Standing up to threats: Translating the two-system model of fear to balance control in older adults

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Highlights

- We apply the ‘two-system’ view of fear to balance control in older adults
- Older adults experienced a postural threat manipulation
- We isolated distinct behaviours associated with conscious experience of fear
- These behaviours differed from those driven by ‘automatic’ threat responses
- We present a novel conceptual framework to explain these findings

Abstract

The ‘two-system’ view of fear builds on traditional conceptualisations of emotion; proposing that the mechanism(s) responsible for behavioural and physiological responses to threat may be distinct from that underpinning the (conscious) emotional experience itself. We empirically tested this notion within a novel, applied context of social and economic importance: fear of falling in older adults. Older adults stood on the edge of a raised platform and were stratified based on whether they reported fear in response to this postural threat. Irrespective of whether participants reported fear, we observed behaviours indicative of postural ‘stiffening’ during the threat condition. Self-reports indicated that participants cognitively monitored these changes in balance, and fear of falling was experienced in those who interpreted these behaviours to imply that harm was likely to occur. Fearful participants exhibited additional changes in balance (increased movement complexity and altered utilisation of sensory feedback) – behaviours likely influenced by attempts to consciously control balance. Taken together, these findings provide novel insight into the systems that regulate behavioural and emotional responses to postural threats. The novel conceptual framework developed from these findings helps identify specific mechanisms that might be targeted for clinical intervention.

Key words: Anxiety; Aging; Fear of falling; Postural threat; Conscious movement processing

Introduction

Many older adults will report feelings of fear when their balance is threatened (Ellmers et al., 2020). Greater fear of falling is independently associated with increased risk of falls in this population (Friedman et al., 2002). Researchers have attempted to isolate fear-related behaviours that may impair balance safety (Adkin & Carpenter, 2018). However, interpretations of this literature have been limited by a failure to acknowledge contemporary theoretical models of fear and anxiety.

The aim of this present study is to explore fear of falling with reference to LeDoux's 'two-system' model of fear (2013, 2014; LeDoux & Pine, 2016). This framework argues that there is one set of neural circuits responsible for the 'automatic' defensive responses (e.g., rapid threat detection, heart rate, freeze response, etc.), and another responsible for the 'conscious' feelings of fear (e.g., the recognition that one is in imminent danger and the subsequent emotional response) and associated behavioural actions (e.g., threat avoidance). Indeed, subliminally presented threats will trigger peripheral physiological 'threat' responses despite participants being unaware of the threat's presence and consequently reporting no change in fear (Frumento et al., 2021; LeDoux, 2014; Luo et al., 2010; Phelps, 2006; Taschereau-Dumouchel et al., 2018; Walen et al., 2004). LeDoux and Pine (2016) argue that fear "reflects awareness of a potential for harm, occurring when one cognitively monitors and interprets signals from the brain and/or body, and integrates these signals with information about the external situation" (p. 1087).

Researchers have sought to experimentally explore behavioural (balance) responses when fearful of falling; typically achieved through threatening a participant's balance via a raised platform (Adkin et al., 2002; Cleworth & Carpenter, 2016; Ellmers et al., 2021; Huffman et al., 2009; Sturnieks et al., 2016). During orthostatic balance, fearful individuals tend to exhibit postural ‘stiffening’, characterised by greater co-contraction of the lower leg muscles in conjunction with increased frequency of postural sway (Adkin & Carpenter, 2018). They will also report directing greater attention towards processing their balance in a conscious attempt to prevent falling (Ellmers et al., 2021; Huffman et al., 2009; Zaback et al., 2019). Consciously regulating balance may reduce safety by interfering with automatic processes (Clark, 2015; Ellmers et al., 2021), leading to less-effective balance control. Researchers have proposed that such conscious strategies may also underpin the changes in sensory processing observed during conditions of postural threat (e.g., altered open- and closed-loop postural control (Wuehr et al., 2014)). Conclusions drawn from this body of research are, however, limited by the lack of consideration for the two distinct systems underpinning threat responses, as described by LeDoux (2014; LeDoux & Pine, 2016). Failure to distinguish between subcortical defensive responses to postural threats and those related to the conscious experience of fear makes it difficult to isolate automatic behaviours from those that are consciously processed, and potentially maladaptive (Clark, 2015).

There is therefore a need to explore behavioural responses to postural threats in older adults that do, and those that do not, experience fear of falling. Conducting such analysis is the primary aim of the present work. This unique analysis will allow us to isolate automatic defensive responses from behaviours associated with the conscious experience of fear. We expected that *automatic* defensive responses would be associated with changes in postural sway frequency, indicative of postural stiffening (Zaback et al., 2019). Previous work has also described that *conscious* attempts to enhance postural stability are associated with both reduced movement complexity (Rhea et al., 2019) and changes in sensory processing outcomes (e.g., earlier transition from open- to closed-loop postural control (Wuehr et al., 2013)). We therefore predicted that changes in these outcomes would only be observed in those individuals reporting fear. Finally, we predicted that fearful individuals would report both greater internal awareness of bodily signals and subsequent attempts to consciously monitor and control balance, while non-fearful individuals would report changes in awareness only (LeDoux & Pine, 2016).

Methods

While preliminary analyses on data for a subset of participants (*N*=26) has been published previously (Ellmers et al., 2021), the primary analysis on the full dataset reported herein (*N*=44) has not been previously reported; nor have the specific between-group (Fear vs. No Fear) analyses.

Participants

Previous research has reported medium-large effect sizes for comparable outcomes during conditions of postural threat compared to baseline (Zaback et al., 2019). A power analysis determined that a minimum of 34 participants would be required to obtain 80% power (medium effect size, $f = 0.25$, $p = .05$) when conducting a 2x2 (Baseline vs. Threat x Fear vs. No Fear) ANOVA.

Forty-four community-dwelling older adults (aged>60; males: 13/44; mean ± *SD* age: 73.91±6.96, range: 61-86 years) were recruited from local community groups. Participants were free from any neurological, cardiovascular or musculoskeletal impairment that prohibited them from standing >2 minutes without support. Participants did not report a current diagnosis for any vestibular condition, nor did they report any bouts of dizziness within the past 6 weeks. Participants were excluded if they demonstrated major cognitive impairment (Montreal Cognitive Assessment [MoCA] score <18/30 (Nasreddine et al., 2005)), or if they were currently prescribed anxiety medication. All participants had normal or corrected-to-normal vision. Ethical approval was obtained from the local ethics committee and the research was carried out in accordance with the Declaration of Helsinki. All participants provided written informed consent prior to participation.

Baseline Assessments

Participants completed a battery of assessments, starting with the MoCA (Nasreddine et al., 2005), a measure of global cognitive function, followed by questionnaires that separately assessed both trait anxiety (Spielberger's State Trait Anxiety Inventory [STAI] (Spielberger et al., 1983)) and generalised concerns about falling (Falls Efficacy Scale-International [FES-I] (Yardley et al., 2005). Finally, they completed the Berg Balance Scale (BBS), a widely used assessment of functional balance (Berg et al., 1992)). See Table 1 for all baseline assessments and demographic information.

Table 1

Protocol

Participants completed narrow-stance (feet 10cm apart) balance trials while standing on the edge of a force platform (Accusway, AMTI Inc., Watertown, MA, USA). Position of the feet was marked to ensure consistency between trials. Participants stood with their hands by their sides looking straight ahead at a cross affixed to the wall 3 metres away. Participants completed a single 60-second trial under a condition designed to threaten their balance ('Threat'; raising the platform to 0.6m) followed by Baseline (ground level).[1] Prior to participation, all participants first completed a 30-second practice trial at ground level. All trials were completed without a safety harness.

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[1] Of the 44 participants, 26 completed an additional Threat-Distraction condition that involved performing a distracting secondary cognitive task during Threat ('Threat Distraction'; see Ellmers, Kal et al., 2020). These participants did not significantly differ from those that only completed Threat and Baseline on any assessed demographic variable (all *p*s > .103), nor whether they exhibited a fear response or not during Threat itself (*p* = .295). Note, the Threat and the Threat Distraction condition were presented in counterbalanced order.

Fear vs. No-Fear Group

Participants were stratified based on their self-reported fear of falling scores during Threat (described in ‘Self-Reported Outcomes’ section below). Those that did not report any change in fear of falling between Baseline and Threat were allocated to the ‘No-Fear’ group ($N = 21$; 0% change in fear between Baseline and Threat). Participants that reported an increase in fear of falling during Threat were allocated to the ‘Fear’ group ($N = 22$; mean increase from 7.3% fearful during Baseline to 38.4% fearful during Threat). One participant was excluded due to reporting *decreased* fear during Threat. As reported in Table 1, participants in the Fear group scored significantly higher on the FES-I (i.e., greater concerns about falling; $p = .009$) and trait-STAI (i.e., greater trait anxiety; $p = .015$). Fearful participants also tended to be smaller (in height), although this did not reach statistical significance ($p = .053$). The two groups were statistically comparable on all other demographic variables (ps > .130). There were no significant between-group differences at Baseline for any self-reported (ps > .111) or postural control (ps > .173) outcome variables.

Self-Reported Outcomes

All materials/questionnaires used to collect self-reported outcomes (including the specific questions asked) are available via an Open Science Framework repository (https://osf.io/pe52a/).

Balance-related measures. Immediately prior to each trial (i.e. while standing in position) participants rated how confident they were that they could maintain their balance and avoid a fall (0–100% confident) (Zaback et al., 2019). Immediately after each trial (i.e., whilst still standing in position on the force platform), participants rated the level of fear of falling they experienced during the trial itself (0–100% fearful) (Zaback et al., 2019). At this point, they also rated the level of subjective stability experienced during the preceding trial (0–100% stable) (Huffman et al., 2009).

Conscious movement processing. After each trial, participants also completed a 4-item questionnaire measuring the degree to which they consciously processed their (balance) movements during the preceding trial (Ellmers & Young, 2018). The questionnaire assesses four components of conscious movement processing: Internal awareness (“I am aware of the way my mind and body works when doing this task”); Conscious movement monitoring/control (“I am always trying to think of my (balance) movements when doing this task”); Self-consciousness (“I am self-conscious about the way that I look when doing this task”), and; Movement concerns (“I am concerned about my style of moving when doing this task”). Each question is scored from 1 (*strongly disagree*) to 6 (*strongly agree*). Previous research has combined answers from all four questions to calculate an overall score of conscious movement processing (Ellmers et al., 2021). However, based on LeDoux and Pine’s (2016) view that fear reflects the integration of internal *awareness* of brain and bodily signals with information about the external situation, investigating the individual components of conscious movement processing is of high theoretical importance. We therefore decided to calculate scores for each individual component of conscious movement processing. Scores for each subscale ranged from 1-6.

Postural Control Outcomes

Centre-of-pressure (COP) data from the force plate were sampled at 500 Hz. Data were low-pass (5Hz) filtered offline with a bidirectional, second order Butterworth filter. Given that the postural threat (platform edge) was anterior to participants, all analyses were confined to anterior-posterior (AP) direction (Zaback et al., 2019) and reflect outcomes from each 60s trial.

Postural sway amplitude. We calculated root-mean-square (RMS) to determine the amplitude of COP adjustments (with respect to the COP mean position (Zaback et al., 2019)).

Postural sway frequency. We calculated mean power frequency (MPF; mean frequency in power spectrum after Fast Fourier Transformation) to assess sway frequency (with respect to the COP mean position (Zaback et al., 2019)). Average COP power within specific frequency ranges of 0-0.05 Hz (Freq_{low}), 0.5–1.8 Hz (Freq_{med}), and 1.8−5 Hz ($\text{Freq}_{\text{high}}$) were also calculated (Zaback et al., 2019).

Complexity of postural sway. Complexity of postural sway was assessed by calculating sample entropy (SampEn) of COP data. For static (balance) tasks, higher values reflect more complex and irregular postural adjustments; characteristic of more automatic (i.e., less consciously processed) postural control (Borg & Laxaback, 2010). We optimised the parameter settings required for the SampEn calculation, resulting in the use of m=3 and r=0.01 (Lake, Richman, Griffin, & Moorman, 2002). As per previous research (Lake et al., 2002; Roerdink et al., 2011), forceplate data were down-sampled to 100 Hz when calculating SampEn.

Stabilogram diffusion analysis. To provide insight into open- and closed-loop control of posture (and associated corrective feedback mechanisms), stabilogram diffusion analysis (SDA) was performed using the method described by Collins and De Luca (1993). SDA plots reveal two regions (short- and long-term diffusion) separated by a critical point where postural control is argued to move from predominantly open- to closed-loop control (i.e., the point at which sensory feedback is used to control posture) (Collins et al., 1995; Collins & De Luca, 1993). During short-term intervals, postural control is regulated without sensory feedback, and COP exhibits persistent behaviour, tending to drift away from a relative equilibrium point. During longer-term intervals, however, sensory feedback is used to return the COP to equilibrium (i.e., anti-persistent behaviour). We first calculated short- and long-term diffusion coefficients (termed D_S and D_L, respectively, and measured in mm^2/s). These outcomes reflect the level of stochastic COP activity, with larger values indicating a less tightly regulated (or, ‘more random’) postural control strategy (Collins et al., 1995; Collins & De Luca, 1993). We also calculated the critical time period (s) and displacement (mm^2) at which corrective feedback mechanisms (i.e., closed-loop control) begins to predominate. Similar to the calculation of SampEn, forceplate data were down-sampled to 100 Hz (Collins et al., 1995; Collins & De Luca, 1993).

Statistical Analysis

As most outcome variables were non-normally distributed, data were analysed using a generalised estimating equation (GEE). We chose an exchangeable working correlation matrix to define dependency amongst measurements. A separate GEE was conducted for each outcome variable, with condition (Baseline vs. Threat) and group (Fear vs. No-Fear) as predictors. For all GEE analyses, Holm–Bonferroni’s *t*-tests followed up significant effects (Holm, 1979).

Data Availability

All analysed data and data analysis scripts are available via an Open Science Framework repository (https://osf.io/pe52a/).

Results

Please see Table 2 and 3 for both mean values (and standard deviation) and GEE outputs for all assessed variables, respectively.

Self-Reported Outcomes

Please see Figure 1 for graphical representation of key significant results for self-reported outcomes.

Fear of falling. There was a significant main effect of both condition (p < .001) and group (p < .001), as well as a significant interaction between the two, with respect to fear of falling (p < .001). Post-hoc tests revealed a significant increase in fear of falling from Baseline to Threat in the Fear group only (p < .001); with fear of falling values being identical between Baseline and Threat for the No Fear group (p = 1.00). Fear of falling during Threat was also significantly higher in the Fear group compared to No-Fear group (p < .001).

Balance confidence. There was a significant main effect of both condition (p < .001) and group (p < .001), as well as a significant interaction between the two, for balance confidence (p < .001). Post-hoc tests revealed a significant decrease in balance confidence from Baseline to Threat for both the Fear (p < .001) and No-Fear group (p = .001). Balance confidence during Threat was also significantly lower in the Fear compared to No-Fear group (p < .001).

Perceived stability. There was a significant main effect of condition (p < .001), but not group (p = .064), for perceived stability. The interaction between condition and group was also significant (p = .037). Post-hoc tests revealed a significant decrease in perceived stability from Baseline to Threat for both the Fear (p < .001) and No-Fear group (p < .001). During Threat, the Fear group's perceptions of stability were lower than those of the No-Fear group, but this difference was non-significant after applying the Holm-Bonferroni correction (p = .063).

Individual components of conscious movement processing. With respect to internal awareness, there was a significant main effect of condition (p = .004), with participants reporting greater awareness during Threat. There was neither a significant main effect of group (*p* = .380), nor an interaction between the two (*p* = .730).

With respect to conscious movement monitoring/control, there was no main effect of group (*p* = .464), but there was a significant main effect of condition (*p* < .001), with greater conscious movement monitoring/control reported during Threat. However, the significant interaction effect (*p* = .004) revealed that this was driven by between-condition changes in the Fear group (*p* < .001). In contrast, there was no significant between-condition change in conscious movement monitoring/control for the No-Fear group (*p* = .515). Conscious movement monitoring/control during Threat was also significantly greater for the Fear group compared to No-Fear (*p* = .029).

With respect to self-consciousness, there was neither a significant main effect of condition (*p* = .184) or group (*p* = .062), nor an interaction between the two (*p* = .639).

Finally, for movement concerns, there was a significant main effect of condition (*p* < .001), but not group (*p* = .094). The interaction between condition and group was also significant (*p* = .013). Post-hoc tests revealed a significant increase in movement concerns from Baseline to Threat for the Fear group only (*p* = .003). There was no significant change for the No-Fear group (*p* = .975).

Table 2

Table 3

Figure 1

Postural Control Outcomes

Please see Figure 2 for graphical representation of key significant results for postural control outcomes.

Sway amplitude (RMS). There was neither a significant main effect of condition (*p* = .681) or group (*p* = .912), nor an interaction between the two (*p* = .209), with respect to sway amplitude.

Sway frequency (MPF). There was a significant main effect of condition (*p* < .001), but not group (*p* = .701), for sway frequency. The interaction between condition and group was also significant (*p* = .042). Post-hoc tests revealed a significant increase in sway frequency from Baseline to Threat for both the Fear (*p* < .001) and No-Fear group (*p* = .017). While there was a tendency for greater sway frequency during Threat for the Fear group (compared to No Fear), this was non-significant (*p* = .073).

Individual components of sway frequency. With respect to Freq_{low}, there was a significant main effect of condition (*p* = .008), with significant reductions in low-frequency sway during Threat. There was neither significant main effect of group (*p* = .931), nor an interaction between the two (*p* = .252). With respect to Freq_{med}, there was similarly a significant main effect of condition (*p* < .001), with significant increases in medium-frequency sway during Threat. There was neither significant main effect of group (*p* = .818), nor any interaction (*p* = .791). Finally, there was a significant main effect of condition (*p* < .001), but not group (*p* = .825), for $\text{Freq}_{\text{high}}$. The interaction between condition and group was also significant (*p* = .029). Post-hoc tests revealed a significant increase in high-frequency sway between Baseline and Threat for the Fear group only (*p* = .002). There was no significant change in $\text{Freq}_{\text{high}}$ for the No-Fear group (*p* = .259).

Sway complexity (SampEn). While no significant main effect of group was found (*p* = .847), there was a significant main effect of condition (*p* = .002) for sway complexity. A significant interaction effect (*p* = .008) revealed that this was driven by the Fear group who exhibited significantly greater sway complexity during Threat (*p* < .001). In contrast, sway complexity did not significantly change between Baseline and Threat for the No-Fear group (*p* = 1.00).

SDA analysis. With respect to short-term diffusion coefficients, there was a significant main effect of condition (*p* < .001), with increased short-term diffusion observed during Threat. There was neither a significant main effect of group (*p* = .693) nor an interaction effect (*p* = .624). In contrast, for long-term diffusion coefficients, we found no significant main effect of either condition (*p* = .620) or group (*p* =.834), nor any significant interaction (*p* = .876).

With respect to the critical time period, there was a significant main effect of condition (*p* = .048), showing reduced critical time during Threat. However, the near-significant interaction effect (*p* = .055) indicated that this was driven by between-condition changes in the Fear group (*p* = .022) rather than the No-Fear group (*p* = 1.00). There was no significant main effect of group (*p* = .642). In contrast, for critical displacement, there was no significant main effect of either condition (*p* = .555) or group (*p* =.994), nor any significant interaction (*p* = .117).

Figure 2

Discussion

The primary aim of this research was to investigate behavioural responses to a postural threat in older adults, and isolate automatic defensive responses from behaviours related to the conscious experience of fear. As hypothesised, we observed both similarities and differences in behavioural responses to the postural threat in the Fear and No Fear group. As we observed a lack of significant between-group difference in any assessed outcomes at

Baseline, the contrasting behavioural responses to the postural threat thus appear to be driven primarily by the psychological (fearful) response to the threat manipulation itself.

There were some clear similarities in behavioural responses to the postural threat between the Fear and No-Fear group. In both groups, the postural threat manipulation resulted in a significant increase in overall sway frequency. This seemed to be underpinned by simultaneous decreases in low-frequency sway and increases in medium-frequency sway. This occurred in conjunction with increased short-term diffusion. Previous research suggests that increased short-term diffusion coefficients reflect greater co-contraction of lower leg muscles (Laughton et al., 2003). Combined, these results imply that the widely reported ‘stiffening’ responses to postural threats during orthostatic balance (Adkin & Carpenter, 2018) likely reflect automatic (subcortical) behaviours that occur independently from conscious fear-related processes.

We also observed key between-group differences in behavioural responses to the postural threat, particularly with respect to movement complexity (SampEn) and utilisation of sensory feedback to control posture (critical time period). While there was no change in complexity of postural sway during Threat for the No Fear group, significant increases in sway complexity were observed in fearful individuals. Unlike the No Fear group, fearful individuals also exhibited significant reductions in the critical time period during Threat. This reveals that fearful individuals relied on open-loop processes for shorter durations and instead used sensory feedback to correct drift in postural sway earlier. Previous research has described increases in sensory gain when fearful of falling (Cleworth & Carpenter, 2016). We therefore suggest that fear-related reductions in critical time periods may be a consequence of fearful individuals having greater sensitivity for detecting smaller changes in body position. Finally, while both groups exhibited threat-related increases in overall sway frequency (consisting of reduced low-frequency and increased medium-frequency sway), the Fear group exhibited additional significant increases in high-frequency sway. This supports previous observations that high-frequency postural sway is likely underpinned by the conscious fear experience rather than automatic threat processes (Zaback et al., 2021).

In addition to the postural outcomes, there also were numerous similarities – and differences – with respect to self-reported psychological outcomes. Both groups reported significant increases in internal awareness of postural movements during Threat, in addition to greater perceptions of postural instability. However, the key between-group distinction was whether these changes led to fear – and associated cognitive responses (conscious attempts to monitor/control movement). Our findings provide strong support for LeDoux and Pine's (2016) assumption that fear is underpinned by integrating interpretations of bodily signals with information about the external context. Both groups exhibited behaviours indicative of postural stiffening during Threat. They also reported increased awareness of postural movements and interpreted these changes as indicating reduced postural stability. However, only the Fear group interpreted these bodily signals to infer that harm was *likely* to occur (and tightened the feedback loop accordingly, leading to the observed decrease in critical time). The Fear group had significantly greater generalised concerns about falling (FES-I scores) and trait anxiety (STAI scores). Whilst the effect sizes for these between-group differences were only moderate (r = .40 and r .37 for FES-I and STAI, respectively), we propose that the interaction between these factors caused the Fear group to believe that the postural threat had a high probability of causing harm. Indeed, while both groups reported reductions in balance confidence during Threat, these decreases were significantly larger in the Fear group. Fearful individuals were therefore less confident in their ability to maintain balance and avoid a fall occurring under threat.

In short, these findings imply that while postural threats may trigger automatic defensive responses (that individuals then consciously interpret), it is the appraisal of the situational context that ultimately determines whether fear is experienced. If the external situation (the threat itself) is appraised as having a high likelihood of causing harm, then a conscious fear response will be triggered. If the situation is appraised as being unlikely to cause harm, then automatic defensive responses will occur in the absence of fear. Why would defensive responses persist even in individuals who interpret the postural threat as non-harmful and thus do not experience fear? Unlike other threatening stimuli, interpreting a postural threat as non-harmful does not necessary imply a complete absence of potential harm – only that the likelihood of harm occurring is low. For instance, someone with good balance may interpret an icy sidewalk as being unlikely to cause harm, and thus does not experience fear. Yet the threat itself remains; it is both genuine and present. It is therefore imperative that defensive responses to postural threats persist even in the absence of fear, as they serve an adaptive purpose and help ensure that harm (a fall) does not occur.

Emotional Responses when Balance is Threatened: A New Conceptual Framework

The present findings provide novel insight into the manifestation of emotional responses (specifically, fear of falling) to postural threats. As illustrated in Figure 3, we propose that a series of subcortical brain and bodily responses will be triggered when an individual's balance is threatened (red boxes; upper right-hand side). Attention will then be directed internally towards interpreting the bodily signals arising from these automatic defensive responses. The interpretation of bodily signals will then be integrated with one's appraisal of the situational context: a judgement on the likelihood of the threat to cause harm. We propose three interacting factors that determine whether a postural threat will be appraised as being likely to cause harm:

1. Level of trait anxiety (trait propensity to emotionally respond to threatening scenarios)

2. Concerns about falling in daily life (which will be influenced by, among other things, previous falls and awareness of one's balance impairments)
3. One's self-schema relating to postural threats (a collection of memories about personal experiences with postural threats, e.g., how one typically feels and acts when balance is threatened)

If the individual appraises the situational context as being likely to cause harm, and interprets the accompanying bodily signals to indicate that they are fearful (and/or anxious), a conscious emotional response will be triggered (green boxes; lower-half of the figure). This will then lead to additional cognitive responses and further (conscious) defensive actions initiated to maximise safety. We contend that these behaviours will be consciously initiated (and controlled). Whether these defensive actions lead to enhanced safety will ultimately be dependent on the task and the postural threat. For example, as consciously processed stepping movements are slower to initiate and more variable (Clark, 2015), such conscious actions may reduce safety during tasks requiring rapid stepping reactions.

While we hypothesise that emotional responses to postural threats rely primarily on the integration between the inspection of automatic defensive responses and one's appraisal of the situation context, it is possible for an emotional response to be triggered independently of the bodily inspection route. For example, someone who has fallen in a variety of contexts and who has poor balance would likely possess a self-schema that defines any situation that threatens their balance as inducing fear and/or anxiety. In this instance, predictions based on prior experience – rather than perceptions of physiological consequences of defensive responses – will trigger a memory-based expectation that directly induces the emotional response (Mobbs et al., 2019). Nonetheless, we contend that automatic defensive responses would still occur (and be interpreted to confirm the classification of the emotion); only their existence will not contribute to the initial emotional experience *per se*.

Figure 3

Applied Implications

Fear of falling can be highly debilitating in older adults (Hadjistavropoulos et al., 2011), particularly when it is disproportionate to the level of actual risk (Delbaere, Close, Brodaty, Sachdev, & Lord, 2010). The conceptual framework described herein identifies numerous points at which maladaptive emotional responses to postural threats can be addressed. For example, techniques could be used that either reduce attention directed towards bodily signals associated with automatic defensive responses (e.g., distraction (Ellmers et al., 2021)) or encourage reappraisal of the interpretations derived from such bodily monitoring (Moore et al., 2015). Relatedly, therapeutic strategies could also encourage cognitive reappraisal of the external situation. We propose that this may be achieved through challenging either trait anxiety, generalised concerns about falling and/or self-schemas relating to postural threats. Recent work has also described that repeated exposure to a postural threat can habituate the emotional response (and associated changes in behaviour) in young adults (Zaback et al., 2021). We argue that such habituation is a likely consequence of individuals reappraising the external situation as being one unlikely to cause harm. Future work should look to confirm this assumption and explore the utility of threat habituation in older adults.

Limitations

The primary limitation of the present research relates to the lack of physiological outcome data (e.g., electrodermal activity, heartrate). As we did not collect physiological responses to the postural threat, we relied solely on behavioural (postural) outcomes when determining the ‘automatic’ defensive responses. However, we argue that this is less of an issue within the context of postural threats and fear of falling, as the behavioural responses are directly associated with the threat stimulus (i.e., the assessed behavioural outcomes are specifically related to balance and postural stability). We therefore contend that it is these outcomes – rather than classic physiological response measures – that will be most salient when one seeks to determine whether they are fearful of falling or not. Work presented by Sturnieks et al. (2016) and Johnson et al. (2019) supports such stance. They observed altered postural control and significant increases in self-reported fear and/or anxiety in older adults exposed to a postural threat – despite measures of physiological arousal remaining at pre-threat levels. Nonetheless, future research should seek to also confirm the role of threat-related physiological responses within this context.

Conclusion

The present work describes a novel method to explore behavioural responses associated with fear of falling. Specifically, our analyses allowed us to isolate automatic defensive responses from behaviours associated with the conscious experience of fear within the context of ageing and balance control. The findings presented provide strong support for the ‘two-system’ view of fear (LeDoux & Pine, 2016) within a novel setting of applied social and economic importance. The resultant conceptual framework informed by our findings provides a roadmap for clinicians to target maladaptive/debilitating fear of falling in older adults and other populations with balance problems.

Declarations

Conflicts of interest

The authors have no competing conflicts of interest.

Availability of data and materials

All analysed data are available via Open Science Framework (https://osf.io/pe52a/). The materials used in the study are available via the same Open Science Framework repository, otherwise they are widely available. Data analysis scripts are available via the same Open Science Framework repository (https://osf.io/pe52a/).

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Figure 1. Means and 95% Confidence Internals for self-reported outcomes for No Fear (grey circles/lines) and Fear groups (black circles/lines). An asterisk (*) represents a significant main effect for either condition (horizontal line) or group (vertical line). A hash (#) represents a significant post-hoc testing following a significant condition x group interaction effect.

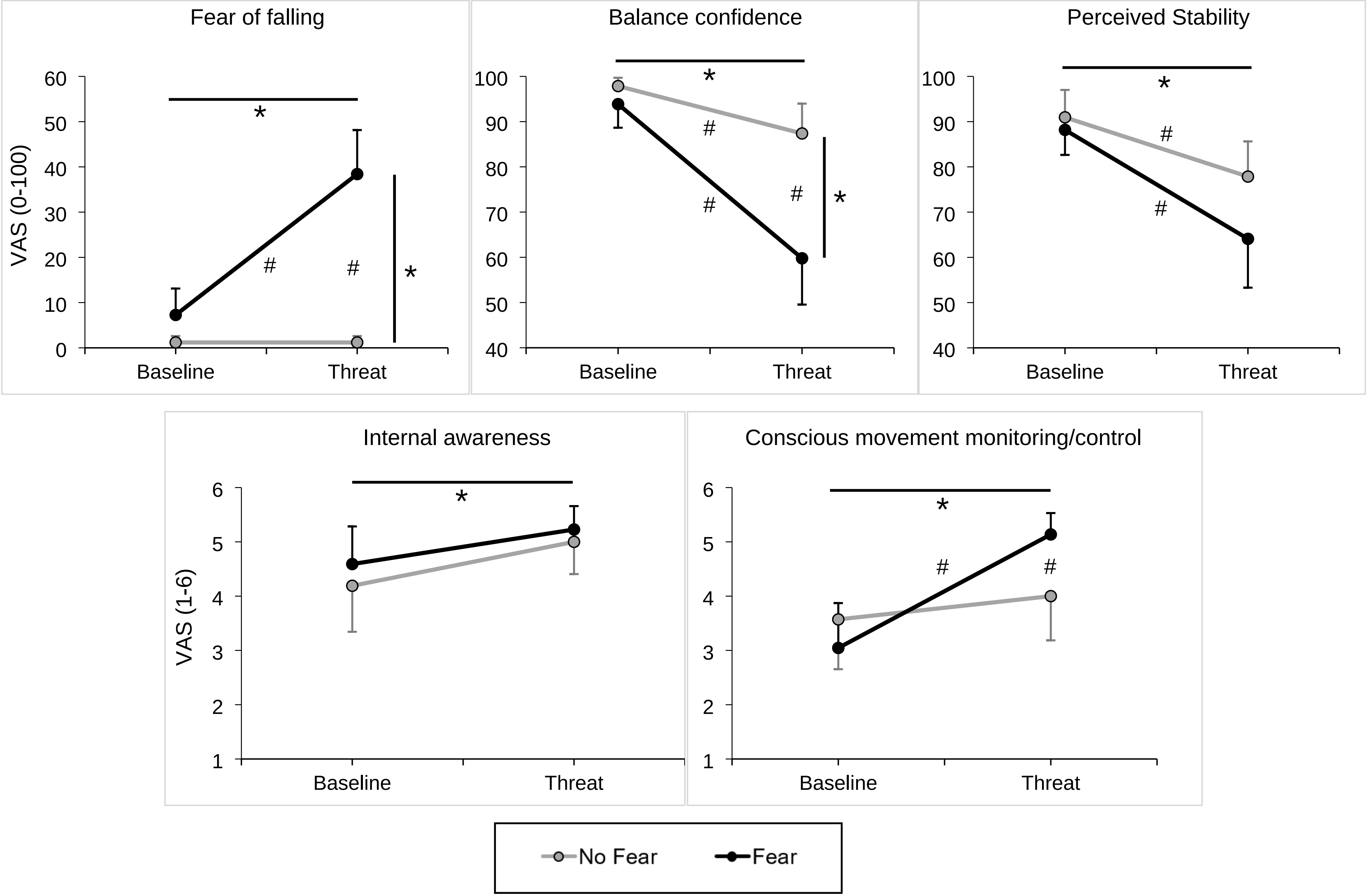


Figure 2. Means and 95% Confidence Internals for postural control outcomes for No Fear (grey circles/lines) and Fear groups (black circles/lines). An asterisk (*) represents a significant main effect for either condition (horizontal line) or group (vertical line). A hash (#) represents a significant post-hoc testing following a significant condition x group interaction effect.

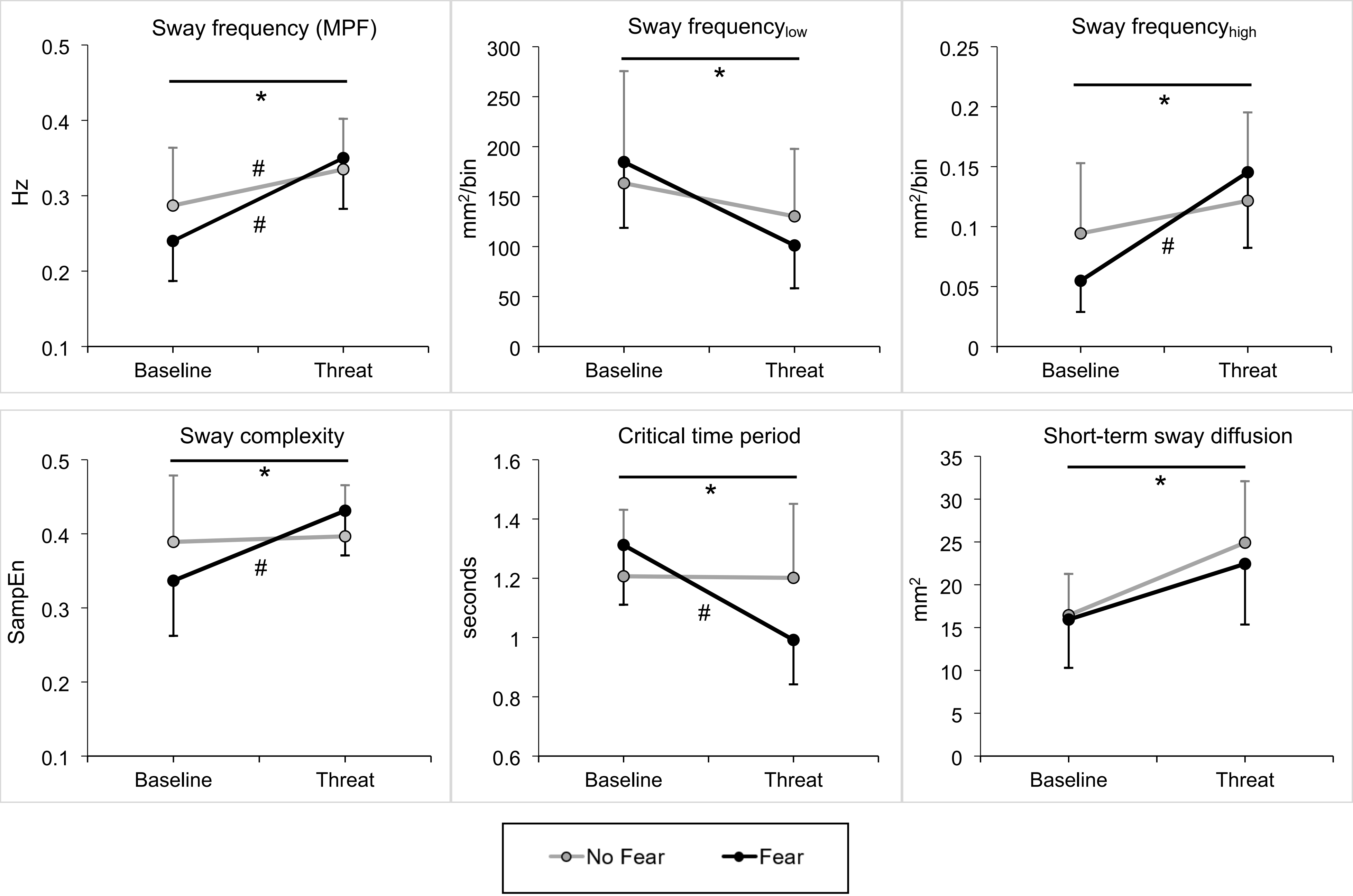
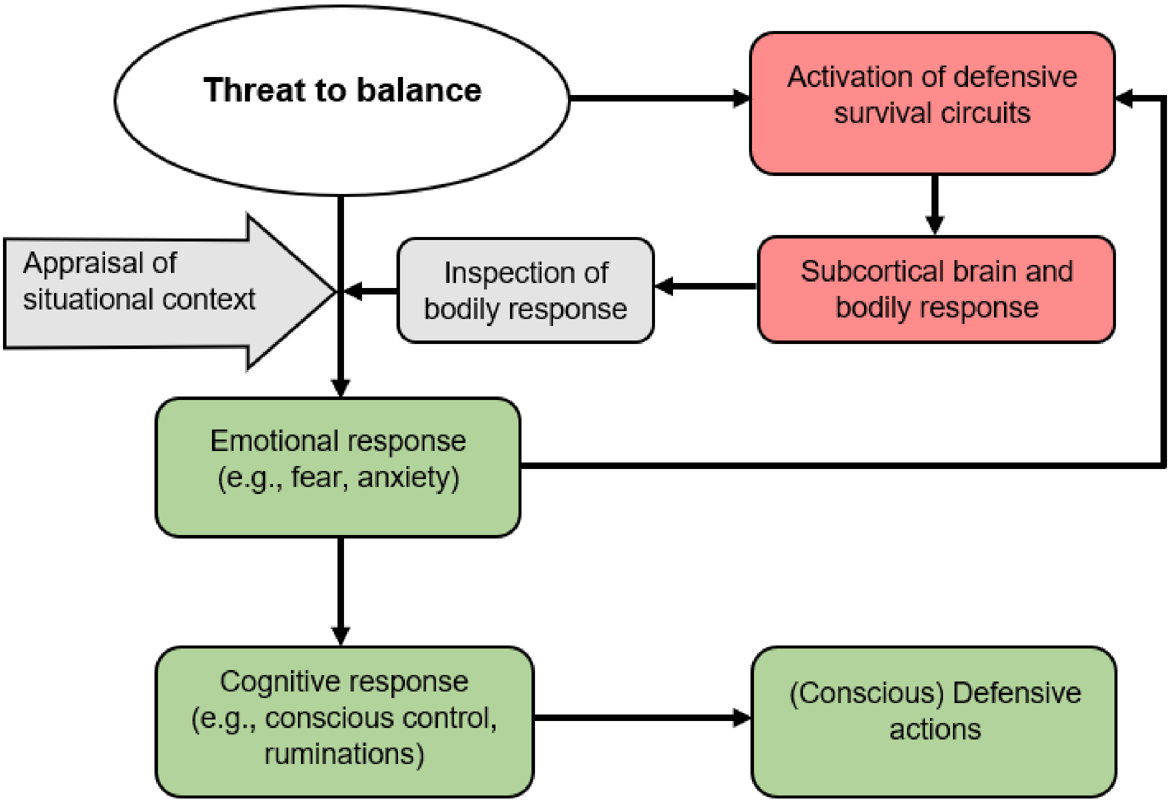


Figure 3. Emotional responses when balance is threatened: A new conceptual framework.



This framework, based on LeDoux's (2014; LeDoux & Pine, 2016) two-system view of fear, describes how emotional, behavioural (balance) and physiological responses to postural threats are triggered. The central tenet of this framework is that postural threats will trigger a series of subcortical (or, 'automatic') defensive responses (red boxes; upper right-hand side) that are then consciously interpreted and integrated with one's appraisal of the situational context. If the situational context is appraised as being likely to cause harm, and the individual interprets the accompanying bodily signals to indicate that they are fearful (and/or anxious), a conscious emotional response will be triggered (green boxes; lower-half of the figure). This will then lead to additional cognitive responses and further (conscious) defensive actions initiated to maximise safety. The specific (automatic) defensive responses and (conscious) defensive actions initiated will likely differ based on both the task being performed and the specific nature of the postural threat itself. Thus, while the defensive responses and actions reported in the present manuscript cannot be generalised beyond either the anterior threat or the orthostatic task in which they were studied, other threats/tasks would trigger their own patterns of stereotyped behaviour.

Table 1. Demographic data for the No Fear and Fear Group.

Mean (range)[a]	**No Fear Group (*n* = 21)**	**Fear Group (*n* = 22)**	***p* value**[b]
Age	72.24 (61-86)	75.50 (64-85)	.131
Gender, males (%)	7/21 (33.33%)	5/22 (22.73%)	.444
Height (cm)	167.57 (153-192)	162.14 (143-175)	.053
Weight (kg)	71.67 (45-113)	69.36 (44-116)	.381
Functional balance (BBS) (0-56)	53.67 (49-56)	52.36 (45-56)	.134
Cognitive function (MoCA) (0-30)	27.24 (20-30)	26.18 (20-29)	.124
Falls in previous year, no. of participants (%)	4/21 (19.05%)	9/22 (40.91%)	.111
No. daily medications	2.29 (0-7)	2.95 (0-6)	.236
Concerns about falling (FES-I)	20.33 (16-34)	23.41 (18-33)	**.009**
Trait anxiety (STAI)	29.00 (20-47)	35.27 (21-56)	**.015**

[a] Unless stated otherwise, variables are reported as the mean (and range).

[b] 2-tailed statistical tests.

Abbreviations: BBS = Berg Balance Scale (scored 0-56, with higher scores indicating better balance); MoCA = Montreal Cognitive Assessment (scored 0-30, with higher scores indicating better cognition); FES-I = Falls Efficacy Scale-International (scored 16-64, with higher scores indicating greater concerns about falling); STAI = Spielberger's State Trait Anxiety Inventory (scored 20-60, with higher scores indicating greater trait anxiety).

Table 2. Mean and standard deviation (*SD*) for all outcome variables.

	No Fear group				**Fear group**			
	Baseline		**Threat**		**Baseline**		**Threat**	
	Mean	*SD*	Mean	*SD*	Mean	*SD*	Mean	*SD*
Self-reported outcomes								
Fear of falling (%)	1.19	3.12	1.19	3.12	7.27	13.16	38.41	21.95
Balance confidence (%)	97.86	4.05	87.38	14.63	93.86	11.75	59.77	23.07
Perceived stability (%)	90.95	13.19	77.86	17.07	88.18	12.49	64.09	24.33
Conscious movement processing								
…Internal awareness	4.19	1.86	5.00	1.30	4.59	1.56	5.23	0.97
…Conscious movement monitoring/control	3.57	2.01	4.00	1.79	3.05	1.86	5.14	0.89
…Self-consciousness	1.33	1.11	1.52	1.21	1.77	1.38	2.09	1.66
…Movement concerns	1.57	1.17	1.81	1.54	1.64	1.29	3.05	1.99
Postural control outcomes								
Sway amplitude (RMS, mm)	4.86	1.84	5.06	1.31	5.10	2.21	4.72	1.45
Sway frequency (MPF, Hz)	0.29	0.17	0.34	0.15	0.24	0.12	0.35	0.15
Sway frequency$_{\mathrm{low}}$ (mm^2/bin)	163.42	246.41	130.25	148.83	184.60	148.59	101.14	96.75
Sway frequency$_{\mathrm{medium}}$ (mm^2/bin)	2.13	1.35	3.39	2.36	1.93	1.61	3.34	2.86
Sway frequency$_{\mathrm{high}}$ (mm^2/bin)	0.09	0.13	0.12	0.16	0.06	0.06	0.15	0.14
Movement complexity (sample entropy)	0.39	0.20	0.40	0.15	0.34	0.17	0.43	0.14
Critical time period (s)	1.21	0.49	1.20	0.55	1.31	0.45	0.99	0.34
Critical displacement (mm^2)	28.76	25.16	33.91	19.59	36.96	48.04	25.60	15.47
Short-term diffusion (D-$y_{s,}$ mm^2/s)	16.45	10.60	24.91	15.76	15.94	12.72	22.44	17.39
Long-term diffusion (D-$y_{l,}$ mm^2/s)	1.16	2.16	1.06	1.65	1.30	1.54	1.11	1.75

Table 3. GEE outputs for self-reported outcome variables.

	Wald χ^2	*p*
Fear of falling		
Condition (*Baseline* vs. *Threat*)	46.71	**<.001**
Group (*No Fear* vs. *Fear*)	49.53	**<.001**
Condition x Group Interaction	46.71	**<.001**
Balance confidence		
Condition (*Baseline* vs. *Threat*)	77.48	**<.001**
Group (*No Fear* vs. *Fear*)	18.70	**<.001**
Condition x Group Interaction	21.75	**<.001**
Perceived stability		
Condition (*Baseline* vs. *Threat*)	49.92	**<.001**
Group (*No Fear* vs. *Fear*)	3.44	.064
Condition x Group Interaction	4.36	**.037**
Internal awareness		
Condition (*Baseline* vs. *Threat*)	8.33	**.004**
Group (*No Fear* vs. *Fear*)	0.77	.380
Condition x Group Interaction	0.12	.730
Conscious movement monitoring/control		
Condition (*Baseline* vs. *Threat*)	19.07	**<.001**
Group (*No Fear* vs. *Fear*)	0.54	.464
Condition x Group Interaction	8.30	**.004**
Self-consciousness		
Condition (*Baseline* vs. *Threat*)	3.49	.062
Group (*No Fear* vs. *Fear*)	1.77	.184
Condition x Group Interaction	0.22	.639
Movement concerns		
Condition (*Baseline* vs. *Threat*)	12.20	**<.001**
Group (*No Fear* vs. *Fear*)	2.81	.094
Condition x Group Interaction	6.17	**.013**

Note: Post-hoc tests that explain any significant interactions are presented in the main text.

Table 4. GEE outputs for postural control outcome variables.

	Wald χ^2	*p*
Sway amplitude (RMS)		
Condition (*Baseline* vs. *Threat*)	0.17	.681
Group (*No Fear* vs. *Fear*)	0.01	.912
Condition x Group Interaction	1.58	.209
Sway frequency (MPF)		
Condition (*Baseline* vs. *Threat*)	27.56	**<.001**
Group (*No Fear* vs. *Fear*)	0.15	.701
Condition x Group Interaction	4.13	**.042**
Sway frequency$_{\mathrm{low}}$		
Condition (*Baseline* vs. *Threat*)	7.04	**.008**
Group (*No Fear* vs. *Fear*)	0.01	.931
Condition x Group Interaction	1.31	.252
Sway frequency$_{\mathrm{mid}}$		
Condition (*Baseline* vs. *Threat*)	19.70	**<.001**
Group (*No Fear* vs. *Fear*)	0.05	.818
Condition x Group Interaction	0.07	.791
Sway frequency$_{\mathrm{high}}$		
Condition (*Baseline* vs. *Threat*)	16.53	**<.001**
Group (*No Fear* vs. *Fear*)	0.05	.825
Condition x Group Interaction	4.78	**.029**
Sway complexity (SampEn)		
Condition (*Baseline* vs. *Threat*)	9.53	**.002**
Group (*No Fear* vs. *Fear*)	0.04	.847
Condition x Group Interaction	6.93	**.008**
Critical time period		
Condition (*Baseline* vs. *Threat*)	3.92	**.048**
Group (*No Fear* vs. *Fear*)	0.22	.642
Condition x Group Interaction	3.67	.055
Critical displacement		
Condition (*Baseline* vs. *Threat*)	0.35	.555
Group (*No Fear* vs. *Fear*)	0.00	.994
Condition x Group Interaction	2.46	.117
Short-term diffusion (D-y_s)		
Condition (*Baseline* vs. *Threat*)	13.97	**<.001**
Group (*No Fear* vs. *Fear*)	0.16	.693
Condition x Group Interaction	0.24	.624
Long-term diffusion (D-y_l)		
Condition (*Baseline* vs. *Threat*)	0.25	.620
Group (*No Fear* vs. *Fear*)	0.04	.834
Condition x Group Interaction	0.02	.876

Note: Post-hoc tests that explain any significant interactions are presented in the main text.