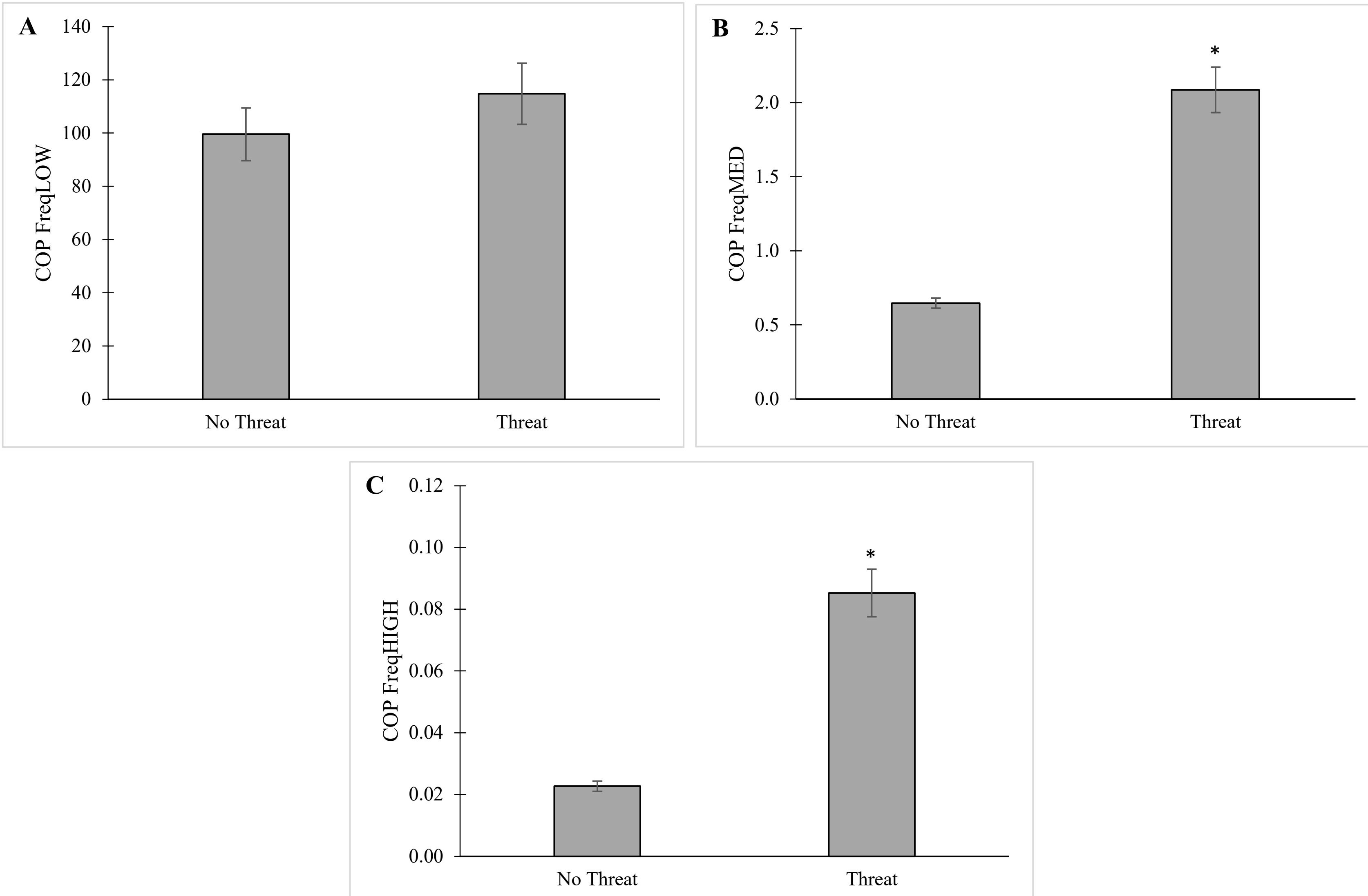

Figure 6. Threat main effects for COP $Freq_{LOW}$ (A), COP $Freq_{MED}$ (B), and COP $Freq_{HIGH}$ (C). * represents a significant difference (p < 0.05) from the No Threat condition.

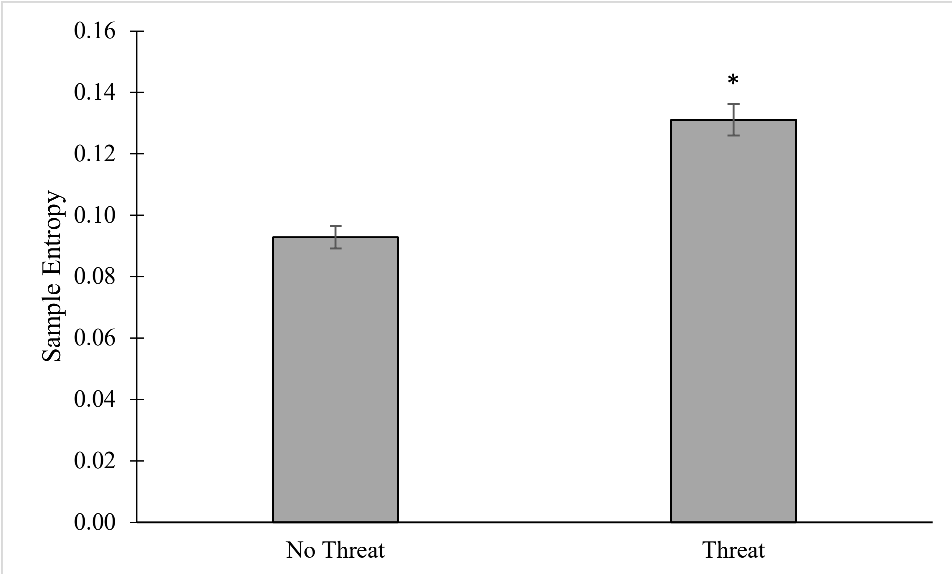

Figure 7. Threat main effects for sample entropy. * represents a significant difference (p < 0.05) from the No Threat condition.

5.6 Associations between threat-related changes in emotions, attention focus, and postural control

There were significant correlations between threat-related changes in physiological arousal, perceived anxiety, attention focus, and postural control (Table 9). Of note, only significant correlations of concern will be reported. Threat-related changes in physiological arousal were significantly correlated with changes in postural control; for example, a larger increase in EDA between No Threat and Threat conditions was significantly associated with larger increases in MPF-COP ($r = 0.215$, $p = 0.033$), COP $Freq_{MED}$ ($r = 0.333$, $p = 0.001$), and COP $Freq_{HIGH}$ ($r = 0.342$, $p = 0.001$). Changes in perceived anxiety between No Threat and Threat conditions were also correlated with changes in postural control. Larger increases in anxiety significantly accounted for larger increases in RMS-COP ($r = 0.322$, $p = 0.001$), COP $Freq_{LOW}$ ($r = 0.202$, $p = 0.039$), COP $Freq_{MED}$ ($r = 0.211$, $p = 0.031$), and COP $Freq_{HIGH}$ ($r = 0.284$, $p = 0.003$).

Threat-related changes in attention were significantly correlated with changes in postural control. For example, increased attention towards movement processes between No Threat and Threat conditions was significantly associated with larger increases in MPOS-COP ($r = 0.243$, $p = 0.013$), RMS-COP ($r = 0.427$, $p < 0.001$), COP $Freq_{LOW}$ ($r = 0.367$, $p < 0.001$), COP $Freq_{MED}$ ($r = 0.248$, $p = 0.011$), and COP $Freq_{HIGH}$ ($r = 0.357$, $p < 0.001$). Increased attention towards task objectives was also significantly associated with changes in RMS-COP ($r = 0.280$, $p = 0.004$) and COP $Freq_{LOW}$ ($r = 0.253$, $p = 0.009$). Similarly, increased attention towards threat-related stimuli between No Threat and Threat conditions accounted for larger increases in RMS-COP ($r = 0.253$, $p = 0.009$) and COP $Freq_{HIGH}$ ($r = 0.217$, $p = 0.026$).

Changes in sample entropy between No Threat and Threat conditions were significantly correlated with changes in amplitude and frequency (i.e., MPF-COP, COP $Freq_{LOW,}$ COP $Freq_{MED,}$ and COP $Freq_{HIGH}$). For example, a larger increase in sample entropy was significantly associated with a larger decrease in RMS-COP ($r = -0.700$, $p < .05$). Larger increases in sample entropy were also associated with larger increases in MPF-COP ($r = 0.755$, $p < .05$), COP $Freq_{MED}$ ($r = 0.193$, $p = 0.049$), and COP $Freq_{HIGH}$ ($r = 0.211$, $p = 0.031$), and decreases in COP $Freq_{LOW}$ ($r = -0.702$, $p < .05$). No significant correlations were reported between threat-related changes in sample entropy and changes in physiological arousal, perceived anxiety, and attention focus.

Table 9: Bivariate correlations for threat-related change scores

	ANX	AF- MP	AF-TO	AF-TRS	AF-SRS	AF-TII	MPOS-COP	RMS-COP	MPF-COP	COP Freq_{LOW}	COP Freq_{MED}	COP Freq_{HIGH}	SampEn
EDA	**.256***	0.134	0.04	0.175	0.079	0.038	0.106	0.161	**.215***	0.07	**.333****	**.342****	0.073
ANX	-	**.384****	0.143	**.792****	**.271****	-0.162	-0.008	**.322****	0.063	**.202***	**.211***	**.284****	-0.068
AF-MP		-	**.451****	**.284****	**.264****	0.094	**.243***	**.427****	0.041	**.367****	**.248***	**.357****	-0.179
AF-TO			-	0.029	**.299****	0.037	0.127	**.280****	-0.104	**.253****	0.065	0.047	-0.149
AF-TRS				-	**.299****	-0.142	-0.033	**.253****	0.051	0.139	0.151	**.217***	-0.102
AF-SRS					-	0.058	0.157	0.191	0.085	0.187	0.14	0.121	-0.009
AF-TII						-	0.005	-0.059	-0.027	-0.03	-0.179	-0.123	-0.008
MPOS-COP							-	**.197***	-0.033	0.13	**.230***	**.206***	-0.066
RMS-COP								-	**-.456****	**.879****	**.327****	**.287****	**-.700****
MPF-COP									-	**-.591****	**.399****	**.477****	**.755****
COP Freq_{LOW}										-	0.047	0.043	**-.702****
COP Freq_{MED}											-	**.833****	**.193***
COP Freq_{HIGH}												-	**.211***
SampEn													-

Note: EDA = electrodermal activity; ANX = self-reported anxiety; AF = attention focus MP = movement processes; TO = task objectives; TRS = threat-related stimuli; SRS = self-regulatory strategies; TII = task-irrelevant information; MPOS = mean position; COP = centre of pressure; RMS = root mean square; MPF = mean power frequency; Freq_{LOW} = low frequency (0–0.05 Hz); Freq_{MED} = medium frequency (0.5–1.8 Hz); Freq_{HIGH} = high frequency (1.8–5 Hz); SampEn = sample entropy

**. Correlation is significant at the 0.01 level (2-tailed).

*. Correlation is significant at the 0.05 level (2-tailed).

The regressions for threat-related changes between No Threat and Threat conditions reveal that changes in physiological arousal, perceived anxiety, and attention focus significantly accounted for changes in RMS-COP (R^2 = 0.225, $F(7, 91)$ = 3.767, p = 0.001), COP $Freq_{LOW}$ (R^2 = 0.154, $F(7, 91)$ = 2.358, p = 0.029), COP $Freq_{MED}$ (R^2 = 0.204, $F(7, 91)$ = 3.333, p = 0.003), and COP $Freq_{HIGH}$ (R^2 = 0.237, $F(7, 91)$ = 4.027, p = 0.001), but not MPOS-COP (R^2 = 0.105, $F(7, 91)$ = 1.532, p = 0.166), MPF-COP (R^2 = 0.079, $F(7, 91)$ = 1.112, p = 0.362), or SampEn (R^2 = 0.067, $F(7, 91)$ = 0.930, p = 0.487; Table 10). Changes in frequency (i.e., MPF-COP, COP $Freq_{MED}$, and COP $Freq_{HIGH}$) were accounted for by changes in physiological arousal; a larger increase in EDA between No Threat and Threat conditions was associated with a larger increase in MPF-COP (β = 0.211, p = 0.046), COP $Freq_{MED}$ (β = 0.305, p = 0.002), and COP $Freq_{HIGH}$ (β = 0.303, p = 0.002). Threat-related changes in attention were also associated with changes in postural control. For example, larger increases in attention to movement processes between No Threat and Threat conditions was associated with larger increases in MPOS-COP (β = 0.294, p = 0.018), RMS-COP (β = 0.290, p = 0.012), COP $Freq_{LOW}$ (β = 0.284, p = 0.018), and COP $Freq_{HIGH}$ (β = 0.322, p = 0.005). Larger increases in attention to task-irrelevant information was associated with larger decreases in COP $Freq_{MED}$ (β = -0.211, p = 0.031).

Table 10: Overall model R^2 and beta values for each variable of the multiple linear regressions

	MPOS-COP	RMS-COP	MPF-COP	COP $Freq_{LOW}$	COP $Freq_{MED}$	COP $Freq_{HIGH}$	SampEn
EDA	0.103	0.080	**0.211****	0.015	**0.305****	**0.303****	0.102
ANX	-0.138	0.131	-0.024	0.078	0.040	0.047	0.063
AF-MP	**.294****	**.290****	0.073	**.284****	0.220	**.322****	-0.135
AF-TO	-0.044	0.120	-0.173	0.098	-0.071	-0.119	-0.140
AF-TRS	-0.046	0.020	0.002	-0.068	-0.045	-0.049	-0.156
AF-SRS	0.144	0.035	0.114	0.082	0.098	0.061	0.080
AF-TII	-0.065	-0.067	-0.072	-0.054	**-0.211****	-0.184	-0.014
Model R	0.105	**.225****	0.079	**.154****	**.204****	**.237****	0.067

Note: EDA = electrodermal activity; ANX = self-reported anxiety; AF = attention focus MP = movement processes; TO = task objectives; TRS = threat-related stimuli; SRS = self-regulatory strategies; TII = task-irrelevant information; MPOS = mean position; COP = centre of pressure; RMS = root mean square; MPF = mean power frequency; $Freq_{LOW}$ = low frequency (0–0.05 Hz); $Freq_{MED}$ = medium frequency (0.5–1.8 Hz); $Freq_{HIGH}$ = high frequency (1.8–5 Hz); SampEn = sample entropy
**. Indicates significant model or beta value

Chapter Six: Discussion

The primary objective of this thesis was to examine the effects of postural threat on sample entropy, for which higher values are thought to correspond to more automatic (i.e., less consciously processed) postural control. Postural threat had a significant effect on sample entropy; higher values were reported when standing with compared to without the expectation of receiving a support surface perturbation. Higher sample entropy values suggest a shift to a more automatic control of posture when threatened, supporting previous research that showed a surface height threat-related increase in sample entropy (Ellmers et al., 2020). Threat-related changes in attention focus and postural control were also reported in this thesis; the threat of receiving a support surface perturbation was confirmed by significant increases in physiological arousal and self-reported state anxiety. When threatened, participants increased attention towards movement processes, task objectives, threat-related stimuli, and self-regulatory strategies, and decreased attention to task-irrelevant information. Participants leaned further forward in anticipation of an A-P support surface perturbation and demonstrated increased amplitude (i.e., RMS-COP) and frequency (i.e., MPF-COP, COP $Freq_{MED}$, and COP $Freq_{HIGH}$) of COP displacements. These observations reinforce and expand upon the results reported in the two published studies from which the data set was derived (Johnson et al., 2019; 2020).

The second objective of this thesis was to examine the relationships between threat-related changes in physiological arousal, perceived anxiety, attention focus, and postural control measures. Threat-related changes in sample entropy were not significantly correlated to physiological arousal, perceived anxiety, or attention focus, suggesting that sample entropy may not be as susceptible to change through these mechanisms. However, changes in sample entropy between No Threat and Threat conditions were significantly correlated with changes in frequency components (i.e., MPF-COP, COP $Freq_{LOW}$, COP $Freq_{MED}$, and COP $Freq_{HIGH}$). Based on the interpretation of sample entropy changes, the results of this thesis suggest a shift to a more automatic control of posture when threatened. Future work should examine the direct and/or indirect relationships between physiological arousal, perceived anxiety, attention focus, and postural control measures (i.e., frequency and sample entropy) in order to provide insight into the potential attentional and/or neurophysiological mechanisms (i.e., proprioceptive and vestibular-evoked reflex gains) underlying threat-related changes in postural control (Adkin & Carpenter, 2018).

6.1 Physiological arousal and perceived anxiety

Threat-related changes in physiological arousal and perceived anxiety were reported. As anticipated, physiological arousal (e.g., mean electrodermal activity) and perceptions of anxiety significantly increased when standing with the threat of a support surface perturbation. Similarly, these results were seen in the two published studies from which the data set was derived (Johnson et al., 2019; 2020). Physiological arousal and perceptions of anxiety also increased when anticipating a medial-lateral support surface perturbation (Johnson et al., 2019b). These results confirm that the threat of perturbation significantly changed physiological and psychological state in this group of healthy young adults.

6.2 Attention focus

Threat-related changes in attention focus were reported prior to a support surface perturbation. When threatened, participants increased attention towards movement processes, task objectives, threat-related stimuli, and self-regulatory strategies, and decreased attention to task-irrelevant information. Similarly, these results were seen in the two published studies from which the data set was derived (Johnson et al., 2019; 2020). While Johnson et al. (2020) reported increased attention towards task objectives, Johnson et al. (2019) did not report a significant effect. Therefore, the combined data set showed that participants increased attention towards task objectives when threatened with the possibility of a support surface perturbation. These broad changes in attention focus were also reported when standing at elevated surface heights (Zaback et al., 2016; 2019) and when anticipating a medial-lateral support surface perturbation (Johnson et al., 2019b).

6.3 Postural control

Threat-related changes in postural control were reported when standing with compared to without the expectation of receiving a support surface perturbation. When threatened, participants leaned further forward and demonstrated increased amplitude (i.e., RMS) and frequency (i.e., MPF) of COP displacements. These results reinforce the two published studies from which the data set was derived (Johnson et al., 2019; 2020). In these studies, participants leaned further forward in anticipation of an A-P support surface perturbation and increased COP frequency (i.e., MPF). While Johnson et al. (2019) reported increased COP amplitude when threatened, Johnson et al. (2020) did not report a significant effect. Thus, the combined thesis data set showed that participants increased COP amplitude when standing with compared to without the expectation of receiving a support surface perturbation.

Threat-related changes within low (0–0.05 Hz), medium (0.5–1.8 Hz), and high frequency (1.8–5 Hz) components were also reported to provide context to the threat-related increases in mean power frequency (MPF) of COP. Significant increases in medium (0.5–1.8 Hz) and high frequency (1.8–5 Hz) components were reported when threatened with the possibility of a support surface perturbation. No significant threat-related changes in low frequency (0–0.05 Hz) components were reported. Of the two published studies from which the data set was derived, only Johnson et al. (2020) reported threat-related changes within these frequency components; results showed similar significant main effects of threat. Therefore, the combined data set shows that increases in MPF-COP were the result of significant increases in medium (0.5–1.8 Hz) and high frequency (1.8–5 Hz) components. Similarly, these results were also reported when standing at elevated surface heights (Zaback et al., 2016; 2019; 2021) and when anticipating a medial-lateral support surface perturbation (Johnson et al., 2019b).

6.4 Sample entropy

6.4.1 Effects of duration on sample entropy

Sample entropy was calculated under combinations of N = 60-s, 30-s (early), and 30-s (late) to examine parameter value N on consistencies in time-series length. The results of the analysis showed significant changes in sample entropy between time-series length; a main effect of time was confirmed by a significant increase in the 30-s early time condition compared to the 60-s and 30-s late time condition. Sample entropy increased under combinations of N, as was observed in studies controlling the down-sampling frequencies (e.g., N = 1500 data points corresponds to 25 Hz x 60-s) of continuous time-series (Lubetzky et al., 2018; Rhea, Kiefer, Wright, Raisbeck, & Haran, 2015). If continuous time-series were down-sampled, comparisons in COP variability and velocity signals were consistent (Rhea et al., 2015), as were significant main effects of surface and group × surface interactions (Lubetzky et al., 2018). Collectively, these results convey that signal processing and parameter selection is critical in the comparison of sample entropy values (i.e., mean and SD). Studies commonly set parameters to m = 2 or 3, r

between 0.1 and 0.25*SD, and N equal to or greater than 1000 (Pincus, 1991, Richman & Moorman, 2000). Comparisons between the original time-series (Franco, Fleury, Diot, & Vuillerme, 2018), data pre-processing (i.e., detrending and differencing; Lubetzky et al., 2018), and digital filtering (Becker & Hung, 2020; Rhea et al., 2019; Stins et al., 2009; 2011) have also been studied. The results of the analysis confirm the significance of parameter selection in the comparison of sample entropy values; there were differences between the 60-s and 30-s early time condition. The results suggested that there should be consistencies in signal processing and parameter selection prior to the comparison of sample entropy. Therefore, the Johnson et al. (2020) study was shortened to a time-series of length N = 30-s (early) for comparison.

Appropriate lengths of time-series have been recommended, for example, during quiet standing for some studied frequency values. Reliability analysis of mean power frequency (MPF) found significant main effects with a time-series of at least N = 60-s (Carpenter et al., 2001). Significant differences were also found between groups; i.e., older adults with and without falls in the last 12 months. Sample entropy only discriminated between groups with a longer time-series of length N = 60-s (Montesinos et al., 2018). To address this potential limitation, a significant main effect of threat was confirmed in a separate analysis for length N = 60-s. Sample entropy was expected to be significantly different between No Threat and Threat conditions. Healthy young adults (N = 25) stood with and without the expectation of receiving a support surface perturbation in the Johnson and colleagues (2020) study. Similar effects were found with a time-series of length N = 60-s; sample entropy increased significantly in the Threat (0.10 ± 0.01) compared to No Threat (0.07 ± 0.01) condition.

6.4.2 Effects of postural threat on sample entropy

Two secondary data sets were combined to compare sample entropy in No Threat and Threat conditions. Sample entropy provides a measure of automaticity, for which higher values correspond to more automatic (i.e., less consciously processed) postural control (Drozdova-Statkevičienė et al., 2018). There is speculation that automaticity, which is characteristic of attention, is significantly associated with sample entropy measures. For example, significant decreases in sample entropy were reported in patients recovering from stroke compared to healthy controls, and significant increases were reported in stroke patients during the course of their rehabilitation. Interpreted as attentional investments in postural control; a significant increase in sample entropy corresponded to a decrease in attention to movement. These results were theoretically significant to the interpretation of the relationship between sample entropy and attention (Roerdink et al., 2006). Expected to be influenced by threat (i.e., consciously processed control); a corresponding decrease in sample entropy was predicted (Roerdink et al., 2011). For example, state-changes in conscious motor processing and movement self-consciousness were reported at two different surface heights: ground level (LOW) and 3.2-m above ground level (HIGH). Furthermore, increases in conscious motor processing and movement self-consciousness were associated with leaning further away from the edge of the surface. Huffman and colleagues (2009) confirmed a direct relationship between threat-related changes in movement reinvestment and MPOS-COP. However, relationships between movement reinvestment and other measures of postural control (i.e., RMS-COP, MPF-COP) were not identified (Huffman et al., 2009). Changes in postural control are more directly related to attention than others, and are therefore not indicative of the amount of attention invested in posture.

Theoretical interpretations of sample entropy were explored in No Threat and Threat conditions. Though procedures varied, Ellmers and colleagues (2020) showed a corresponding change in sample entropy in asymptomatic older adults standing at a surface height of 0.6-m. The objective of this thesis was to examine the effects of the postural perturbation (anticipation) threat model on sample entropy. A significant decrease in sample entropy was expected in the Threat compared to No Threat condition. It was also expected that threat-related changes in attention focus to movement processes would coincide with threat-related changes in sample entropy. The results of this thesis show a significant increase in sample entropy when standing with the expectation of receiving a support surface perturbation. The percentage change increase from the No Threat to Threat condition was 40.9%, which supports the surface height threat model (Ellmers et al., 2020). Conversely, Stins et al. (2011) contradicts these results at two different surface heights: ground level (LOW) and 1-m above ground level (HIGH). No significant differences in sample entropy were observed between height conditions; a surface height of 1-m may not have been perceived as threatening for healthy young adults (Stins et al., 2011).

Differences in experimental design and analysis could describe some of the contradictory results (i.e., demographics, parameter settings). For example, Ellmers and colleagues (2020) evaluated asymptomatic older adults (i.e., no current diagnosis for any neurological or vestibular condition, nor any recent dizziness) standing at a surface height of 0.6-m prior to completing the Baseline condition. Research limitations include not rating subjective anxiety scores (e.g., STAI; Spielberger et al., 1983), so it is unknown if anxiety was actually experienced. Research is also limited by the use of the surface height threat model (Ellmers et al., 2020; Stins et al., 2011). Despite the limitations, the results of this thesis support Ellmers and colleagues (2020) examining whether entropy-based measures underpin the distorted perceptions of instability. Results showed a significant increase in sample entropy; coinciding with significant increases in medium (0.5–1.8 Hz) and high frequency (1.8–5 Hz) components. While neurophysiological mechanisms may underpin (distorted) threat-related perceptions of instability and postural control, Ellmers et al. (2020) did not study any significant interactions. This thesis will discuss sample entropy and the relationships among attention focus and postural control in Threat compared to No Threat conditions.

6.5 Associations between threat-related changes in emotions, attention focus, and postural control

Associations between threat-related changes in physiological arousal, perceived anxiety, attention focus, and postural control have been identified in previous studies. However, these associations are inconsistent. There are potential neurophysiological and attentional mechanisms that may explain these threat-related changes in postural control (Adkin & Carpenter, 2018). State-related changes in physiological arousal and anxiety (Adkin et al., 2002; Davis et al., 2009; Huffman et al., 2009; Zaback et al., 2015), and ratings of stability and balance-related confidence (Hauck et al., 2008; Huffman et al., 2009) have been consistently reported. For example, increased confidence (i.e., task-specific balance efficacy) was significantly associated with decreased COP frequency and increased one-leg stance duration (Hauck et al., 2008). Research has also shown increases in proprioceptive (Davis et al., 2011; Horslen et al., 2013; 2014) and vestibular-evoked reflex gains (Naranjo et al., 2015; 2016), which is known to actively modulate muscle spindle sensitivity to stretch. This is assessed indirectly through changes in soleus tendon-tap reflex (t-reflex) and Hoffmann (H-) reflex (Horslen et al., 2014). Research has shown that increased sensory gain contributes to participants perceiving themselves to be swaying at larger amplitudes than actually exhibited. For example, leaning amplitude decreased under HIGH (3.2-m) threat conditions and participants perceived themselves to be at a further position relative to their actual position. The mean difference (i.e., HIGH – LOW) in perception of lean was 4.9% (Cleworth et al., 2018). A distorted perception could be interpreted as increases in conscious motor processing (Ellmers et al., 2020). Therefore, a combination of neurophysiological and attentional mechanisms may underpin (distorted) threat-related perceptions of instability and postural control (Adkin & Carpenter, 2018).

Sample entropy is thought to provide a measure of automaticity, for which higher values correspond to minimal (or less) attention towards movement (Roerdink et al., 2011). Therefore, the objective of this thesis was to examine the relationships between threat-related changes in physiological arousal, perceived anxiety, attention focus, and postural control measures. Theories claim that changes in attention are associated with sample entropy measures (Roerdink et al., 2011). Contrary to theoretical claims, increased self-reports of conscious movement processing was not the sole mechanism underpinning (distorted) threat-related perceptions of instability. Ellmers and colleagues (2020) showed a significant increase in sample entropy coinciding with significant increases in medium (0.5–1.8 Hz) and high frequency (1.8–5 Hz) components. Such postural threat effects confirm the potential of attentional and/or neurophysiological mechanisms underlying sample entropy measures. Threat-related change scores were therefore calculated to confirm any significant correlations between physiological arousal, perceived anxiety, attention focus, and postural control measures. Threat-related changes between No Threat and Threat conditions showed that changes in physiological arousal and attention focus are significantly associated with changes in amplitude (i.e., RMS-COP) and frequency (i.e., COP $Freq_{LOW}$, COP $Freq_{MED}$, and COP $Freq_{HIGH}$). For example, changes in frequency (i.e., $Freq_{MED}$ and COP

$Freq_{HIGH}$) were accounted for by changes in physiological arousal. Similar threat-related changes in frequency were seen at surface heights; however, these changes were not associated with changes in physiological arousal. Increased frequency was significantly associated with decreased balance confidence under HIGH (3.2-m) threat conditions (Huffman et al., 2009). Changes in task-specific balance efficacy (Carpenter et al., 2006) and physical risk-taking (Zaback et al., 2015) were also associated with changes in frequency (i.e., MPF-COP).

Threat-related changes in attention focus to movement processes, threat-related stimuli, and task-irrelevant information were the only attention focus measures associated with changes in postural control. Previous research has shown changes in frequency (i.e., MPF-COP) were accounted for by changes in attention towards self-regulatory strategies; the examination of higher frequency components could explain why these changes were not observed (Johnson et al., 2019). When threatened, a larger increase in attention to movement processes was associated with larger increases in amplitude (i.e., RMS-COP) and frequency (i.e., COP $Freq_{LOW}$, COP $Freq_{MED}$, and COP $Freq_{HIGH}$). These results reinforce the Johnson et al. (2019) study from which the data set was derived; a larger increase in attention to movement processes was associated with larger increases in mean position and amplitude. Similar to height-related threat, changes in amplitude were accounted for by state-related changes in conscious motor processing (Zaback et al., 2015). Threat-related changes in amplitude were also accounted for by changes in perceived stability (Hauck et al., 2008) and anxiety. For example, a larger increase in anxiety was associated with larger increases in amplitude (i.e., RMS-COP) without perturbation experience. After the perturbation was experienced, changes in RMS-COP were accounted for by changes in attention focus (Johnson et al., 2019). Contrary to the hypotheses, no significant correlations were reported between threat-related changes in sample entropy and changes in physiological arousal, perceived anxiety, and attention focus. Changes in sample entropy between No Threat and Threat conditions were not correlated with changes in attention focus. Significant effects of distraction on sample entropy were therefore examined in a time-series of length N = 60-s. Healthy young adults counted the occurrence of a pre-selected letter in an auditory sequence of letters presented at two second intervals in No Threat and Threat conditions. The percentage change increase from the No Threat condition was 33.2% for the Threat and 38.7% for the Threat-Distraction condition. These changes did not reach statistical significance (Johnson et al., 2020). Participants were not as influenced by the threat (i.e., less consciously processed control) while performing the secondary task, which supports Ellmers et al. (2020) results in their Threat-Distraction conditions. However, changes in sample entropy were significantly correlated with changes in frequency (i.e., MPF-COP, COP $Freq_{LOW}$, COP $Freq_{MED}$, and COP $Freq_{HIGH}$). When threatened, a larger increase in sample entropy was associated with a larger increase in MPF-COP, COP $Freq_{MED}$, and COP $Freq_{HIGH}$.

The results of this thesis appear to contradict theoretical claims that threat-related changes in attention focus would be significantly associated with threat-related changes in sample entropy. However, threat-related changes in attention to movement processes was not the only change in attention that was reported prior to a support surface perturbation. Participants also increased attention towards task objectives, threat-related stimuli, and self-regulatory strategies. Considering these broad threat-related changes in attention focus, it is possible that the attentional strategy contributes to the contradictory results. It should be considered whether different attentional strategies (i.e., instructed focus of attention) affect threat-related changes in attention focus and their associations with sample entropy. For example, Becker and Hung (2020) compared sample entropy with internal focus instructions (i.e., instructed to focus on keeping their feet level), external focus instructions (i.e., instructed to focus on keeping the markers level), or holistic focus instructions (i.e., focus on feeling calm and stable). Sample entropy increased significantly in the external focus condition compared to the internal and holistic focus conditions. Conversely, sample entropy significantly increased in the external focus and dual-task (e.g., DNS; double-number sequence) condition compared to the control condition in the M-L direction. Sample entropy only increased in the dual-task (e.g., SNS; single-number sequence) condition compared to the control condition in the A-P direction, and no effect was observed in the external focus and DNS condition (Richer & Lajoie, 2020). Entropy-based measures should therefore be complemented with conventional summary statistics that examine threat-related changes in attention focus and postural control (Liau et al., 2019; Turnock & Layne, 2009), as outlined in Figure 1. Sample entropy increased significantly when standing prior to a support surface perturbation; coinciding with significant increases in medium frequency (0.5–1.8 Hz), and high frequency (1.8–5 Hz) components. The results of this thesis specify that increases in sample entropy between No Threat and Threat conditions were significantly correlated with increases in MPF-COP, medium (0.5–1.8 Hz), and high frequency (1.8–5 Hz) components. Thus, it is possible that neurophysiological mechanisms (i.e., increased SOL-TA co-contraction) observed in the surface height threat model may also underpin threat-related changes in postural control. For example, high frequency (> 1.83 Hz) and SOL-TA co-contraction are positively correlated under HIGH (3.2-m) threat conditions; and are susceptible to change following repeated threat exposure (Zaback et al., 2019). Or it is possible that threat-related changes in postural control correspond to an inability to exert effective attentive control (Borg & Laxåback, 2010).

The results of this thesis suggest a combination of neurophysiological and attentional mechanisms in the postural perturbation threat model; and proposes that sample entropy is susceptible to change through attention to some extent. Considering the broad threat-related changes in attention focus, the attentional strategy could result in a shift to a more automatic control of posture. This may be an appropriate strategy for healthy young adults in response to a support surface perturbation (Borg & Laxåback, 2010). Or, changes in high frequency (> 1.83 Hz) and SOL-TA co-contraction under HIGH (3.2-m) threat conditions could contribute to changes in attention (i.e., movement processes, threat-related stimuli, and self-regulatory strategies), causing participants to perceive themselves to be swaying at larger amplitudes than actually exhibited (Cleworth et al., 2018). Thus, sample entropy theories predicted participants to be influenced by the threat, and assumed that sample entropy was associated with attention focus.

6.6 Limitations

There are limitations that should be acknowledged when interpreting the results of this thesis. One limitation is that the time-series was shortened to $N = 30$-s for consistency in time-series length (Johnson et al., 2020). Appropriate lengths of time-series have been recommended, for example, to standardize the length of the time-series to some reasonable value ($N = 600$, equivalent to a 30-s duration). However, lengths equal to or greater than $N = 60$-s have also been recommended (Kuznetsov et al., 2013; Yentes et al., 2013). A separate analysis was conducted to confirm significant changes in sample entropy for length $N = 60$-s. Sample entropy increased in the Threat compared to No Threat condition. Since the time-series was shortened, anxiety and attention focus responses were rated across 30-s (Johnson et al., 2019) and 60-s (Johnson et al., 2020). The results were still able to provide indication into how attention was direction. Third, the results are only generalizable to healthy young adults experiencing temporally unpredictable A-P support surface perturbations. Future research should examine correlations in different populations and under different threat models. Another limitation is that the self-report questionnaires are susceptible to expectancy and desirability bias.

6.7 Conclusions

This thesis explored the effects of postural threat on sample entropy and the relationships between physiological arousal, perceived anxiety, attention focus, and postural control. When threatened, participants reported increases in physiological arousal and perceived anxiety, as well as broad changes in attention focus. Participants leaned further forward and increased the amplitude and frequency of COP displacements. This thesis provides evidence of a relationship between threat-related changes in postural control and sample entropy. This would suggest a shift to a more automatic control of posture despite increased attention towards movement processes. However, threat-related changes in physiological arousal, perceived anxiety, and attention focus were not significantly related to changes in sample entropy. Further investigations of these relationships should consider how broad threat-related changes in attention focus affect their associations with sample entropy.

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APPENDIX A – Brock University ethics clearance

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:	7/23/2020
PRINCIPAL INVESTIGATOR:	ADKIN, Allan - Kinesiology
FILE:	19-356 - ADKIN
TYPE:	Faculty Research

TITLE: Exploring relationships between personality traits, threat-related changes in attention, and postural control

ETHICS CLEARANCE GRANTED

Type of Clearance: NEW Expiry Date: 7/1/2021

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. Clearance granted from **7/23/2020** to **7/1/2021**.

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 7/1/2021. 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: ____________________________

Gail Frost, Acting 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 – Demographic and health questionnaire

Participant ID Code: ___________

Age: ____________________

Height: ____________________

Weight: ____________________

Biological Sex: ____________________

Foot Length: ____________________

Heel to Ankle Length: ____________________

Have you, or are you currently diagnosed as having any of the following conditions? Please check all that apply.

☐ Hearing impairment

☐ Diabetes

☐ Multiple sclerosis

☐ Other neurological disorders

☐ Fracture (< 8 weeks)

☐ Previous experience on platform

☐ Any other issues (e.g., sensory dysfunction) that may interfere with your balance or walking? If so, please specify.

____

APPENDIX C – Trait form of the state-trait anxiety inventory

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 D – Trait version of the movement specific reinvestment scale

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. Answer as honestly as possible.

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 myself 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 E – Risk taking form of the domain specific risk-taking scale

Directions: 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 an unsafe area of town _______
27. Moving to a city far away from 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 F – Self-reported anxiety questionnaire

Directions: Please respond to the following statements as honestly as possible about how you felt from the start to the end of the standing trial (or the time prior to the platform moving).

1. 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

2. Using the following scale, please rate how physically anxious (e.g., tense) you felt when performing the balance task:

0	10	20	30	40	50	60	70	80	90	100
Not at all worried					Moderately worried					Very worried

APPENDIX G – Attention focus questionnaire

Directions: 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:

1. 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

2. 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

3. 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

4. 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

5. Thoughts unrelated to balance (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

---

6. Concentrating on the specific secondary task (i.e., letters):

   1 2 3 4 5 6 7 8 9

   Not at all Slightly Moderately Quite a bit Very