Title: Fear of falling alters anticipatory postural control during cued gait initiation

Toby J. Ellmers Ph.D[ab]
Amy Maslivec Ph.D[c]
William R. Young Ph.D[ad]

[a] *College of Health and Life Sciences, Brunel University London, UK*
[b] *Institute of Environment, Health and Societies, Brunel University London, UK*
[c] *Department of Surgery & Cancer, Faculty of Medicine, Imperial College London, UK*
[d] *School of Sport and Health Sciences, University of Exeter, UK*

Corresponding author: Toby Ellmers
Email address: toby.ellmers@brunel.ac.uk

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Abstract

Fear of falling can have a profound influence on anticipatory postural control during dynamic balance tasks (e.g., rise-to-toes and leg-raise tasks), with fearful individuals typically exhibiting postural adjustments of smaller magnitudes prior to movement onset. However, very little is known about how fear of falling influences the generation of anticipatory postural adjustments (APAs) during gait initiation; a task in which producing smaller APAs may compromise stability. Sixteen young adults initiated gait as fast as possible following an auditory cue during two conditions: Baseline (ground level), and Threat (fear of falling induced via a platform raised 1.1 metres). While the magnitude and duration of APAs did not change between conditions, participants executed steps of shorter lengths during Threat. As APAs during gait initiation are typically proportionate to the length of the first step, the APAs during Threat are therefore disproportionately large (given the shorter step length). We suggest that such failure to scale the APA to the magnitude of the motor output represents a fear-related ‘overcompensation’, whereby fearful participants sought to ensure that the APA was sufficient for ensuring that their centre of mass was positioned above the support leg prior to gait initiation. During conditions of threat, participants also exhibited greater postural sway prior to initiating gait (i.e., following the auditory cue) and took longer to generate the APA (i.e., impaired reaction). As greater reaction times during voluntary stepping is consistently associated with increased fall-risk, we suggest this as one mechanism through which fear of falling may reduce balance safety.

Key Words: Anxiety; Emotion; Postural threat; Anticipatory postural adjustment; Postural sway; Stepping

Introduction

Humans experience frequent disturbances to the equilibrium of vertical posture (Maki and McIlroy, 1997; Santos et al., 2010a, 2010b). These disturbances can manifest as either external perturbations (such as slipping on an icy pavement) or internal, self-initiated movements (such as reaching forwards to grasp an item from a cupboard). To minimise a loss of stability resulting from these perturbations, humans utilise rapid, coordinated postural adjustments that can be classified as either 'anticipatory' or 'compensatory' (Maki and McIlroy, 1997; Santos et al., 2010a, 2010b). In instances where the perturbation is generated internally, or when an external perturbation is anticipated, the human body will use anticipatory postural adjustments (APA) *prior* to perturbation onset, in an attempt to minimise the destabilising impact of the postural disturbance (Aruin and Latash, 1995; Li and Aruin, 2007; Maki and McIlroy, 2007; Santos et al., 2010a, 2010b). If, however, the perturbation is unexpected—or, if the perturbation is too large to be corrected solely by an APA—individuals will initiate compensatory postural adjustments (CPA) *after* the perturbation has occurred (Maki and McIlroy, 2007; Weerdesteyn et al., 2008; Santos et al., 2010a, 2010b). Thus, while CPAs reflect a programmed neuromuscular response to a loss of equilibrium, APAs are initiated to minimise the possibility that a loss of equilibrium will occur at all (Maki and McIlroy, 2007; Weerdesteyn et al., 2008).

Generating an appropriate APA is critical to maintaining stability during a range of self-generated movements, including stepping (Hyodo et al., 2012), upper limb reaching (Friedli et al., 1988; Balasubramaniam and Wing, 2002), as well as grasping (and subsequently pulling) an object (Elble and Leffler, 2000). The effective generation of APAs is negatively influenced by both ageing (Elble and Leffler, 2000; Kubicki et al., 2015; Lee et al., 2015) and neurological disease, such as Parkinson's (Elble and Leffler, 2000). Typically, older adults and individuals with Parkinson's Disease will both 'under-respond'; that is, they will generate APAs of smaller magnitudes than which are required to effectively counteract the magnitude of the postural disturbance (Weeks, 1994; Błaszczyk et al., 1997; Ustinova et al., 2004). These individuals appear to have particular difficulty effectively generating APAs when initiating gait from a stationary position. For example, when initiating gait in response to an external cue, older adults—particularly those deemed to be at a high-risk of falling—and individuals with Parkinson's Disease are slower to initiate the APA, subsequently exhibiting APAs of smaller amplitudes but longer durations (Halliday et al., 1998; Melzer et al., 2007, 2009, 2010; Hass et al., 2008; Callisaya et al., 2016; Tisserand et al., 2016).

Gait initiation, while a common requirement for everyday living, requires the complex integration of neural, physiological and biomechanical factors (Halliday et al., 1998). The stable initiation of gait is characterised by a stereotyped postural adjustment (see Fig. 1 and 2) involving an initial lateral (and posterior) weight shift towards the swing/stepping leg (the 'APA' phase). This APA serves to subsequently propel the centre of mass (COM) laterally towards the stance/support leg (the 'weight transfer' or 'unloading' phase) (Naugle et al., 2011). A sufficient APA during gait initiation ensures that the COM is repositioned above the new base of support (the stance/support leg), preventing the body from toppling towards the swing leg following the transition from a bipedal to unipedal stance once gait has been initiated (Yiou et al., 2016). Conversely, if the APA is insufficient (i.e., if the lateral APA is too small to effectively reposition the COM above the stance/support leg), the walker will be required to compensate for this reduction in stability—typically, by stepping more laterally with the foot that is initiating gait and thus widening the base of support (Zettel et al., 2002). However, these compensatory behaviours may not always be effective for re-establishing postural stability, nor may the constraints of the task (e.g., time restrictions) or the characteristics of the individual (e.g., level of mobility or functional balance) allow for such compensatory mechanisms to be triggered in the first place (Yiou et al., 2016). Given the clear link between increased fall-risk and the generation of inappropriate APAs during gait initiation (Melzer et al., 2007, 2009, 2010; Callisaya et al., 2016), there is a need to explore the factors which can disrupt anticipatory postural control during this task.

Fear of falling—a commonly reported occurrence in both older adults (Hadjistavropoulos et al., 2011) and individuals with Parkinson's Disease (Jonasson et al., 2018)—has been highlighted as one potential mechanism underlying disrupted APA generation. For example, APAs of reduced velocity and magnitude have been reported in young adults completing a rise-to-toes task while standing on the edge of a platform raised 1.6m above ground, and thus experiencing fear of falling (Adkin et al., 2002; Zaback et al., 2015). Interestingly, while Adkin et al. (2002) observed behaviours indicating more cautious postural adjustments (smaller, slower movements) when at height, participants exhibited more frequent movement failures when performing the rise-to-toes task (following the APA). The authors concluded that when individuals are fearful about falling, "[...] it appears that the CNS [central nervous system] will employ a more cautious strategy to ensure safety during voluntary movement, even one that may place the completion of the movement at risk" (Adkin et al., 2002, p. 168). Similarly, in another study, Zaback et al. (2016) found that individuals who reported greater attention directed toward anxiety-related threatening stimuli were more likely to show larger decreases in APA magnitudes when performing a rise-to-toes task at height. Comparable reductions in APA amplitude have also been reported in participants raising their leg towards the edge of an elevated platform, with these reductions also accompanied by an increase in APA duration (Yiou et al., 2011; Gendre et al., 2016). The authors proposed that these behaviours may reflect a tighter control of the COM designed to minimise the likelihood of falling—with increased APA duration thus representing an adaptive mechanism designed to compensate for the reduction in movement amplitude.

These findings imply that individuals fearful of falling will adopt more cautious patterns of postural adjustments (i.e., smaller adjustments of increased duration) aimed at minimising postural disturbances during the APA itself. However, as this research did not explore APAs during stepping tasks, it remains unknown whether individuals fearful of falling will adopt the same cautious patterns of APAs (i.e., smaller APA magnitudes) when initiating gait—given that doing so will likely jeopardise stability and safety (Yiou et al., 2016). Thus, while APAs of reduced magnitudes *have* been reported during gait initiation in individuals deemed to be at a high-risk of falling (Halliday et al., 1998; Hass et al., 2008; Tisserand et al., 2016), it is possible that these altered APAs are simply a consequence of impaired postural control (e.g., smaller lateral/backwards shift to ensure their COM doesn't approach their reduced limits of stability), rather than altered psychological state.

While this previous work did not explore the effects of fear of falling on APAs during stepping tasks, it is nonetheless well-documented that anticipatory postural control during gait initiation is influenced by the walker's emotional state (Naugle et al., 2011; Stins and Beek, 2011; Bouman et al., 2015; Bouman and Stins, 2018). For example, negative affect induced by the presentation of unpleasant images during gait initiation has been reported to result in an initial 'freezing' response (i.e., reduced postural sway prior to APA initiation) (Stins and Beek, 2011), followed by the generation of smaller APAs of reduced velocity (Naugle et al., 2011). Other research has reported associations between smaller APAs during gait initiation and greater arousal, irrespective of whether this increased arousal was accompanied by positive or negative affect (Bouman et al., 2015). However, as these studies have confined explorations primarily to emotional states induced by viewing negatively valenced images unrelated to gait/balance, it is difficult to translate these findings to individuals fearful of falling for whom the threat (of falling) will be inherently related to the gait task being performed. While Uemura et al. (2012) have described prolonged lateral APAs during gait initiation in older adults reporting greater fear of falling, this work failed to explore how fear of falling influences the magnitude of postural adjustments, instead restricting analyses to the temporal components of the APA. Furthermore, the cross-sectional design of this work also makes it difficult to ascertain causality.

The aim of the present research was to therefore examine the influence of experimentally-induced fear of falling (standing on a narrow elevated walkway without a safety harness) on anticipatory postural control during gait initiation. As the raised walkway represented a bi-lateral threat (participants could experience a fall in both the medio-lateral and posterior direction), we predicted that fearful participants would adopt a cautious postural strategy, favouring smaller anticipatory postural adjustments of increased durations. Specifically, we predicted that fearful participants would display: (1) A ‘freezing’ response characterised by reduced postural sway following the auditory cue (and prior to APA onset), (2) increased APA latency (i.e., increased time between the auditory cue and APA onset), (3) reduced APA amplitude in both posterior and lateral direction (i.e., APAs of smaller magnitudes), (4) prolonged APA duration, and (5) smaller first step lengths (following gait initiation). Given that almost 50% of older adult falls can be attributed to an incorrect transfer or shift of bodyweight (Robinovitch et al., 2013), identifying factors which can impact postural adjustments during the initiation of gait is of high importance.

Experimental Procedures

Participants

Previous research exploring the effects of experimentally-induced postural threat on APA characteristics has reported large effect sizes for key, comparable variables (Yiou et al., 2011). Consequently, a power analysis determined that 12 participants would be required to obtain 80% power to detect a similarly large effect with a paired samples *t*-test. Sixteen young adults (female/male: 8/8; mean ± SD age: 25.88 ± 2.76 years) were subsequently recruited from postgraduate courses at the lead institution. Participants were free from any musculoskeletal or neurological impairment. Ethical approval was obtained by the local ethics committee and the research protocol was carried out in accordance with the principals laid down by the Declaration of Helsinki. All participants provided written and informed consent.

Protocol

Participants stood barefoot on a force platform, with their feet shoulder-width apart and their eyes closed (in order to prevent participants becoming desensitised to the threat manipulation [see below for description] prior to gait initiation). The force platform was mounted in a wooden walkway (length = 3.3m; width = 0.4m). Participants were instructed to open their eyes and step as quickly as possible following an auditory ‘go’ tone, and then continue walking along the length of the wooden walkway. The onset of this auditory cue occurred randomly between 5 and 15 s, so that participants could not anticipate its timing. For all trials, participants initiated gait with their right foot. Any trials in which gait was initiated with the left foot were repeated (*N* = 3 trials). Participants completed the protocol under two conditions: (1) Baseline, and (2) Threat. Baseline involved participants completing the protocol at ‘ground’ level (i.e., the wooden walkway resting on the laboratory floor, resulting in participants being raised 4 cm above ground). Threat involved participants completing the protocol on a walkway elevated 1.1 m above the laboratory floor, supported by a rigid scaffolding-mount. All trials were completed in the absence of a safety harness. Participants completed one block of 5 trials for each condition, with this number of trials selected to avoid participants becoming desensitised to the threat manipulation. The presentation order of these conditions was counterbalanced across participants. Foot positioning was traced to ensure consistency between trials.

Instrumentation and data analysis

Centre of pressure (COP) data were collected at 1kHz using a Kistler 9286B Force Platform (Kistler Instrument Corp., Winterthur, Switzerland), while kinematic data (dependent variable: ‘step length’, defined as the forward distance [cm] travelled by the heel marker on the stepping foot, calculated between the starting position prior to cue onset and the final position following the completion of the step) were collected at 100Hz using a VICON motion capture system (Oxford Metrics, England). Data were passed through a low-pass butterworth filter with a cut-off frequency of 5 Hz and analysed using custom algorithms in MATLAB version 7.11 (MathWorks, Natick, MA).

The following gait initiation events were extracted from the COP data (Naugle et al., 2011; Bouman et al., 2015): (1) The onset of the auditory cue; (2) APA phase onset (S1), defined at the time point at which AP COP displacement overcame the threshold defined as 3 standard deviations of its peak-to-peak value during static posture (200ms before cue onset); (3) APA offset, defined as the point in which the COP reaches the most posterior and lateral displacement towards the swing/stepping foot; (4) Weight-shift phase onset (S2), defined as the point in which the COP begins to move laterally towards the stance/support foot; and (5) Weight-shift offset, defined as the end of the ML COP shift towards the stance/support foot (see Fig. 1 and 2). From these events, the following gait initiation variables were then calculated:

APA latency. Defined as the time difference (ms) between the onset of the auditory cue and the APA phase (i.e., reaction phase).

Amplitude of APA and weight-shift phase. Maximum COP displacement (cm) in the anterior-posterior (AP) and medio-lateral (ML) direction was calculated between the onset and offset of both the APA and weight-shift phase. Note, given the weight-shift phase primarily constitutes a lateral, rather than AP, postural movement, amplitude analysis was confined to the ML direction for this phase.

Duration of APA and weight-shift phase. Defined as the time difference (ms) between the onset and offset of the APA and weight-shift phase, respectively.

APA efficiency. To explore any changes in APA efficiency, a ratio value was calculated based on Bouisset and Do's (2008) formula whereby task performance (e.g., step length, accuracy, etc.) is evaluated in reference to the motor input (e.g., duration). Thus, APA efficiency was calculated as step length/APA duration, with a lower ratio indicating reduced APA efficiency.

Sway path during reaction phase. Our data also allowed us to explore 'freezing' responses (Stins and Beek, 2011) during the reaction phase (i.e., between the auditory cue and APA onset). To this end, the COP path (sway path length, cm) was calculated in both the AP and ML direction between cue onset and APA onset.

Figure 1

Figure 2

After each block, participants reported state fear of falling on a scale ranging from 0% (not at all fearful) to 100% (completely fearful) (Zaback et al., 2015). The degree to which an individual consciously processed their movement was also assessed after each block, using a shortened version of the Movement Specific Reinvestment Scale utilised previously by Ellmers and Young (2018). This 4-item questionnaire consists of two 2-item subscales: conscious motor processing (state-CMP; e.g., "I am always trying to think about my movements when I am doing this task" and "I'm aware of the way my mind and body works when I am doing this task") and movement self-consciousness (state-MSC; e.g., "I'm self-conscious about the way I look when I am doing this task" and "I am concerned about my style of moving when I am doing this task”). Items are rated on a 6-point Likert scale (1 = *strongly disagree*; 6 = *strongly agree*). Scores range from 2–12 (for each subscale), with higher scores reflecting greater conscious movement processing.

Statistical analysis

For all variables, separate paired-samples *t*-tests were used to determine any changes between Baseline and Threat. Where data were non-normally distributed, separate Wilcoxon tests were used instead. For all statistical comparisons, effect sizes are reported as Cohen’s *d*, unless the assumption of normality is violated, where effect sizes are reported as $r=Z/\sqrt{N}$.

Results

All analysed data is made openly available via the following link: https://osf.io/b3ykj/

Self-reported state psychological measures

The postural threat manipulation significantly altered participants’ psychological state. Specifically, participants reported significantly greater fear of falling (Z = -3.30, p < .001, r = 0.83), in addition to significantly increased state-CMP (one subscale of conscious movement processing; t(15) = -3.20, p = .003, d = 0.66). There was no significant change in state-MSC (the other sub-scale of conscious movement processing; t(15) = -0.88, p = .20, d = 0.23).

Gait initiation parameters

Representative COP gait initiation data for both conditions is depicted in Figure 3.

Figure 3

Gait initiation parameters exhibited several notable differences during conditions of increased postural threat. We first computed the latency of the APA (i.e., the reaction phase of the movement), and observed significantly longer onset latency during Threat (Z = -2.12, p = .017, r = 0.53) (Figure 4). Next, we calculated the amplitude and duration of both the APA and weight-shift phase of gait initiation. With regards to the APA phase, neither movement amplitude (AP direction: t(15) = 0.47, p = .323, d = 0.10; ML direction: Z = -0.31, p = .378, r = 0.08) nor movement duration (t(15) = -0.08, p = .470, d = 0.01) significantly differed between Threat and Baseline. There was a similar lack of between-condition difference in either movement amplitude (in the ML direction: t(15) = 0.23, p = .409, d = 0.05) or duration (t(15)

= 0.62, *p* = .273, *d* = 0.18) during the weight-shift phase. We then calculated the length of the first step following gait initiation, and the overall efficiency of the APA generating this motor output. Significant between-condition differences were observed for both outcomes measures. Reduced step lengths during Threat were recorded in 12 out of 16 participants, with this difference reaching statistical significance (*Z* = -1.66, *p* = .049, *r* = 0.42) (Figure 4). APA efficiency was also significantly reduced during Threat (*t*(15) = 2.16, *p* = .024, *d* = 0.29) (Figure 4).

Figure 4

Sway path during reaction phase

Finally, we assessed changes in sway path during the reaction phase (i.e., prior to APA onset). Participants exhibited significantly greater sway paths during Threat, in both AP (*Z* = -2.43, *p* = .008, *r* = 0.61) and ML directions (*Z* = -3.05, *p* = .001, *r* = 0.76) (Figure 5).

Figure 5

Discussion

The present experiment sought to investigate how fear of falling, induced experimentally through a postural threat, influences anticipatory postural control during the execution of the common, everyday dynamic task of forward gait initiation. As hypothesised, postural threat was shown to increase both fear of falling and state-CMP (a measure of conscious movement processing/control) (Huffman et al., 2009; Zaback et al., 2015; Ellmers and Young, 2018), in addition to modifying various aspects of anticipatory postural control (Adkin et al., 2002; Yiou et al., 2011; Uemura et al., 2012; Zaback et al., 2015). However, while we had predicted to observe participants adopting a cautious postural control strategy during Threat, characterised by APAs of reduced amplitude and increased duration, the results of this study largely failed to support these hypotheses.

As predicted, APA latency (the delay between the auditory ‘go’ cue and APA onset) was significantly increased during Threat, thus indicating impaired reaction. Increased APA latency during gait initiation has been reported previously in participants performing a cognitive dual-task (Melzer et al., 2010; Martin et al., 2011; Uemura et al., 2012; Callisaya et al., 2016). This strongly implies that the rapid initiation of an APA during forward stepping requires cognitive resources. It is well-accepted that fear of falling can reduce the cognitive resources available for directing towards gait-related processes (Gage et al., 2003; Uemura et al., 2012; Ellmers and Young, 2018), with fearful individuals, for example, instead processing ruminative/worrisome thoughts related to the consequences of falling (Ellmers et al., 2019). We thus view the increased APA latency observed during Threat to be the likely consequence of a fear-related reduction in attentional processing efficiency (i.e., an anxiety-related reduction in working memory resources) (Eysenck et al., 2007). This is further supported by research presented by Uemura et al. (2012), who described significantly longer APA latency during gait initiation in older adults self-reporting fear of falling during conditions of dual-task. Alternatively, it is possible that this increase in APA latency represents fearful participants adopting a more conscious mode of postural control. Consistent with previous research (Ellmers & Young, 2018; Ellmers et al., 2019; Huffman et al., 2009; Johnson et al., 2019; Zaback et al., 2015; Zaback et al., 2016), participants in the present research reported greater state-CMP (a measure of conscious movement processing/control) during Threat trials. Such attempts to consciously regulate and control stepping actions will likely result in slower, less efficient and more variable motor outcomes (Clark, 2015). As such, it is entirely plausible that the prolonged APA latency may instead represent the increased time required to consciously initiate and regulate the APA.

Contrary to our predictions, fearful participants also exhibited significantly greater postural sway (COP sway path in both AP and ML direction) during the reaction phase (i.e., in the time between the auditory cue which signalled that they could begin initiating gait and APA onset). During static postural tasks such as quiet standing, fear of falling consistently leads to reduced postural sway (Huffman et al., 2009; Zaback et al., 2015; Adkin and Carpenter, 2018). While the sway measure used in the present research (COP sway path between the auditory cue and onset of APA) does not allow for a direct comparison to this previous research which typically explores sway amplitude via root mean square over a 60s period, these findings nonetheless highlight that the way in which fear of falling affects postural sway may be task dependent. Indeed, recent work has similarly reported increased sway amplitude in fearful individuals prior to an anticipated perturbation (Johnson et al., 2019). Based on these findings, we propose that fear of falling may lead to increased postural sway during dynamic tasks such as preparing to initiate gait or respond to a perturbation, and reduced sway during tasks in which reduced postural adjustments are likely to enhance stability (e.g., quiet standing on an unstable surface).

The exact mechanisms through which fear of falling led to increased sway in the present research remain unknown, although we suggest these results may represent an implicit attempt by the CNS to acquire the sensory information necessary to plan and initiate a dynamic action; such as forward stepping (as in the present research) or recovering from a perturbation (as in the research presented by Johnson et al., 2019). Increased amplitude in postural sway has traditionally been interpreted as instability and a gauge of error in the balance control system (van Emmerik and van Wegen, 2002). However, recent studies instead suggest that increased postural sway may reflect an adaptive mechanism used by the CNS to gain essential information about the environment (Carpenter et al., 2010; Murnaghan et al., 2011). These findings illustrate how postural sway can, in part, be considered as an exploratory behaviour that serves to provide information regarding the position of the body relative to its limits of stability (Riley et al., 1997; van Wegen et al., 2002). This suggestion is supported by the theoretical perspective that increased movement variability would stimulate a greater variety of sensory receptors (Johansson and Vallbo, 1983), and facilitate integration of multiple sensory inputs (Horak and MacPherson, 1996). The fear-related increases in postural sway observed in the present research may thus represent an overriding response to postural stiffening when planning a dynamic movement, for which reducing postural sway serves no functional/stabilising benefit—and may even limit the acquisition of sensory information needed to effectively execute this movement. Future research should look to further examine these speculations.

In contrast to previous research exploring the effects of fear of falling (similarly induced by a raised platform) on APA behaviour during both rise-to-toes tasks (Adkin et al., 2002; Zaback et al., 2015) and leg-raise tasks (Yiou et al., 2011; Gendre et al., 2016), we did not observe any changes in APA amplitude when initiating gait. Also, contrary to our predictions, we observed a lack of significant increase in APA duration during Threat. While previous research has described significantly longer APA duration during conditions of postural threat (leg-raise task; Yiou et al., 2011), other research has similarly observed no significant change (Adkin et al., 2002; Phanthanourak et al., 2016).

The lack of change in APA amplitude or duration during Threat was particularly surprising, given that participants exhibited significantly shorter steps following the APA during this condition. As the length of the first step during gait initiation is largely associated with the spatio-temporal components of the APA which preceded it (Elble et al., 1996), we would have expected either the amplitude or duration of the APA (or both) to have been proportionately scaled to the shorter steps observed during Threat. However, this was not the case. Instead, fearful participants required APAs of proportionately larger magnitudes and longer durations to produce a forward step during Threat; thus indicating a reduction in APA efficiency (see Fig. 4). We propose that this likely reflects a fear-related cautious strategy of ‘overcompensation’ intended to reduce the postural destabilisation associated with the initiation of forward stepping.

In contrast to the tasks utilised in previous research (e.g., rise-to-toes or leg-raises), producing an insufficient APA when initiating gait will likely impair both stability and safety. During gait initiation, producing an effective APA is paramount for ensuring stability; as doing so will prevent the body from toppling towards the swing/stepping leg mid-air once gait has been initiated (Yiou et al., 2016). If the APA is too small to allow for the COM to be effectively repositioned above the stance/support leg, then the walker will need to compensate for this reduction in stability—typically, by stepping more laterally with the foot that is initiating gait and thus widening the base of support (Zettel et al., 2002). However, the narrow walkway utilised in the present research would have afforded little opportunity for participants to have triggered a self-correcting lateral step in any instances of an insufficient APA. We therefore view the lack of APA scaling (in relation to reduced step length) observed during Threat to indicate a fear-related overcompensation to ensure that the COM was adequately positioned above the stance/support leg at the time of step initiation, thereby minimising any requirement for subsequent (and potentially destabilising) behavioural adaptations (Yiou et al., 2016).

It is important to note that we did not control for step length in the present experiment, as we sought to explore gait initiation without unnaturally constraining step behaviour. For example, the influence of fear of falling on reduced step length is well-established (Gage et al., 2003; Delbaere et al., 2009). Thus, unnaturally constraining participants to execute steps of the same length during Baseline and Threat would have likely elicited behaviour unlikely to translate to real-life fear-inducing scenarios. However, given the observed pattern of results, we deem it likely that participants would have displayed APAs of both greater amplitude and duration during Threat, had they been required to produce steps of the same length as those produced during Baseline. This idea is supported by research which has reported significantly greater APA amplitude during a rise-to-toes task performed during conditions of postural threat, when the motor output (degree to which participants rose to their toes) was made consistent across experimental conditions (Phanthanourak et al., 2016). Nonetheless, future research should look to confirm this hypothesis.

The relationship between fear of falling and increased fall-risk is well-accepted (Friedman et al., 2002; Hadjistavropoulos et al., 2011). Research exploring APA execution during gait initiation in older adults has also consistently reported associations between fall-risk and APA latency (Melzer et al., 2007, 2009, 2010; Martin et al., 2011; Callisaya et al., 2016). The findings from the present research highlight fear of falling as one potential factor underpinning these previously observed fall-risk-related differences; a suggestion further supported by the fact that older adults deemed to be at a high risk of falling will typically report greater fear of falling (Hadjistavropoulos et al., 2011). The present work therefore suggests impaired stepping reactions (i.e., increased APA latency) as one mechanism through which fear of falling may increase an individual's likelihood of falling. Consequently, these findings identify fear of falling as one potential factor to target when seeking to enhance voluntary stepping reactions in older adults.

In conclusion, this work investigated the influence of fear of falling on anticipatory postural control during cued gait initiation. Results showed that under conditions of postural threat, fearful participants took significantly longer to initiate APAs. Given the well-established relationship between impaired reaction times during voluntary stepping and greater fall-risk (Melzer et al., 2007, 2009, 2010; Martin et al., 2011; Callisaya et al., 2016), we suggest this as one mechanism through which fear of falling may reduce balance safety. Contrary to our predictions, we observed a lack of change in either APA amplitude or duration when participants were fearful of falling—despite fearful participants producing steps of shorter lengths. This implies that proportionately larger APAs were required to produce the motor output (gait initiation) during Threat, highlighting reduced APA efficiency. We suggest that such failure to scale the APA to the magnitude of the motor output may reflect a fear-related 'overcompensation', whereby fearful participants sought to ensure that the magnitude of the APA was sufficient for ensuring that their centre of mass was adequately positioned above the stance/support leg prior to gait initiation. As age-related differences exist regarding attentional responses to postural threats (Ellmers et al., 2019), future research should look to investigate whether older adults display similar anticipatory postural behaviours during the preparation and execution of stepping actions during conditions designed to induce fear of falling.

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Figure 1

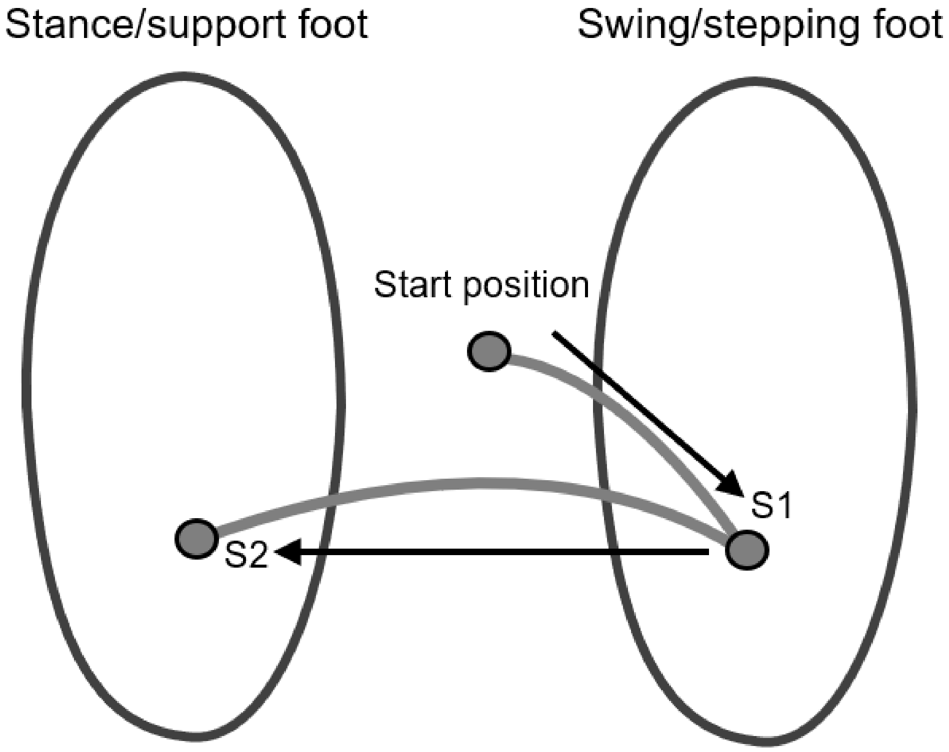
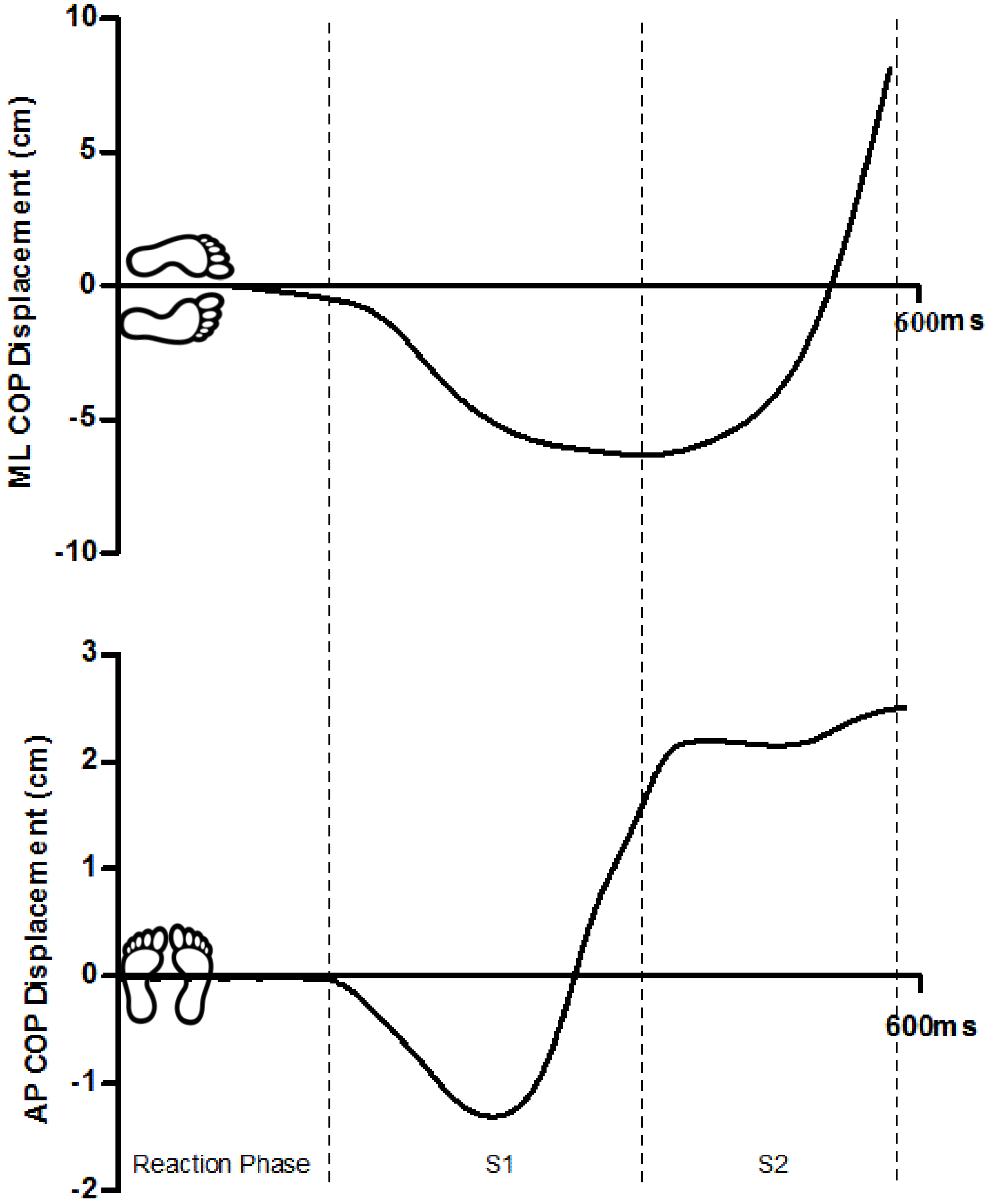

Stance/support foot
Swing/stepping foot
Start position
S1
S2

Figure 2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0
-5
-10
600ms
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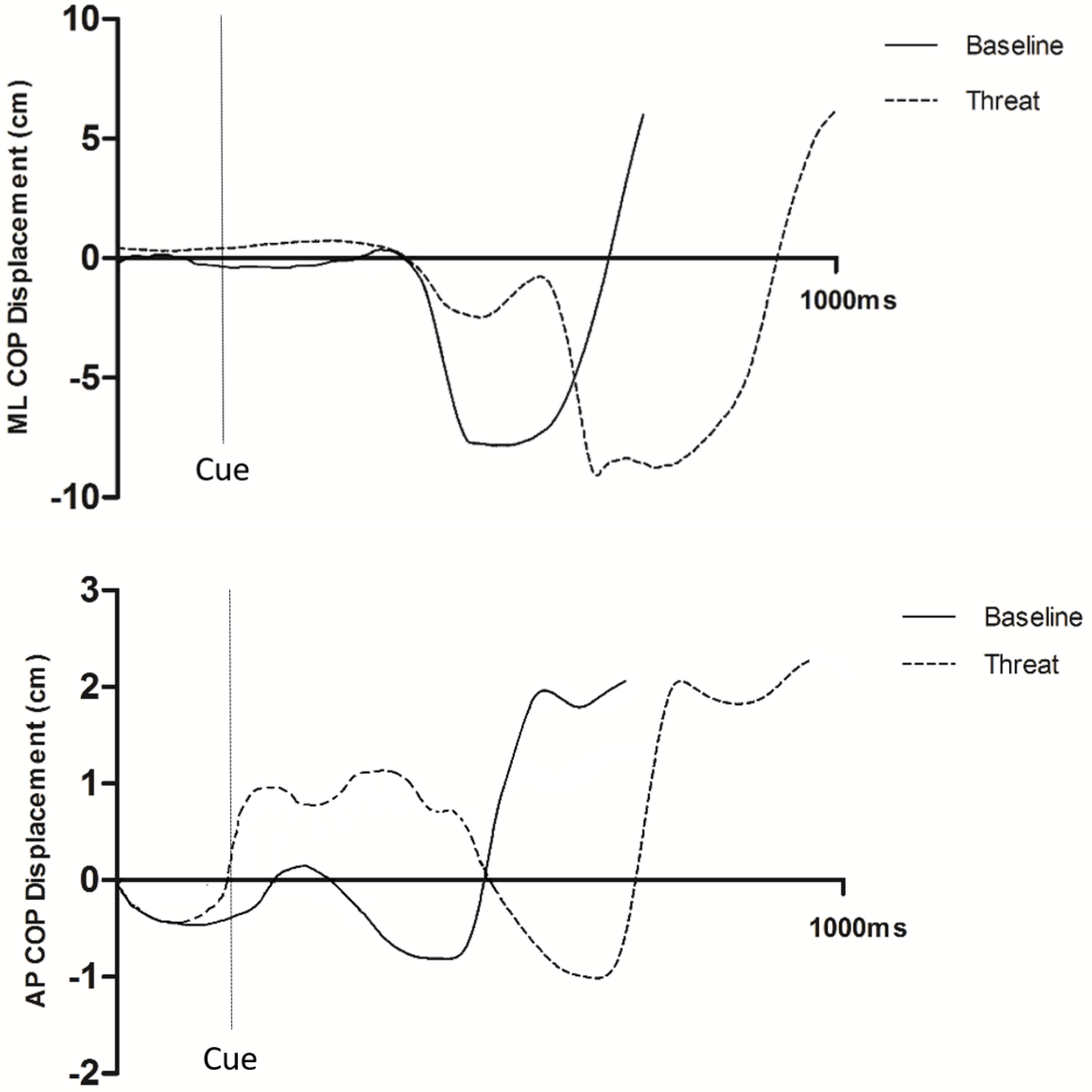
3
2
1
0
-1
-2
600ms
Reaction Phase
S1
S2

Figure 3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Threat
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AP COP Displacement (cm)
Cue
1000ms
Baseline
Threat

Figure 4

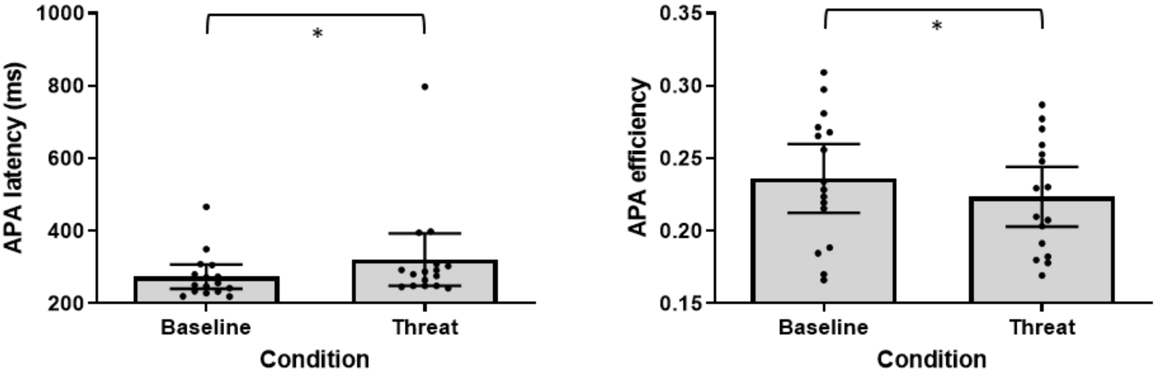

Figure 5

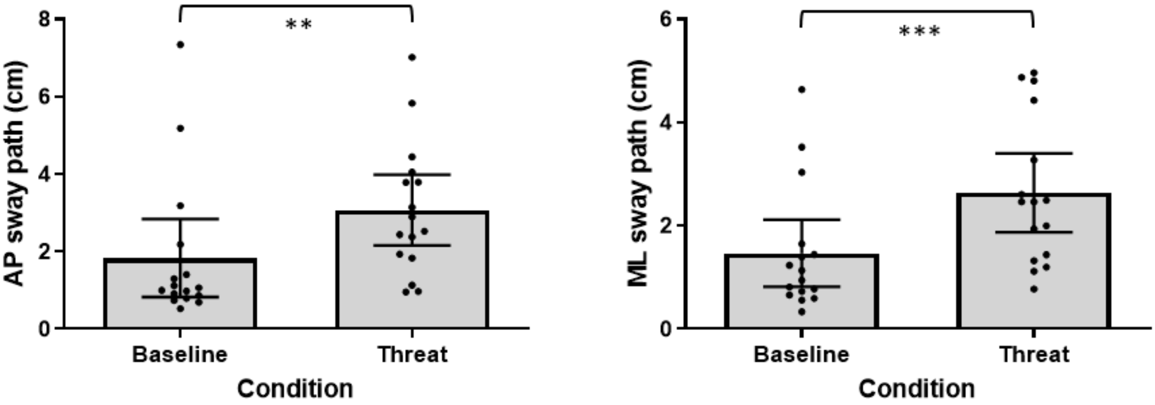

Figure Captions

Figure 1. A graphical representation of the COP trace during gait initiation when stepping with the right foot. There are two distinct phases of postural adjustment prior to step initiation: S1 (the *APA phase*) involves the posterior and lateral shift of the COP towards the swing/stepping foot, which is followed by; S2 (the *weight-shift phase*), the lateral shifting of the COP towards the stance/support foot. Following this weight-shift, the COM is now repositioned above the stance/support foot, and the swing/stepping foot is unloaded and free to initiate gait.

Figure 2. Centre of pressure (COP) displacement in the medio-lateral (ML; top) and anterior-posterior (AP; bottom) directions, when initiating gait with the right foot. S1 = APA phase; S2 = weight-shift phase.

Figure 3. Centre of pressure (COP) data for a representative participant during a single Baseline and Threat trial, in the medio-lateral (ML; top) and anterior-posterior (AP; bottom) direction.

Figure 4. Changes in APA latency (left figure) and efficiency (right figure) between Baseline and Threat, *$p < .05$ (mean ± 95% confidence intervals, and individual data points).

Figure 5. Sway path, in the AP (left figure) and ML (right figure) direction, in the reaction phase (i.e., between the auditory cue and APA onset) during Baseline and Threat, **$p < .01$, ***$p = .001$ (mean ± 95% confidence intervals, and individual data points).