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CrossTalk proposal: Fear of falling does influence vestibular-evoked balance responses

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Introduction

Fear of falling (FoF) is an autonomic, cognitive and behavioural response to a real or imminent threat of a fall (Hadjistavropoulos *et al.* 2011). Given its multidimensional nature, the assessment of fear usually relies on self-report and converging evidence from a number of independent but related measures, such as anxiety (Davis *et al.* 2010), confidence (self-efficacy) and arousal (Hadjistavropoulos *et al.* 2011). Recent studies, in which young healthy adults have been exposed to a postural threat (e.g. standing on an elevated platform where the consequences of a fall are severe), have shown that fear and related factors directly affect control of quiet standing and dynamic balance responses (Brown & Frank, 1997; Carpenter *et al.* 2001, 2004; Sibley *et al.* 2010); however, the mechanisms underlying these fear-related postural changes are yet to be understood fully. Of recent debate is whether FoF-related changes in vestibular function, as evidenced by modulation (or lack thereof) of vestibular-evoked balance responses, might contribute to threat-related adjustments in balance behaviours (Osler *et al.* 2013; Horslen *et al.* 2014). Our position is that FoF does influence vestibular-evoked balance responses.

Evidence in support of our position

We would expect to observe changes in vestibular-evoked balance responses with FoF because of the strong excitatory reciprocal projections between all vestibular nuclei and neural regions responsible for fear-related processes, including the amygdala, the parabrachial nuclei (Balaban, 2002) and the histaminergic system (de Waele *et al.* 1992). These fear-related networks have been implicated in the relationship between anxiety and vestibular or dizziness disorders (Furman & Jacob, 2001; Staab *et al.* 2013). These networks are also thought to be engaged transiently to limit body movement with threat (Balaban, 2002), as part of the ‘freezing’ response to threatening stimuli (Lang *et al.* 2000). As such, larger vestibular-evoked balance responses may be a result of excitation of the central vestibular system, which might normally serve to limit movement, in the presence of a postural threat (Horslen *et al.* 2014).

Vestibular-evoked balance responses can be probed with percutaneous electrical stimulation over the mastoid processes bilaterally to modulate vestibular afferent firing rates (Goldberg *et al.* 1984). This activation of vestibular afferents leads to a virtual head perturbation (Fitzpatrick & Day, 2004). Electrical vestibular stimulation (EVS) evokes patterned activity in axial and appendicular muscles which, when added vectorially, exert a net force onto the ground causing whole-body movement (Britton *et al.* 1993; Fitzpatrick & Day, 2004; Forbes *et al.* 2015). The early responses are most likely to reflect the body’s compensation to an isolated vestibular perturbation (Fitzpatrick & Day, 2004). If the stimulation persists, then feedback from non-vestibular sources can be used to counteract the evoked balance response (Day & Guerraz, 2007). Continuously varying stochastic electrical vestibular stimulation (SVS; Fitzpatrick *et al.* 1996; Dakin *et al.* 2007) evokes muscle and balance responses similar to those elicited with EVS (Dakin *et al.* 2007). Cross-correlations (between SVS and physiological recordings) can resolve the short- (SL) and medium-latency (ML) responses typically examined in response to EVS (Dakin *et al.* 2007, 2010; Reynolds, 2010). Likewise, frequency-based analyses can be used to assess the strength of input–output coupling and gain of the relationship (Dakin *et al.* 2010).

In recent experiments, we showed increased vestibular-evoked balance responses to SVS when subjects stood with their toes at the edge of a platform 3.2 m high, compared with standing at ground level (Horslen *et al.* 2014). Specifically, height-induced threat significantly increased vestibular-evoked SL and ML peak force amplitudes (Fig. 1*A*), as well as gain and coherence between SVS and ground reaction forces. Vestibular-evoked balance responses were also increased in postural muscles when subjects stood under the threat of unpredictable lateral support surface tilt perturbations (Lim, 2014). Both SL and ML peak muscle responses were larger (Fig. 1*B* and *C*), and gain and coherence were increased when

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the threat of perturbation was present, compared with no-threat conditions. Taken together, these findings indicate that the threat of increased consequence or likelihood of a fall increases vestibular gain, as measured by vestibular-evoked balance responses. Osler *et al.* (2013), in contrast, used square-wave EVS to evoke balance responses in subjects who stood with feet in a tandem orientation on an elevated beam and found that trunk kinematic responses were only affected (reduced) in later phases of the response (>800 ms). They concluded that FoF has no effect on early 'feedforward vestibular-evoked balance responses', but 'strongly attenuates the feedback' response (Osler *et al.* 2013). While these results may seem contradictory to the observations of Horslen *et al.* (2014) and Lim (2014), methodological considerations may account for the reported differences. In particular, the high-frequency threat-related changes observed in ground reaction forces (Horslen *et al.* 2014) and muscle activity (Lim, 2014) would be less evident in trunk kinematics because of natural low-pass filtering in conversion from muscle activity or force to sway (Dakin *et al.* 2010; Forbes *et al.* 2015). Likewise, differences in the level of stability due to foot position (tandem *vs.* side by side), threat location/type (both sides *vs.* front *vs.* support surface tilt) and/or EVS characteristics (square-wave *vs.* zero-mean stochastic) may offer additional explanations for the incongruent observations of threat-related changes in early vestibular-evoked balance responses between studies (Osler *et al.* 2013; Horslen *et al.* 2014; Lim, 2014).

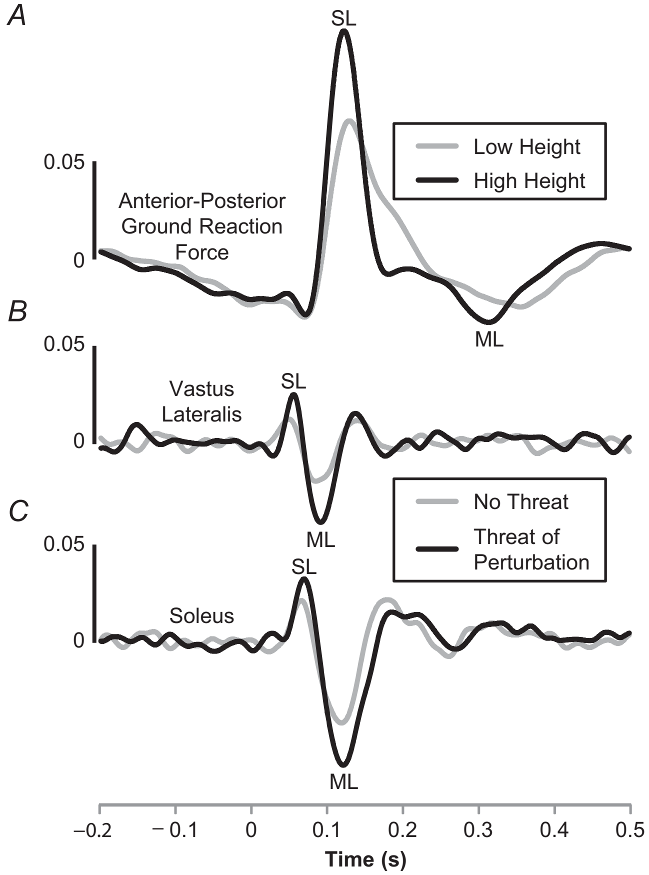

Figure 1. Short- (SL) and medium-latency (ML) vestibular-evoked balance responses with threat

Amplitude-normalized cumulant density plots representing cross-correlation between stochastic electrical vestibular stimulation (SVS) and anterior–posterior ground reaction forces acting on the body (*A*), vastus lateralis (*B*) and soleus muscle activity (*C*). In all cases, positive peaks reflect a positive correlation between SVS and the respective measure [e.g. a positive current caused a forward-directed force (*A*) or increase in muscle activity (*B* and *C*)]. The ground reaction force trace (*A*) is reproduced from Horslen *et al.* (2014; their Fig. 2*C*); SVS (2–25 Hz bandwidth) evoked balance responses while subjects ($n = 10$) stood at low and high surface heights with feet at the edge and head turned 90 deg to the right. The muscle activity traces (*B* and *C*) were reproduced with permission from Lim (2014; her Fig. 3.12); SVS (0–25 Hz) evoked responses while subjects ($n = 13$) stood with the head facing forward with and without the threat of laterally directed support surface perturbations.

Further evidence supporting fear-related influences on vestibular-evoked responses can be drawn from studies that have used alternative methods to probe vestibular function. Vestibular-evoked myogenic potentials (VEMPs) use loud auditory tones or clicks to activate the vestibular receptors directly and evoke short-latency reflexes in tonically engaged muscles (Rosengren *et al.* 2010). Naranjo *et al.* (2015) observed significant increases in VEMP amplitudes in neck and leg muscles actively involved in stabilizing the body and head when subjects stood at the edge of a high compared with a low surface. Furthermore, changes in VEMP amplitude were positively correlated with changes in both FoF and anxiety. These results are consistent with prior evidence of increased vestibulo-ocular reflex gain in conditions of increased anxiety (Yardley *et al.* 1995) or vigilance (Collins, 1988) that would normally accompany a fear response. The SVS, VEMP and vestibulo-ocular reflex studies all demonstrate anxiety- or fear-related excitation of vestibular responses. Combined, this evidence implicates the vestibular nuclei as a likely site for modulation, because vestibular-evoked reflexes in the leg, neck and eye muscles all relay through the vestibular nuclei.

Concluding remarks

Based on the evidence reviewed here, we conclude that FoF increases the amplitude of vestibular-evoked balance responses. One question that remains is how (and if) changes in vestibular-evoked balance responses with FoF contribute to the increases in balance-correcting responses to whole-body perturbation with threat (Brown & Frank, 1997; Carpenter *et al.*

2004; Sibley *et al.* 2010). Vestibular-evoked balance responses are thought to reflect reactions to virtual head perturbation and are distinct from balance-correcting responses to whole-body support surface perturbations (Wardman *et al.* 2003). However, support surface perturbations induce early head accelerations (15–40 ms; Carpenter *et al.* 1999), and balance-correcting responses are known to be attenuated with vestibular deficits (Horlings *et al.* 2009). As such, it is possible that the networks responsible for vestibular-evoked responses can contribute, at least in part, to fear-related changes in balance-correcting responses.

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Additional information

Competing interests

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