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ORIGINAL ARTICLE

Exploring the relationship between threat-related changes in anxiety, attention focus, and postural control

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Abstract Individuals report directing attention toward and away from multiple sources when standing under height-related postural threat, and these changes in attention focus are associated with postural control modifications. As it is unknown whether these changes generalize to other types of threat situations, this study aimed to quantify changes in attention focus and examine their relationship with postural control changes in response to a direct threat to stability. Eighty young adults stood on a force plate fixed to a translating platform. Three postural threat conditions were created by altering the expectation of, and prior experience with, a postural perturbation: no threat of perturbation, threat without perturbation experience, and threat with perturbation experience. When threatened, participants were more anxious and reported directing more attention to movement processes, threat-related stimuli, and self-regulatory strategies, and less to task-irrelevant information. Postural sway amplitude and frequency increased with threat, with greater increases in frequency and smaller increases in amplitude observed with experience. Without experience, threat-related changes in postural control were accounted for by changes in anxiety; larger changes in anxiety were related to larger changes in sway amplitude. With experience, threat-related postural control changes were accounted for by changes in attention focus; increases in attention to movement processes were related to greater forward leaning and increases in sway amplitude, while increases in attention to self-regulatory strategies were related to greater increases in sway frequency. Results suggest that relationships between threat-related changes in anxiety, attention focus, and postural control depend on the context associated with the threat.

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Introduction

Research has shown that postural threat, evoked by raising the height of the surface on which individuals stand, influences postural control. When standing on an elevated surface, healthy young adults typically lean away from the edge and limit body movement by adopting a stiffness strategy characterized by higher frequency and lower amplitude postural adjustments (Adkin, Frank, Carpenter, & Peysar, 2000; Brown, Polych, & Doan, 2006; Carpenter, Adkin, Brawley, & Frank, 2006; Carpenter, Frank, & Silcher, 1999; Carpenter, Frank, Silcher, & Peysar, 2001; Zaback, Cleworth, Carpenter, & Adkin, 2015). Evidence suggests that changes in attention may contribute to changes in postural control when threatened (Huffman, Horslen, Carpenter, & Adkin, 2009; Zaback, Carpenter, & Adkin, 2016; Zaback et al., 2015). For example, research has shown that individuals report more conscious monitoring of postural control when standing on an elevated surface (Huffman et al., 2009; Zaback et al., 2015), with this change in attention associated with leaning further away from the edge (Huffman et al., 2009). There is also evidence that individuals' propensity to reinvest attention in their movement, considered to be a personality trait (Masters & Maxwell, 2008), is associated with threat-related changes in postural control (Zaback et al., 2015). Individuals who are more prone to consciously control their movements are more likely to lean further away from the edge and have larger amplitude postural sway when threatened, whereas individuals who are more self-conscious of their movement appearance are more likely to have smaller amplitude postural sway (Zaback et al., 2015). This research provides evidence that directing attention to the processes underlying movement has the potential to contribute to threat-related changes in postural control (Huffman et al., 2009; Zaback et al., 2015).

Directing attention to movement processes may not be the only change in attention that occurs when threatened. According to attentional control theory (ACT), anxious individuals have an attentional bias to threat-related stimuli (Eysenck, Derakshan, Santos, & Calvo, 2007). This bias may reduce allocation of attention resources to the task at hand, potentially leading to impairments in performance (Eysenck et al., 2007). However, ACT also predicts that anxiety has a motivational component, such that anxious individuals invest additional on-task effort or engage in alternative processing strategies (e.g., directing attention to movement processes) as a mechanism to compensate for this attentional bias to threat-related stimuli (Eysenck et al., 2007). These strategies may help to alleviate anxiety and maintain performance on tasks with minimal cognitive demands; however, adopting certain strategies may not always be beneficial to performance (Eysenck et al., 2007). For example, according to the constrained action hypothesis (Wulf & Prinz, 2001), directing attention to otherwise automatic movement processes may disrupt task performance, which has been shown for a variety of motor and postural tasks (Wulf, 2013). As stated above, individuals have a tendency to focus on this information when standing under conditions of height-related threat (Huffman et al., 2009; Zaback et al., 2015). Although ACT would predict broad changes in attention focus when anxious individuals perform postural tasks, it has been questioned as to whether ACT may be relevant for explaining the threat-related changes that are observed for less demanding postural tasks such as quiet standing (Young & Williams, 2015).

As it was unknown whether the assumptions of ACT could apply to the performance of postural tasks when anxious, Zaback et al. (2016) aimed to describe changes in attention focus in young adults standing under height-related threat. To assess where attention was directed when standing under non-threat and threat conditions, Zaback et al. (2016) used an open-ended question (i.e., "What did you think about or direct your attention toward during the balance task?") coupled with a follow-up interview. Based on participant responses, five attention focus categories were generated including attention to movement processes, task objectives, threat-related stimuli, self-regulatory strategies, and task-irrelevant information (Table 1). When threatened by surface height, individuals reported directing more attention to movement processes, threat-related stimuli, and self-regulatory strategies, and less to task objectives and task-irrelevant information (Zaback et al., 2016). Findings from this study support ACT which suggests that there is an attentional bias to threat-related stimuli and that individuals may also direct attention to other information, such as movement processes and self-regulatory strategies. Also consistent with ACT was the observation that individuals reported directing less attention to specific task objectives and task-irrelevant information, suggesting a possible impairment in processing efficiency. Interestingly, these threat-related changes in attention focus were associated with specific changes in postural control. Thus, this work showed broader changes in attention focus occur when threatened, beyond directing attention to movement processes (Huffman et al., 2009; Zaback et al., 2015). However, one limitation of this research is that the findings are only generalizable to height-related threat. It is currently unknown whether the threat-related changes in attention focus identified and their relationships to standing postural control generalize to other threat situations, which would be important to establish to provide support for ACT.

Different from what is typically observed when standing on an elevated surface, individuals anticipating a trunk perturbation (Shaw, Stefanyk, Frank, Jog, & Adkin, 2012), vibratory stimulus to the calf muscle (Holmberg, Tjernstrom, Karlberg, Fransson, & Magnusson, 2009), or aversive sound (Ishida, Saitoh, Wada, & Nagai, 2010) have demonstrated increases in postural sway amplitude. Furthermore, an individuals' prior experience with the postural threat may also modify postural control strategy (Adkin et al., 2000; Brown & Frank, 1997; Maki & Whitelaw, 1993). For example, individuals with experience of a more threatening condition demonstrated a less restrictive postural strategy (i.e., increased postural sway amplitude) compared to those who did not have this experience (Adkin et al., 2000). As daily life provides a number of movement situations that present unique threats, which can be more or less threatening depending on whether an individual has had prior experience with the threat, it is important to determine if threat-related changes in attention focus and postural control extend to other types of threat situations.

The primary objectives of this study were to quantify changes in attention focus and postural control in healthy young adults when standing with and without the expectation of a postural perturbation, and to explore if prior experience with the perturbation influences these changes. Postural threat was manipulated by changing the expectation of a postural perturbation during stance. Prior experience was defined as having previously responded to the postural perturbation. Allocation of attention to the sources

Table 1 Attention focus questions

Category	Questions
Movement processes	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.)
Task objectives	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)
Threat-related stimuli	Feelings of anxiety or worry (e.g., concern about the possibility or consequences of falling or failing at the task, etc.)
Self-regulatory strategies	Coping strategies to help remain confident, calm, and/or focused (e.g., regulated breathing, purposeful distraction, positive/relaxing thoughts, etc.)
Task-irrelevant information	Thoughts unrelated to balance task (e.g., plans for after study, events from yesterday, trivial environmental distractions, etc.)

Participants responded to five questions that probed attention focus. The following statement preceded 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:" Participants rated their responses on a 9-point Likert scale from 1 ("Not at all") to 9 ("Very much so"). The questions and the associated category (not presented to the participant) were developed from Zaback et al. (2016)

identified by Zaback et al. (2016) was quantified using Likert responses and compared between non-threat and threat conditions. It was hypothesized that when standing with the expectation of a postural perturbation, individuals would be more anxious and report allocating more attention to movement processes, threat-related stimuli, self-regulatory strategies, and less to task objectives and task-irrelevant information (Zaback et al., 2016). Similar to what is typically observed when exposed to an anticipatory threat, postural sway would increase (Shaw et al., 2012). It was also expected that prior experience with the perturbation would reduce anxiety, lessening threat-related changes in attention focus and postural control (Adkin et al., 2000). A secondary aim of this study was to explore whether threat-related changes in attention focus, as well as perceived anxiety and physiological arousal (measures typically modified in response to postural threat, Adkin, Frank, Carpenter, & Peysar, 2002; Carpenter et al., 2006; Hauck, Carpenter, & Frank, 2008; Huffman et al., 2009; Zaback et al., 2015) are related to changes in postural control. Although exploratory, it was expected that specific threat-related changes in perceived anxiety, physiological arousal, and attention focus would be associated with distinct changes in postural control (Zaback et al., 2016).

Methods

Participants

Eighty healthy young adults (50 females, 30 males) volunteered to participate in this study. The participants had a mean age of 21.7 years (SD = 3.0), height of 171.54 cm (SD = 9.65), and weight of 70.24 kg (SD = 12.11). Participants were excluded from the study if they reported any neurological or musculoskeletal condition that could influence postural control.

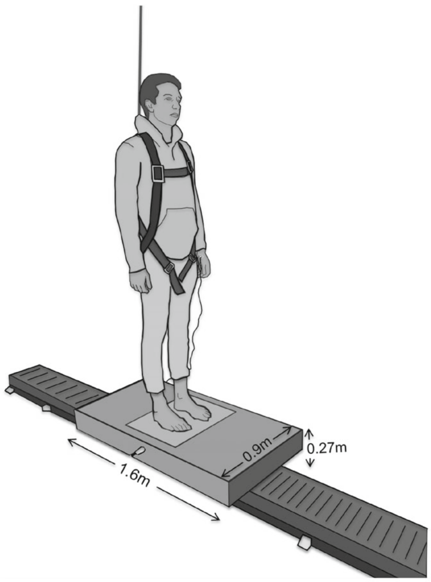
Procedures

Experimental set up

All experimental procedures were approved by the Brock University Research Ethics Board and were performed in accordance with the Declaration of Helsinki. All participants were naïve to the experimental procedure and each participant provided written informed consent prior to the start of the experiment. For all conditions, participants stood quietly on a force plate (OR6-7, AMTI, Watertown, MA, USA). The force plate was surrounded by a wooden platform (0.9-m × 1.6-m) fitted flush with its surface (Fig. 1). The force plate and wooden platform were affixed to a 4.3-m linear positioning stage (H2W Technologies Inc., Valencia, CA, USA). The total elevation of the force plate and wooden platform was 0.27-m. Participants stood barefoot with a stance width equal to their foot length, with their arms relaxed at their sides, and their gaze focused on an eye-level target located 4-m away. Participants' feet were traced on the force plate to keep stance position consistent across all conditions. Throughout the experiment, participants wore a harness attached to a track secured to the ceiling to ensure safety. The harness only provided support in the case of a fall; no falls occurred during the study.

Postural threat manipulation

Postural threat was altered by manipulating the expectation of a postural perturbation (Fig. 1). The perturbation was a temporally and directionally unpredictable support surface



Trial	Condition	Expectation of Perturbation	Delivery of Perturbation
1	No Threat	No	No
2*	Threat_{noexp}	Yes	No
3*	Threat	Yes	Yes
4*	Threat	Yes	Yes
5*	Threat_{exp}	Yes	No
6	No Threat	No	No

* For trials 2-5, there was the possibility of an unexpected postural perturbation that was unpredictable in both direction (i.e., forward or backward platform movement) and timing. Only for trials 3 and 4 was the perturbation actually delivered.

Fig. 1 Experimental set-up and postural threat conditions

translation that could occur in the forward or backward direction (displacement = 0.25 m, peak velocity = 0.9 m/s, peak acceleration = 1.7 m/s^2). Three threat conditions were created: (1) no possibility of a perturbation (No Threat), (2) possibility of a perturbation before having gained experience with the perturbation (Threat_{noexp}), and (3) possibility of a perturbation after having gained experience with the perturbation (Threat_{exp}).

First, participants completed one 30-s practice trial of quiet standing with the instruction that the platform on which they were standing would not move during the trial. This practice trial served to minimize possible first trial effects on postural control (Adkin et al., 2000) and priming effects associated with the questionnaires; data from this trial were not analyzed. Next, participants completed another 30-s quiet standing trial with the same instructions; this trial served as the first No Threat trial. Following this trial, participants visually observed the platform translate in the forward and backward directions while seated in a chair positioned away from the platform. This was done so participants could see the speed and magnitude of the perturbation without physically experiencing it. Participants then stood quietly on the platform with the instruction that the platform may translate forward or backward at any time during the trial. On the first threat trial (Threat_{noexp}), participants stood for 30-s with the expectation that the platform could move; however, the platform did not move. For the subsequent threat trials, the instructions remained the same. However, on the second and third threat trials, the platform translated forward after 10-s and backward after 15-s, respectively. Participants were not aware of the direction or timing of the perturbation. Data from these trials were not analyzed; they were only completed to give participants experience with the perturbation and encourage the belief that the perturbation could occur in the forward or backward direction at any time during the fourth threat trial. On this fourth trial (Threat_{exp}), participants stood for 30-s with the expectation that the platform could move, but it did not.

For all trials, participants were not aware of the trial duration. The number of trials conducted was limited to minimize the chance that participants would become aware of the trial duration. Immediately after each 30-s trial, participants were seated in a chair away from the platform and asked to complete questionnaires assessing state anxiety and attention focus (see "Anxiety and arousal measures" and "Attention focus measures"); this typically took 3 min to complete.

To account for a possible order effect between the postural threat conditions (as the No Threat trial was always performed first), a second No Threat trial was performed after the threat conditions were completed (Adkin et al., 2000). Similar to the first No Threat trial, participants stood for 30-s after being told explicitly that the platform would not move at any time during the trial (same instructions as first No Threat trial). Paired samples *t* tests, corrected for the number of comparisons made, were performed on all 13 dependent measures (see "Dependent measures") to determine whether the two No Threat trials were similar. As electrodermal activity (EDA) was the only measure that was significantly different between the No Threat trials (i.e., higher for the second No

Threat trial), only the first No Threat trial was used in the statistical analyses.

Dependent measures

The following dependent measures were obtained for each 30-s standing trial in the no threat and threat conditions (i.e., No Threat, $\text{Threat}_{\text{noexp}}$, and $\text{Threat}_{\text{exp}}$).

Anxiety and arousal measures

Following each 30-s standing trial, participants answered two questions that probed their perceived anxiety. Worry-related anxiety was rated on a scale ranging from 0 ("I was not at all worried") to 100 ("I was very worried") for the question "How worried were you when performing the balance task (e.g., worried about losing balance, worried about performing the task incorrectly, etc.)?", while somatic anxiety was rated on a scale ranging from 0 ("I did not feel anxious at all") to 100 ("I felt very anxious") for the question "How physically anxious (e.g., tense or nervous) did you feel when performing the balance task?". Both questions were adapted from a longer form state anxiety questionnaire used in previous experiments (Adkin et al., 2002; Hauck et al., 2008). Responses to these two questions were averaged to produce a single measure of perceived anxiety.

EDA was recorded during each trial to estimate changes in physiological arousal (EDA100C, BIOPAC Systems Inc., Goleta, USA). Two electrodes were placed on the thenar and hypothenar eminences of the non-dominant hand (Fowles et al., 1981). EDA data were A/D sampled at 1000 Hz (Micro1401, CED, Cambridge, UK) and recorded using Spike2 software (CED, Cambridge, UK). Mean EDA was calculated for each 30-s trial.

Attention focus measures

Following each 30-s standing trial, participants rated, on a 9-point Likert scale from 1 ("Not at all") to 9 ("Very much so"), how much they thought about or directed attention to information related to (1) movement processes, (2) task objectives, (3) threat-related stimuli, (4) self-regulatory strategies, and (5) task-irrelevant information. The specific questions used for each of the five attention focus categories, based on data from Zaback et al. (2016), are presented in Table 1.

Postural control measures

Ground reaction forces and moments from the force plate were sampled at 1000 Hz and low-pass filtered offline using a dual-pass second order Butterworth filter with a cut-off frequency of 5 Hz. From these data, centre of pressure (COP), which reflects the weighted average of pressure applied by the feet on the force plate, was calculated in both the anterior–posterior (AP) and medial–lateral (ML) plane. The COP reflects the involvement of the central nervous system in controlling the body's centre of mass (COM) through the generation of ankle torques in the AP plane, and lateral weight shifts in the ML plane (Winter, 1995), making it a useful measure to assess postural control during quiet standing.

Position and frequency based measures were calculated to characterize the COP signal (Adkin et al., 2000; Zaback et al., 2015). Mean position (MPOS) was calculated to determine the average location of the COP over the 30-s trial. MPOS in the AP plane was referenced to the ankle joint and reflects how much an individual leaned forward or backward, while MPOS in the ML plane was referenced to the middle of the force plate and reflects how much an individual leaned to one side or the other. MPOS was then subtracted from each COP signal to un-bias the signal prior to calculating root mean square (RMS) and mean power frequency (MPF) measures. RMS reflects the amplitude of postural adjustments over the 30-s trial. MPF reflects the average frequency of postural adjustments over the 30-s trial, calculated as the average frequency contained within the COP power spectrum after fast Fourier transformation. The combination of RMS and MPF can be used to describe the oscillatory nature of the COP and its control over the COM during quiet standing. For example, assuming the body is modeled as an inverted pendulum (Winter, 1995), an increased MPF coupled with a decreased RMS reflects an ankle stiffening strategy, which permits tighter control over the COM. Thus, there were six postural control dependent measures: AP-COP MPOS, AP-COP RMS, AP-COP MPF, ML-COP MPOS, ML-COP RMS, and ML-COP MPF.

Statistical analysis

Effects of postural threat

Descriptive statistics for anxiety, arousal, attention focus, and postural control measures were calculated for each postural threat condition. Assumptions of normality were confirmed prior to all statistical analyses. One-way repeated measures ANOVA with a within-subject factor of postural threat (No Threat, $\text{Threat}_{\text{noexp}}$, and $\text{Threat}_{\text{exp}}$) were conducted for all dependent measures. If Mauchly's test indicated that the assumption of sphericity was violated, a degrees of freedom correction using the Greenhouse–Geisser estimate was used. To correct for the number of ANOVAs conducted and control for Type I error, significance level was set at $p < 0.0038$. If the ANOVA revealed a significant effect for postural threat, follow-up comparisons were conducted to explore the differences between the No Threat, $Threat_{noexp}$, and $Threat_{exp}$ conditions. Significance level was corrected for the number of comparisons made. Of note, as initial analyses showed that sex was not a significant factor that interacted with threat for any of the dependent measures, data were collapsed between females and males.

Associations between threat-related changes in anxiety, arousal, attention focus, and postural control measures

To examine associations between anxiety, arousal, attention focus, and postural control measures, change scores between $Threat_{noexp}$ and No Threat conditions and between $Threat_{exp}$ and No Threat conditions were calculated for all dependent variables. Bivariate correlations between the $Threat_{noexp}$ and No Threat change scores and $Threat_{exp}$ and No Threat change scores were examined for multicollinearity (Table 2); no variables were considered to be highly related ($r > 0.80$; Field, 2009).

Multiple linear regressions were performed to determine if changes in anxiety, arousal, and attention focus contribute to changes in postural control between the $Threat_{noexp}$ and No Threat conditions and between the $Threat_{exp}$ and No Threat conditions. To limit the number of analyses conducted and the number of independent variables entered into each regression model, measures were only included in the regressions if a significant postural threat effect was observed. As a result, a total of six multiple linear regressions were conducted, with perceived anxiety, EDA, and attention to movement processes, threat-related stimuli, self-regulatory strategies, and task-irrelevant information as the independent variables, and AP-COP MPOS, AP-COP RMS, and AP-COP MPF as the dependent variables. Significance level was set at $p < 0.05$.

Results

Effects of postural threat

Anxiety and arousal

ANOVAs revealed a significant postural threat effect for perceived anxiety ($F(1.86, 146.95) = 198.21$, $p < 0.001$) and EDA ($F(1.68, 133.01) = 66.67$, $p < 0.001$). Follow-up comparisons between the three postural threat conditions revealed that perceived anxiety was greater and EDA was higher in the $Threat_{noexp}$ and $Threat_{exp}$ conditions compared to the No Threat condition. However, these measures were not different between $Threat_{noexp}$ and $Threat_{exp}$ conditions (Fig. 2).

Attention focus

ANOVAs revealed a significant postural threat effect for attention to movement processes ($F(1.54, 121.37) = 36.08$, $p < 0.001$), threat-related stimuli ($F(1.76,139.13) = 165.07$, $p < 0.001$), self-regulatory strategies ($F(2,158) = 9.44$, $p < 0.001$), task-irrelevant information ($F(1.28, 100.87) = 32.65$, $p < 0.001$), but not task objectives ($F(2,158) = 1.42$, $p = 0.243$). Compared to the No Threat condition, individuals reported directing more attention to movement processes, threat-related stimuli, and self-regulatory strategies, and less attention directed to task-irrelevant

Table 2 Bivariate correlations for threat-related change scores

Variable	1	2	3	4	5	6	7	8	9
(1) Anxiety	–	0.117	0.240*	0.649**	− 0.030	− 0.198	− 0.122	0.393**	− 0.244*
(2) EDA	0.226*	–	− 0.003	0.099	0.006	− 0.111	− 0.205	0.070	− 0.021
(3) Movement processes	0.370**	0.090	–	0.252*	0.151	0.201	0.050	0.117	− 0.068
(4) Threat-related stimuli	0.765**	0.164	0.293**	–	0.153	− 0.145	− 0.054	0.163	− 0.090
(5) Self-regulatory strategies	0.305**	0.184	0.263*	0.282*	–	0.114	0.110	0.081	− 0.009
(6) Task-irrelevant information	− 0.192	− 0.040	0.121	− 0.228*	0.132	–	− 0.030	− 0.101	− 0.154
(7) AP-COP MPOS	0.021	0.116	0.278*	− 0.003	0.224*	− 0.086	–	0.167	− 0.071
(8) AP-COP RMS	0.376**	0.126	0.411**	0.313**	0.198	− 0.018	0.237*	–	− 0.222*
(9) AP-COP MPF	− 0.190	0.172	0.084	− 0.188	0.192	0.028	− 0.058	− 0.231*	–

Change scores between No Threat and $Threat_{noexp}$ shown above the diagonal; Change scores between No Threat and $Threat_{exp}$ shown below the diagonal

EDA electrodermal activity, *AP* anterior–posterior, *COP* centre of pressure, *MPOS* mean position, *RMS* root mean square, *MPF* mean power–frequency

* $p < 0.05$, ** $p < 0.01$

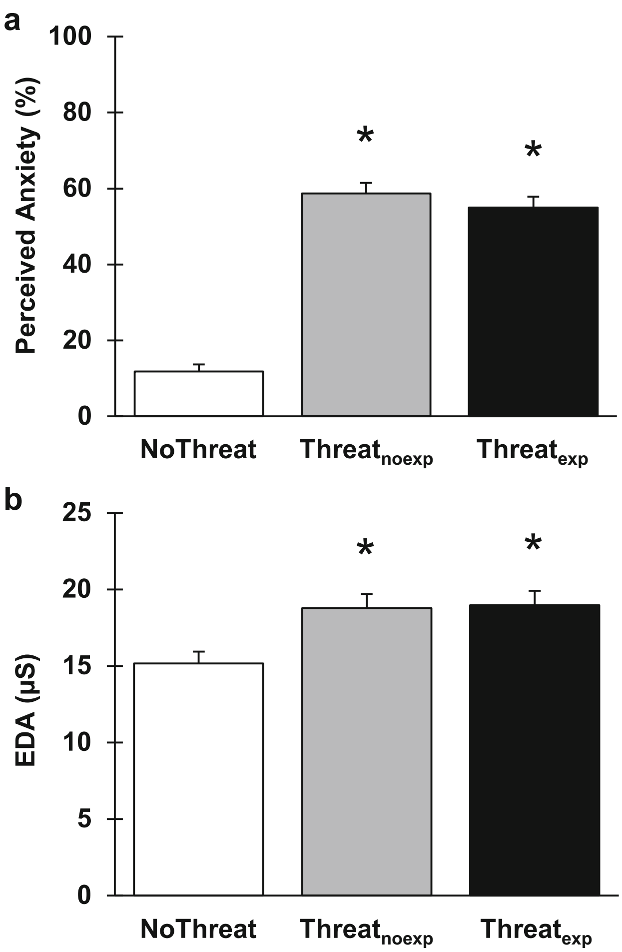


Fig. 2 Main effect of postural threat on perceived anxiety (**a**) and EDA (**b**) measures. Error bars represent the standard error of the mean. Asterisk reflects a condition significantly different from the No Threat condition

information in the $\text{Threat}_{\text{noexp}}$ and $\text{Threat}_{\text{exp}}$ conditions. These attention focus measures were not different between $\text{Threat}_{\text{noexp}}$ and $\text{Threat}_{\text{exp}}$ conditions (Fig. 3).

Postural control

ANOVAs revealed a significant postural threat effect for AP-COP MPOS ($F(2, 158) = 35.68$, $p < 0.001$), AP-COP RMS ($F(1.79, 141.29) = 13.40$, $p < 0.001$), AP-COP MPF ($F(1.79, 141.77) = 43.35$, $p < 0.001$), but not ML-COP MPOS ($F(1.69, 133.61) = 0.18$, $p = 0.803$), ML-COP RMS ($F(2, 158) = 2.74$, $p = 0.068$), or ML-COP MPF ($F(2, 158) = 2.07$, $p = 0.130$). AP-COP MPOS was shifted forward, AP-COP RMS was larger, and AP-COP MPF was greater in the $\text{Threat}_{\text{noexp}}$ and $\text{Threat}_{\text{exp}}$ conditions compared to the No Threat condition. Differences were also observed between the $\text{Threat}_{\text{noexp}}$ and $\text{Threat}_{\text{exp}}$ conditions, with greater increases in AP-COP MPF and smaller increases in AP-COP RMS observed for the $\text{Threat}_{\text{exp}}$ compared to the $\text{Threat}_{\text{noexp}}$ condition (Fig. 4).

Associations between threat-related changes in anxiety, arousal, attention focus, and postural control measures

The results of the multiple linear regressions are presented in Table 3. The regressions for threat-related changes between the $\text{Threat}_{\text{noexp}}$ and No Threat conditions revealed that changes in anxiety, arousal, and attention focus significantly accounted for changes in AP-COP RMS ($R^2 = 0.189$, $F(6, 73) = 2.83$, $p = 0.016$), but not AP-COP MPOS ($R^2 = 0.077$, $F(6, 73) = 1.02$, $p = 0.421$) or AP-COP MPF ($R^2 = 0.111$, $F(6, 73) = 1.53$, $p = 0.182$). Perceived anxiety changes emerged as the only significant variable to account for AP-COP RMS changes; a larger increase in perceived anxiety between $\text{Threat}_{\text{noexp}}$ and No Threat conditions was associated with a larger increase in AP-COP RMS ($\beta = 0.511$, $p = 0.001$).

For the threat-related changes between the $\text{Threat}_{\text{exp}}$ and No Threat conditions, the regressions revealed that anxiety, arousal, and attention focus changes significantly accounted for changes in AP-COP MPOS ($R^2 = 0.165$, $F(6, 73) = 2.40$, $p = 0.036$), AP-COP RMS ($R^2 = 0.231$, $F(6, 73) = 3.66$, $p = 0.003$), and AP-COP MPF ($R^2 = 0.173$, $F(6, 73) = 2.54$, $p = 0.027$). A larger increase in attention directed to movement processes between the $\text{Threat}_{\text{exp}}$ and No Threat conditions was associated with a greater forward shift in AP-COP MPOS ($\beta = 0.320$, $p = 0.009$) and a larger increase in AP-COP RMS ($\beta = 0.310$, $p = 0.008$), whereas a larger increase in attention directed to self-regulatory strategies between the $\text{Threat}_{\text{exp}}$ and No Threat conditions was associated with a larger increase in AP-COP MPF ($\beta = 0.255$, $p = 0.033$).

Discussion

The results of this study extend our understanding of how different types of postural threat modify attention focus and postural control. When threatened (i.e., anticipating a postural perturbation), individuals were more anxious, and reported directing more attention to threat-related stimuli, movement processes, and self-regulatory strategies, and less attention to task-irrelevant information. Individuals leaned forward and demonstrated increased amplitude and frequency of postural sway when threatened. However, individuals modified this strategy after physically experiencing the postural perturbation; larger increases in sway frequency and smaller increases in sway amplitude were observed after experiencing the

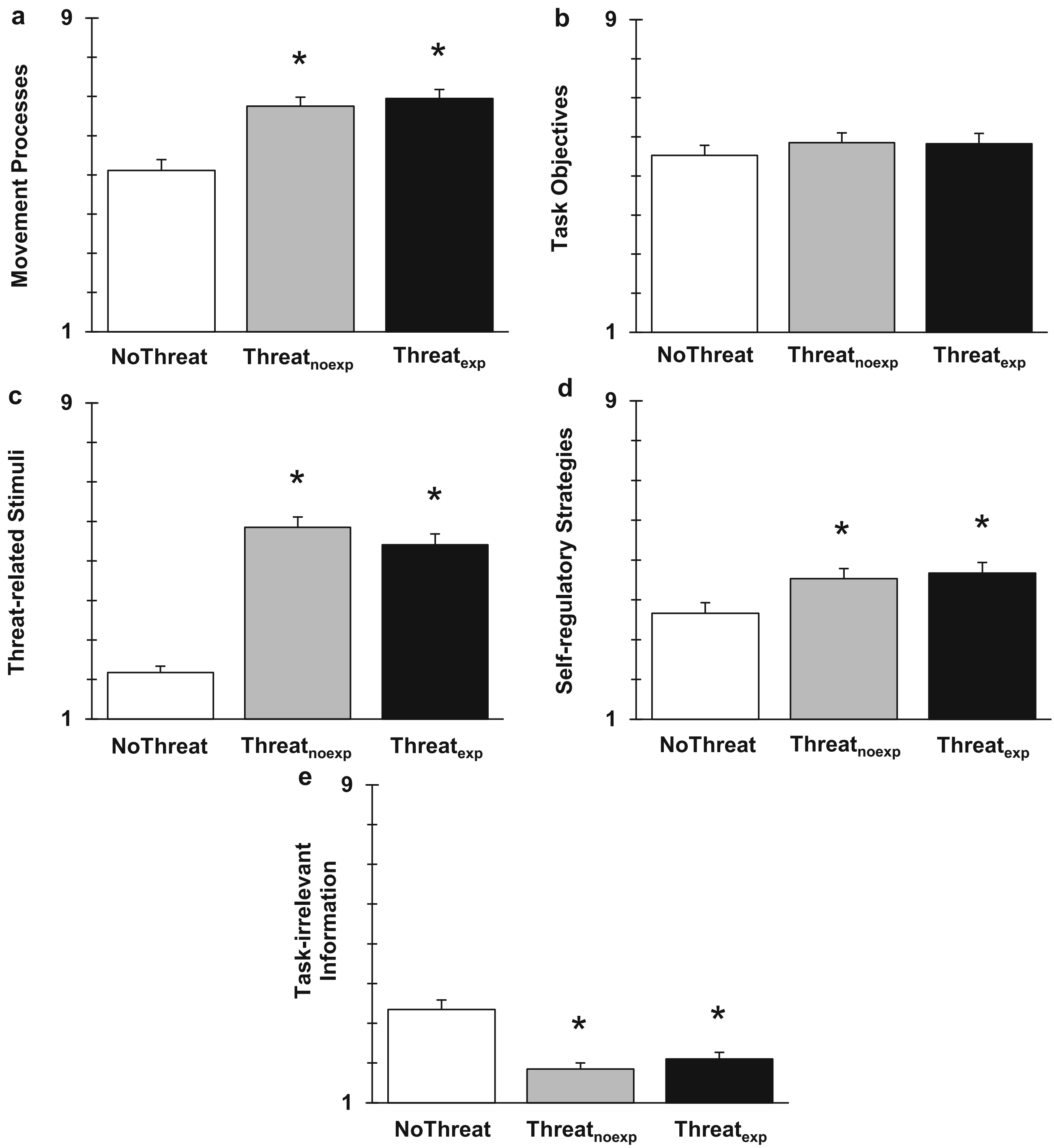


Fig. 3 Main effect of postural threat on attention to movement processes (**a**), task objectives (**b**), threat-related stimuli (**c**), self-regulatory strategies (**d**), and task-irrelevant information (**e**). Error bars represent the standard error of the mean. Asterisk reflects a condition significantly different from the No Threat condition

perturbation. This study also showed that threat-related changes in anxiety, arousal, and attention focus were associated with changes in postural control, with these relationships dependent on experience with the threat. Change in anxiety was the strongest contributor to threat-related changes in postural control before perturbation experience, and changes in attention focus were the strongest contributors after perturbation experience. These results provide evidence that changes in anxiety and attention focus may contribute to threat-related changes in postural control, with these relationships dependent on whether an individual has had prior experience with the threat.

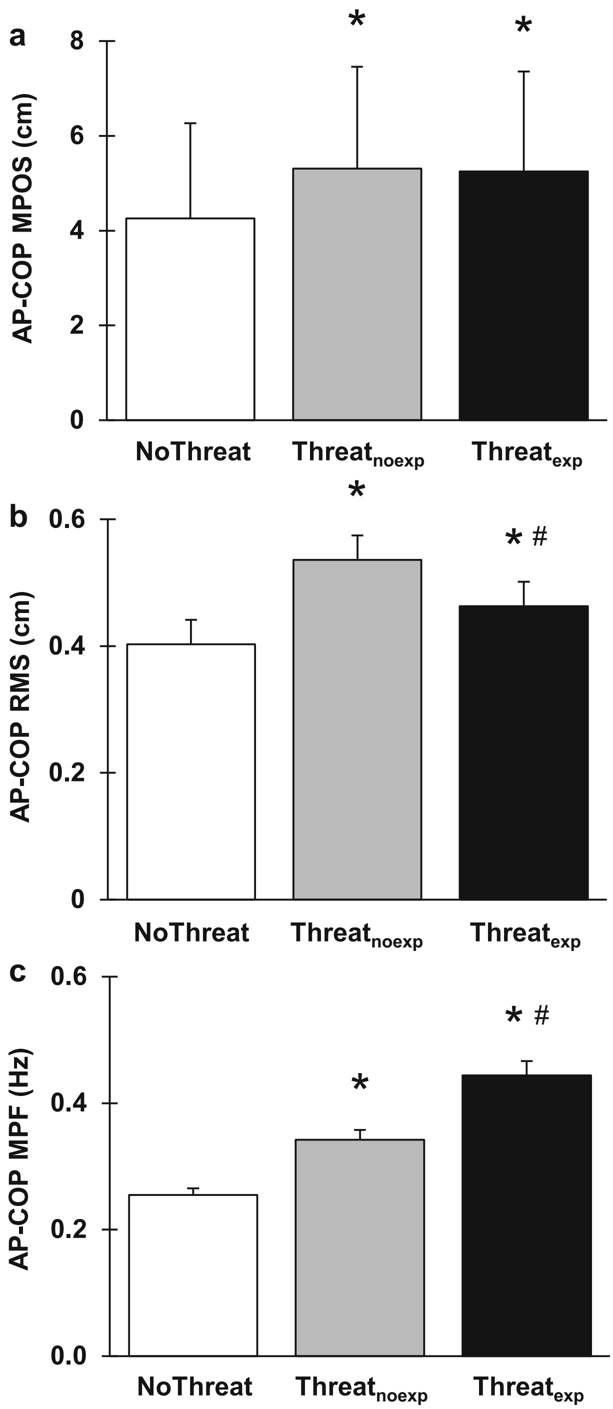


Fig. 4 Main effect of postural threat on AP COP MPOS (**a**), RMS (**b**), and MPF (**c**). Error bars represent the standard error of the mean. Asterisk reflects a condition significantly different from the No Threat condition, while a hash symbol reflects a condition significantly different from the $Threat_{noexp}$ condition

Threat-related changes in arousal and anxiety

Similar to what has been observed when standing at the edge of an elevated surface (Adkin et al., 2002; Carpenter et al., 2006; Hauck et al., 2008; Huffman et al., 2009; Zaback et al., 2015), individuals reported being more anxious and had higher physiological arousal (as indicated by higher EDA levels) when anticipating a support surface perturbation. The observed changes in anxiety and arousal in the current study suggest anticipating this type of perturbation can alter an individual's physiological arousal level and emotional state, and supports the use of this model to explore threat-related changes in attention focus and postural control. Importantly, physiological arousal and emotional state were manipulated without the individual needing to experience the perturbation, which has methodological implications for the ability to assess these influences on postural control in populations where an actual perturbation may pose a considerable risk.

Threat-related changes in attention focus

This study was the first to quantify changes in attention focus when standing with and without a direct threat to stability, reflecting a situation that may be encountered during many of our daily activities. When anticipating a support surface perturbation, individuals reported directing more attention to threat-related stimuli, movement processes, and self-regulatory strategies, less attention to task-irrelevant information, and reported no change in attention directed to task objectives. These findings, for the most part, are consistent with the assumptions of ACT, as individuals were more attentive to threat-related stimuli and employed alternative processing strategies (i.e., attention to movement processes, attention to self-regulatory strategies) presumably in an attempt to compensate for these attentional changes.

As expected based on previous research using height-related threat (Zaback et al., 2016), individuals reported directing more attention to threat-related stimuli when anticipating a support surface perturbation. These anxious feelings and thoughts are in most cases not present in the No Threat condition as individuals are simply not anxious; however, once threatened, these feelings and thoughts become present and are highly attended. Other research has also shown that anxious individuals direct attention to threat-related stimuli (Bar-Haim, Lamy, Pergamin, Bakermans-Kranenburg, & van IJzendoorn, 2007; Staab, Balaban, & Furman, 2013). Based on the assumptions of ACT, an attentional bias to threat-related stimuli may perpetuate feelings of anxiety and distract attention from task-relevant information (Eysenck et al., 2007). While an inability to withdraw attention from threat-related stimuli has the potential to compromise task performance, ACT also predicts that individuals are more likely to invest additional on-task effort and employ alternate processing strategies to compensate for negative effects associated with increased

Table 3 Overall model R^2, and beta values for each variable for each of the six multiple linear regressions

	Change between $Threat_{noexp}$ and No Threat			Change between $Threat_{exp}$ and No Threat		
	AP-COP MPOS	AP-COP RMS	AP-COP MPF	AP-COP MPOS	AP-COP RMS	AP-COP MPF
Perceived anxiety	− 0.140	**0.511***	**− 0.368***	− 0.134	0.203	− 0.272
EDA	− 0.201	0.025	− 0.013	0.088	0.037	0.194
Movement processes	0.088	0.037	0.038	**0.320***	**0.310***	0.157
Threat-related stimuli	0.003	− 0.208	0.111	− 0.119	0.050	− 0.153
Self-regulatory strategies	0.105	0.128	− 0.018	0.225	0.035	**0.255***
Task-irrelevant information	− 0.109	− 0.049	− 0.218	− 0.204	− 0.008	− 0.104
Model R^2	0.077	**0.189***	0.111	**0.165***	**0.231***	**0.173***

An asterisk and bold font reflects significant model or beta value

No Threat no perturbation threat, *Threat_{noexp}* threat without perturbation experience, *Threat_{exp}* threat with perturbation experience, *EDA* electrodermal activity, *AP* anterior–posterior, *COP* centre of pressure, *MPOS* mean position, *RMS* root mean square, *MPF* mean power–frequency

anxiety in an attempt to preserve task performance (Eysenck et al., 2007). However, depending on the characteristics of the task, these alternate processing strategies may not be effective.

The finding that individuals reported directing more attention to movement processes when anticipating a support surface perturbation is consistent with reports of more conscious monitoring of movement observed in response to height-related threat (Huffman et al., 2009; Zaback et al., 2016). Although this attentional strategy may serve to minimize the risk of instability should the platform actually move, directing attention resources to movement may interfere with otherwise automatic processes involved in postural control (Masters & Maxwell, 2008; Wulf, 2013; Wulf, McNevin, & Shea, 2001; Wulf & Prinz, 2001; Young & Williams, 2015), resulting in movement that is less efficient (Vuillerme & Nafati, 2007). Individuals also reported directing more attention to self-regulatory strategies when anticipating a support surface perturbation, supporting what has been observed when standing at height (Zaback et al., 2016). If used appropriately, these strategies can ameliorate threat-related anxiety (Wilson, 2008; Webb, Miles, & Sheeran, 2012), potentially limiting changes in postural control. However, not all forms of self-regulation are equally effective (Webb et al., 2012), and research suggests these strategies may need to be trained before they can be used effectively (Oudejans & Pijpers, 2010).

Individuals also reported directing attention away from task-irrelevant information, supporting what has been demonstrated when individuals stand at height (Zaback et al., 2016). When threatened, irrelevant thoughts may be set aside as attention is directed to other sources more relevant to the task at hand (i.e., threat-related stimuli, movement processes, self-regulatory strategies). However, contrasting the findings of Zaback et al. (2016), individuals reported no change in the amount of attention they directed toward task objectives. This disparity may be explained by the nature of the questionnaire used in the current study (i.e., Likert responses compared to source(s) listed in response to an open-ended question that summed to 100% Zaback et al., 2016). Standing at the edge of an elevated platform may also impose a greater cognitive demand than standing with the anticipation of a perturbation, attributing this difference in attention to the context associated with the threat.

In the current study, while performing a task with low cognitive demands (i.e., quiet standing), individuals may have increased overall cognitive effort to maintain adequate focus on the task despite reallocating attention to monitor other aspects of the situation (i.e., threat-related stimuli, movement processes, self-regulatory strategies) when anxious. According to ACT, enhancing cognitive effort to meet the demands of the task coincides with a reduction in processing efficiency (Eysenck et al., 2007). While this may be less consequential during the performance of tasks with low cognitive demands, these cognitive changes may have more noticeable effects during challenging and more dynamic postural tasks. Kahneman's spare-utilized capacity threading model of attention dictates that as individuals actively engage in task-related mental operations, spare capacity is mobilized to utilized capacity, resulting in a decreased attentional capacity for the purpose of monitoring (Kahneman, 1973). Based on the predictions of ACT and Kahneman's theory of attention, a performance trade-off may accompany these cognitive changes during tasks that place greater demands on working memory. Future research should aim to describe changes in attention when performing more complex postural tasks under postural threat (Young & Williams, 2015).

Threat-related changes in postural control

Individuals leaned forward when anticipating a support surface perturbation. While it is advantageous for individuals standing on an elevated surface to lean away from the edge (Adkin et al., 2000; Carpenter et al., 1999, 2001; Huffman et al., 2009; Zaback et al., 2015), leaning forward may be more appropriate in this context as this strategy has been shown to efficiently counteract both forward and backward body movement in response to platform perturbations (Maki & Whitelaw, 1993). In addition, with no restrictions placed on the recovery strategy, a forward lean may facilitate compensatory stepping to recover balance. Leaning forward has been observed when standing and performing a math task in anxious healthy young adults, with leaning further forward related to higher arousal levels (Maki & McIlroy, 1996). Fearful older adults with a history of falls have also been shown to lean forward during quiet stance (Maki, Holliday, & Topper, 1994).

Individuals demonstrated greater amplitude and frequency of postural adjustments when anticipating a support surface perturbation compared to standing without this expectation. These changes in postural sway support previous research that has shown increases in postural sway when exposed to an anticipatory threat (Shaw et al., 2012; Ishida et al., 2010; Holmberg et al., 2009). This postural strategy may allow the body to rapidly respond to a perturbation and facilitate stepping to recover balance (Shaw et al., 2012). This postural strategy differs from what is seen with height-related threat, under which conditions there is typically an increase in sway frequency, but a reduction in sway amplitude (Adkin et al., 2000; Brown et al., 2006; Carpenter et al., 1999, 2001, 2006; Zaback et al., 2015). However, individuals standing at height have also demonstrated either no change (Huffman et al., 2009; Stins, Roerdink, & Beek, 2011), or in the case of individuals reporting a robust fear response (Davis, Campbell, Adkin, & Carpenter, 2009), individuals standing at heights greater than 9-m (Alpers & Adolph, 2008; Nakahara, Takemori, & Tsuruoka, 2000; Simeonov & Hsaio, 2001), and individuals prone to reinvest in their movement (Zaback et al., 2015), an increase in sway amplitude. Further, fearful older adults and individuals with anxiety disorders have also been shown to sway at larger amplitudes compared to non-fearful older adults and healthy controls, respectively (Maki, Holliday, & Topper, 1991; Perna et al., 2001).

Differences in threat-related postural changes with experience

There was also an observed change in postural strategy between the two threat conditions. When anticipating the movement of the platform without prior experience, individuals demonstrated an increased frequency and amplitude of postural adjustments compared to standing under no threat. However, after experience with the perturbation, sway frequency increased further but sway amplitude decreased. This supports previous research, suggesting that experience with postural threat may influence postural control during quiet standing (Adkin et al., 2000; Maki & Whitelaw, 1993). It also appears to be consistent with research suggesting that a platform perturbation with unknown magnitude and velocity produces an overcompensated initial postural response, and that the amplitude of this response may be reduced with practice or exposure in healthy young adults (Horak, Diener, & Nashner, 1989; McIlroy & Maki, 1995). After experiencing the perturbation in the current study, individuals may acquire more specific information regarding the magnitude and velocity of the perturbation (i.e., compared to only a visual observation of the platform movement), thereby contributing to changes in postural sway when anticipating the perturbation.

Associations between threat-related changes in anxiety, arousal, attention focus, and postural control measures

As little is known about the relationships between threat-related changes in anxiety, arousal, attention focus, and postural control, this study explored these associations. When standing under a condition of threat without experience, changes in sway amplitude were accounted for by changes in perceived anxiety. While research has reported threat-related changes in sway amplitude, these changes have not typically been associated with changes in perceived anxiety (Hauck et al., 2008; Huffman et al., 2009). However, greater postural sway has been shown to be related to higher levels of state anxiety in healthy young adults (Ohno, Wada, Saitoh, Sunaga, & Nagai, 2004).

Interestingly, when standing under a condition of threat with experience, attention focus measures were the only variables to be associated with changes in postural control. In this threat condition, larger increases in attention to movement processes were associated with leaning further forward and swaying at greater amplitudes. Leaning has been associated with conscious monitoring of posture in response to height-related threat, although in the opposite direction (Huffman et al., 2009). Individuals who are more prone to consciously monitor their movements have also been shown to sway at greater amplitudes when threatened (Zaback et al., 2015). Furthermore, a larger increase in attention to self-regulatory strategies was associated with greater increases in sway frequency. The nature of this relationship is unclear as it would be expected that attempts to self-regulate would limit threat-related changes in sway. However, since different self-regulatory strategies have been shown to vary in their effectiveness (Webb et al., 2012) and may require training (Oudejans & Pijpers, 2010), it is possible that individuals had a tendency to use maladaptive or ineffective strategies.

These relationships identified between threat-related changes in anxiety, arousal, attention focus, and postural control may provide important information for developing strategies for assessment and training of postural control in threatening situations. This information may also provide insight for the design of future studies to test the assumptions of ACT (e.g., to determine if providing specific attention focus instructions to anxious individuals can improve postural task performance; Young & Williams, 2015).

Limitations

There are limitations to this study that should be acknowledged. First, threat-related changes in attention focus and postural control were limited to quiet standing; the effects of these changes on postural reactions to the perturbation were not examined due to the few number of perturbation trials performed. Second, it is possible that the attention focus questionnaire used in the present study was unable to comprehensively assess attention focus. Some evidence suggests individuals have poor recollection of information they clearly used when completing some tasks (Moore & Egeth, 1998). However, because the trials of quiet standing were kept brief (30-s) and questionnaires were completed immediately after each trial, it is assumed that individuals were able to adequately recall salient thought processes (Ericsson & Simon, 1993; Ericsson, 2006). On a similar note, the use of self-report measures to describe changes in attention focus and anxiety are potentially susceptible to expectation and desirability bias. Third, attention focus categories were limited to those described by Zaback et al. (2016) which were identified using height-related threat; it is possible that unique attention focus categories may emerge depending on the nature of the threat. While this may be the case, an open-ended question (“Was there anything else that you focused on or thought about when doing the balance task?”) was used in this study and did not provide any additional sources of information that individuals reported directing their attention toward. Fourth, although the results of this study provide further understanding of the changes that occur across broad categories of attention when threatened, specific attention strategies were not determined. For example, although there was a shift to more attention to movement processes in general, it is unclear where this attention was focused (e.g., pressure under the feet, movement of the ankle, trunk or head, etc.). Finally, measurement error and correlations between independent variables are known to influence the power and precision of regression models (Green, 1991; Maxwell, 2000). Since measures of COP are only moderately reliable when sampled for 30-s (Carpenter, Frank, Winter, & Peysar, 2001), and some covariation (Table 2) was observed between independent variables (albeit within an acceptable level), the regression coefficients should be interpreted with caution. In addition, a limitation of the regression analyses is that the directions of the relationships are unclear. For example, it could not be determined if individuals swayed at larger amplitudes because they directed attention to their movements, or if their larger amplitude sway caused them to direct more attention to their movements.

Conclusion

This study was the first to quantify changes in attention focus under a direct threat to stability, extending previous findings observed in response to height-related threat. Significant changes in anxiety, arousal, attention focus, and postural control were observed when anticipating a support surface perturbation both before and after it had been experienced. Before the perturbation was experienced, changes in sway amplitude were accounted for by changes in anxiety. After the perturbation was experienced, changes in mean position, sway amplitude, and sway frequency were accounted for by changes in attention focus. This work improves our understanding of how the nature of threat influences anxiety, attention, and postural control. Future work should explore how threat-related changes in anxiety, arousal, and attention focus influence postural control strategies for more challenging task situations and in different populations (e.g., older adults with and without a fear of falling, and people with balance problems).

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Compliance with ethical standards

Conflict of interest Kyle Johnson declares that he has no conflict of interest. Martin Zaback declares that he has no conflict of interest. Craig Tokuno declares that he has no conflict of interest. Mark Carpenter declares that he has no conflict of interest. Allan Adkin declares that he has no conflict of interest.

Ethical approval All procedures performed in studies involving human participants were in accordance with the ethical standards of the institutional and/or national research committee and with the 1964 Helsinki declaration and its later amendments or comparable ethical standards.

Informed consent Informed consent was obtained from all individual participants included in the study.

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