Virtual Reality applications in assessing the effect of anxiety on sensorimotor integration in human postural control

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***Abstract*— Falls are a leading cause of injury and mortality among adults over the age of 65 years. Given the strong relation between fear of falling and fall risk, identification of the mechanisms that underlie anxiety-related changes in postural control may pave the way to the development of novel therapeutic strategies aimed at reducing fall risk in older adults. First, we review potential mechanisms underlying anxiety-mediated changes in postural control in older adults with and without neurological conditions. We then present a system that allows for the simultaneous recording of neural, physiological, and behavioral data in an immersive virtual reality (VR) environment while implementing sensory and mechanical perturbations to evaluate alterations in sensorimotor integration under conditions with high postural threat. We also discuss applications of VR in minimizing falls in older adults and potential future studies.**

I. INTRODUCTION

Falls are a prevalent and significant problem in older adults, particularly in those with neurological disorders [1], [2]. Fear of falling is also prevalent in community dwelling older adults, and is strongly associated with a reduced quality of life, activity restriction, loss of independence, and fall-risk [3], [4]. Building upon a model between fear of falling and impaired balance function [4], Young and Williams provide a theoretical framework for how fear of falling influences fall-risk via changes in attentional processes that impact motor control and the retention of salient sensory information from the environment [5]. Consistent with the role of emotional processes in guiding volitional movement, fall-related anxiety is expected to modulate fight-or-flight responses and overall muscle tone via projections from the hypothalamus to the brainstem [6], [7]. However, questions remain about the underlying cause of the stiffening behaviors observed under conditions with high anxiety.

Previous research on how anxiety mediates postural control in older adults has shown a clear relationship between psychological and physiological markers of efficacy and state anxiety on postural control. Carpenter et al.[8] tested the effect of surface height on self-efficacy, state anxiety, and physiological arousal following standing balance tasks in young and older adults. Results showed that center of pressure (COP) displacement, anxiety, and balance efficacy were significantly influenced by surface heights ranging from 0.4 to 1.6 m. These results are echoed by a study from Davis et al.[9], wherein participants completed a standing task at surface heights ranging from 0.8 to 3.2 m, with eyes open, eyes closed, and with blinders. Based on self-reported fear of falling scores taken after each trial, participants were classified as fearful or non-fearful for the analysis. Results showed that fearful and non-fearful participants engaged in different strategies as a function of increased surface height. Specifically, fearful participants showed increased mean power frequency and root mean square of COP displacement at increased heights. Non-fearful participants also showed increased mean power frequency, but decreased root mean square of COP displacement at increased height.

Taken together, these results show the potential for additive effects of psychological and physiological factors on postural control strategies. However, across both studies, the maximum vertical height exposure for an older adult was 1.6 m, which might not be high enough to elicit a robust fear response [9], [10]. In order to circumvent safety issues related to exposing older adults to heights greater than 1.6 m, Cleworth, Horslen, and Carpenter [11] used a head-mounted virtual reality (VR) display to compare the efficacy of real versus virtual height in two height conditions: 0.8 m (low) and 3.2 m (high) above ground. Results showed that COP displacement was greater following changes in height for the real compared to virtual condition. Interestingly, measures of electrodermal activity, anxiety, fear, and COP displacement increased with height irrespective of environment type, while perceived stability, balance confidence, and COP amplitude decreased. Thus, VR is capable of inducing the psychological effects comparable to real world height manipulations, while avoiding the associated risks to health and safety. In this study, we present a system that allows for the simultaneous recording of neural, physiological, and behavioral data in an immersive VR environment while implementing sensory and mechanical perturbations to evaluate alterations in sensorimotor integration under conditions with high postural threat, which may provide a rich testbed for examining the mechanisms underlying stiffening strategies in older adults with fall-related anxiety.

II. ANXIETY INDUCING FACTORS

Anxiety can be defined as a multisystem response to a perceived threat or danger. Anxiety brings about a variety of physical symptoms, such as cardiac acceleration, sweating, and tremors. When looking at the relationship between balance and anxiety, previous studies have shown that people with vestibular disorders are prone to be more anxious [12]. Studies have also suggested a correlation between emotional

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state and sensory organization during postural control [13]. Since the maintenance of balance is dependent on the integration of sensory inputs from various modes including visual, auditory, vestibular and somatosensory stimuli, a potential threat to any of them is expected to have an adverse effect on postural stability. Stance modifications made in response to such threats can be observed using COP sway data and a better understanding of our physiological response to anxiety can be formulated. Furthermore, depending on the amount of anxiety induced, freezing behaviors may also be produced by individuals [14].

A. *Sensory Perturbations*

As shown by various studies, the contribution of the visual system to balance is unique [15], [16], [17]. Visual conflicts, such as moving visual environments, can cause postural changes, disequilibrium, and motion sickness in healthy adults. It is also seen that individuals with anxiety disorders who exhibit space and motion discomfort show a sensitivity to these environments in a very similar way to that shown by patients with balance disorders [18]. Visual threat can not only be introduced by moving environments but also by elevating real or virtual height [11]. Fear of falling when standing on an elevated surface necessitates modifications in strategies used to maintain postural control [9].

Similarly, auditory stimuli can also be used to induce anxiety. The impact of music on emotions has been documented in previous studies [19], [20], [21]. Fear-inducing sounds have also been shown to increase motor evoked potentials in transcranial magnetic stimulation studies [22]. Auditory stimuli can also be used to induce anticipatory anxiety as an aversive stimuli, which can significantly impact postural sway [23]. Thus, together with visual stimuli, auditory stimuli would be expected to further modulate anxiety-mediated postural control changes in older adults.

B. *Mechanical Perturbations*

Another way of inducing anxiety is by introducing a physical postural threat. The expectation of experiencing a mechanical perturbation can cause anticipatory anxiety in subjects and this has been shown to cause trunk sway alterations [24]. Previous studies [24] have shown that the effects of anticipatory anxiety on postural control are dependent on the age and disease status of the individual. Young adults are known to show an increased trunk sway in both anterior-posterior and medial-lateral directions while older adults have demonstrated decreased trunk sway in the medial-lateral directions when expecting a postural threat. On the other hand individuals with Parkinson's Disease showed no significant stance modifications in similar conditions. However, further exploration is needed across older adults with varying levels of fall-risk anxiety.

III. Materials and Methods

Our system consists of a pair of tilting and sliding force platforms (NeuroCom SMART EquiTest computerized posturography clinical research system; Natus Medical Incorporated, Seattle, WA), a head-mounted display (HMD, Oculus Rift DK2, Oculus VR LLC., Menlo Park, CA), optoelectronic sensors (Impulse X2 system, Phasespace, Inc., San Leandro, CA), inertial sensors (IntertiaCubeBT, Thales Visionix, Inc., Billerica, MA), three computers, an analog-digital converter, and a 64 channel actiCHamp active electrode EEG System (Brain Vision LLC, Morrisville, NC) with external electrooculogram (EOG), electromyogram (EMG), and galvanic skin response (GSR) sensors (Fig. 1). VR provides not only a controlled visual stimuli, but also a means to synchronize and temporally align all devices. Using a computer, a virtual environment was rendered in Vizard 5 (WorldViz LLC, Santa Barbara, CA) and displayed on the HMD, while a TTL pulse is transmitted to synchronize force platform measures, platform perturbations, and EEG system. The VR software allows for the integration of motion capture data and inertial measurement unit (IMU) data from gyroscope, accelerometer, and magnetometer sensors in the OculusRift DK2.

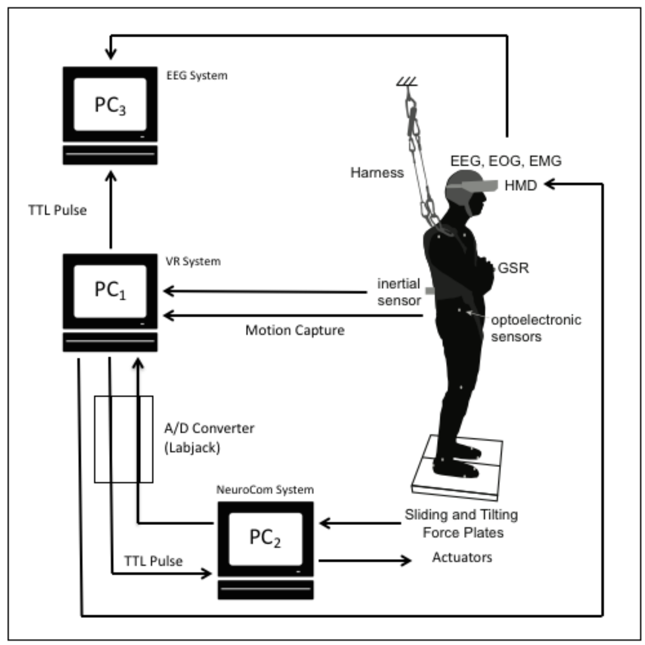

Fig. 1. Main hardware components and data flow.

A. *Force Plate Posturography*

Force plates (Dualtop Accusway, AMTI Inc., Watertown, MA) were used to measure ground reaction forces caused by human body movement. The dual-top force plate allows for independent measurement of forces under the right and left leg (Fig. 1). Using hall-effect sensors 6-degree of freedom measures are obtained from each leg to use for the calculation of left, right, and average center of pressure (COP) measures. A stepper motor-driven system was used to independently tilt the platforms around the mediolateral axis and translate in an anteroposterior direction. Custom movement sequences are programmable to control the motors. A TTL signal from the VR system (PC_1, Fig. 1) was used to synchronize the start and stop of a trial during experimental sessions.

To observe the effect of anxiety on postural control, COP sway velocities and accelerations were evaluated, and together with measurements of the participant's base of support, using a 3D digitizer (FASTRAK, Polhemus, Colchester, Vermont), the virtual time-to-contact was calculated [25]. In addition, the rambling-trembling decomposition of the COP trajectory was used to examine the migration of a reference point (rambling) and the deviation away from that point (trembling) in quiet standing [26] under conditions of sensory and mechanical perturbations.

B. Virtual Reality

In order to assess anxiety-related changes in human postural control, VR environments were developed for precisely controlling visual and auditory stimuli. A stereoscopic display was needed for depth perception, and was implemented via a HMD with built-in sensors for orientation and position tracking. The OculusRift DK2 uses a 1080p OLED panel, split to a 75 Hz 960x1080 per eye rendering. To ensure fast enough rendering of the VR environments, a computer with an nVidia GeForce 750 series graphics card was used and powered both the OLED display on the HMD as well as a monitor that allowed the operator to simultaneously view the VR environments during experiments.

The VR environment consisted of a large room with two platforms. Platform A raised (and lowered) from 0 to 8 m above ground, while platform B consisted of the surrounding floor and lowered (and raised) from 0 to 8 m below ground, via operator's defined inputs. A separate application built using C++ was ran in the background to log IMU data from the OculusRift DK2 and platform height changes in the VR environment for off-line alignment of IMU and VR data. Distribution of data collection, actuation control, and VR environment was carried out to adequately handle VR environment rendering and high-density multimodal data recording.

C. Galvanic Skin Response

Galvanic Skin Response (GSR) offers insight as an efficient means to measure anxiety induced in the different Virtual Reality situations. GSR works by capturing the autonomic nerve responses as a parameter of sweat gland function [27]. The amount of sweat produced can be related back to the amount of anxiety induced in a particular trial. GSR data collected in this setup provided a quantitative assessment of anxiety to use in unison with self-reported evaluations in between trials.

D. EEG

Using electroencephalography (EEG), anxiety has been linked to changes in frontal EEG asymmetry and alpha (8-12 Hz) band activity [28] that is amenable to biofeedback and physical training [29], [30]. Alpha power has been shown to be correlated with nonclinical depression and anxiety [28]. Thus, EEG data collected during quiet standing tasks in high-anxiety conditions provide salient information about the neural mechanisms underlying the generation of emotionally-mediated stiffening behaviors.

E. Inertial and optoelectronic sensors

Together with the recording of EOG and EMG data, inertial and optoelectronic sensors were utilized to monitor changes in movement strategies. Using inertial sensors from the OculusRift DK2 and from an approximation of the participant's center of mass position, along the center of L5/S1, both head and body sway can be monitored during trials. Using optoelectronic sensors provides further kinematic data used to differentiate between the use of ankle, hip, and mixed postural control strategies across conditions.

F. Applications

The use of VR to examine postural control changes due to visual stimuli has been well documented [31], [32], [33], and has been shown to be effective in training individuals with balance difficulties [34]. However, we can further the applicability of our system with the introduction of EEG and GSR based biofeedback paradigms that can be used to benefit people with a heightened risk of falling and anxiety. Providing visual or auditory information about alpha rhythms or physiological states could then be used to reduce anxiety levels and inspect the compensatory postural adjustments made by the individual. Thus, this system may further complement existing methods of balance training.

The treatment of anxiety in people with balance dysfunction is another promising application. There is evidence that anxiety and balance share some common neural pathways [35], [36]. Balance dysfunction in people with Parkinson's disease, multiple sclerosis, vestibular dysfunction, stroke patients or even healthy older adults can therefore have a causal effect on anxiety. Hence, improving the balance control with the use of our VR setup may not only improve stability but also act as a treatment for some anxiety disorders [37]. We have already talked about the capacity to introduce auditory stimuli as a fear-inducing stimuli. Conversely, auditory stimuli can also be used in a VR environment to alleviate the fear of falling as discussed by Seinfeld et al. [38]. Such techniques can again be used to alleviate anxiety and improve postural control.

A possible rehabilitation modality for individuals with visual vertigo is yet another application worth exploring. Visual vertigo symptoms are provoked by excessive or disorientating visual stimuli and previous studies have shown that VR environments are a useful adjunct to vestibular rehabilitation programs [39]. Such VR-based training programs have already proven advantageous in people with Parkinson's disease, multiple sclerosis, chronic stroke, and cerebral palsy [40], [41]. Thus, the use of VR training on individuals with visual vertigo merits further investigation.

IV. Conclusion

The capability to introduce and have control over various forms of visual, postural and proprioceptive stimuli in a safe environment, in unison with synchronized neural and behavioral measures is crucial to examining the mechanisms that underlie anxiety-related changes in postural control. Through the consideration for the comfort and safety of participants, the VR setup introduced may provide a rich testbed for evaluating alterations in sensorimotor integration under conditions with high postural threat and during future rehabilitative applications.

References

[1] W. Koller, S. Glatt, B. Vetere-Overfield, and R. Hassanein, "Falls and parkinson's disease," *Clin Neuropharmacol*, vol. 12, no. 2, pp. 98–105, 1989.

[2] M. Nevitt, S. Cummings, and E. Hudes, "Risk factors for injurious falls: a prospective study," *J Gerontol*, vol. 46, no. 5, pp. M164–70, 1991.

[3] S. Friedman, B. Munoz, S. West, G. Rubin, and L. Fried, "Falls and fear of falling: which comes first? a longitudinal prediction model suggests strategies for primary and secondary prevention," *J Am Geriatr Soc*, vol. 50, no. 8, pp. 1329–35, 2002.

[4] T. Hadjistavropoulos, K. Delbaere, and T. Fitzgerald, "Reconceptualizing the role of fear of falling and balance confidence in fall risk," *J Aging Health*, vol. 23, no. 1, pp. 3–23, 2011.

[5] W. Young and A. Mark Williams, "How fear of falling can increase fall-risk in older adults: applying psychological theory to practical observations," *Gait Posture*, vol. 41, no. 1, pp. 7–12, 2015.

[6] K. Takakusaki, K. Saitoh, H. Harada, and M. Kashiwayanagi, "Role of basal ganglia-brainstem pathways in the control of motor behaviors," *Neurosci Res*, vol. 50, no. 2, pp. 137–51, 2004.

[7] K. Takakusaki, "Neurophysiology of gait: from the spinal cord to the frontal lobe," *Mov Disord*, vol. 28, no. 11, pp. 1483–91, 2013.

[8] M. Carpenter, A. Adkin, L. Brawley, and J. Frank, "Postural, physiological and psychological reactions to challenging balance: does age make a difference?" *Age Ageing*, vol. 35, no. 3, pp. 298–303, 2006.

[9] J. Davis, A. Campbell, A. Adkin, and M. Carpenter, "The relationship between fear of falling and human postural control," *Gait Posture*, vol. 29, no. 2, pp. 275–9, 2009.

[10] L. Brown, M. Polych, and J. Doan, "The effect of anxiety on the regulation of upright standing among younger and older adults," *Gait Posture*, vol. 24, no. 4, pp. 397–405, 2006.

[11] T. Cleworth, B. Horslen, and M. Carpenter, "Influence of real and virtual heights on standing balance," *Gait Posture*, vol. 36, no. 2, pp. 172–6, 2012.

[12] S. Eagger, L. Luxon, R. Davies, A. Coelho, and M. Ron, "Psychiatric morbidity in patients with peripheral vestibular disorder: a clinical and neuro-otological study," *J. Neurol. Neurosurg. Psychiatry*, vol. 55, no. 5, pp. 383–387, 1992.

[13] B. Bolmont, P. Gangloff, A. Vouriot, and P. Perrin, "Mood states and anxiety influence abilities to maintain balance control in healthy human subjects," *Neurosci. Lett.*, vol. 329, no. 1, pp. 96–100, 2002.

[14] J. Stins, M. Roerdink, and P. Beek, "To freeze or not to freeze? affective and cognitive perturbations have markedly different effects on postural control," *Hum Mov Sci*, vol. 30, no. 2, pp. 190–202, 2011.

[15] M. Redfern, L. Yardley, and A. M. Bronstein, "Visual influences on balance," *J. Anxiety Disord.*, vol. 15, no. 1-2, pp. 81–94, 2001.

[16] W. Paulus, A. Stuabe, and T. Brandt, "Visual stabilization of posture. physiological stimulus characteristics and clinical aspects," *Brain*, vol. 107, no. 4, pp. 1143–1163, 1984.

[17] A. Bronstein, "Suppression of visually evoked postural responses," *Experimental Brain Research*, vol. 63, no. 3, pp. 655–658, 1986.

[18] R. Jacob, M. Redfern, and J. Furman, "Optic flow-induced sway in anxiety disorders associated with space and motion discomfort," *Journal of Anxiety Disorders*, vol. 9, no. 5, pp. 411–425, 1995.

[19] T. Baumgartner, K. Lutz, C. Schmidt, and L. Jncke, "The emotional power of music: how music enhances the feeling of affective pictures," *Brain Res*, vol. 1075, no. 1, pp. 151–64, 2006.

[20] T. Baumgartner, M. Esslen, and L. Jncke, "From emotion perception to emotion experience: emotions evoked by pictures and classical music," *Int J Psychophysiol*, vol. 61, no. 1, pp. 34–43, 2006.

[21] T. Baumgartner, M. Willi, and L. Jncke, "Modulation of corticospinal activity by strong emotions evoked by pictures and classical music: a transcranial magnetic stimulation study," *Neuroreport*, vol. 18, no. 3, pp. 261–265, 2007.

[22] F. Giovannelli, C. Banfi, A. Borgheresi, E. Fiori, I. Innocenti, S. Rossi, G. Zaccara, M. Viggiano, and M. Cincotta, "The effect of music on corticospinal excitability is related to the perceived emotion: a transcranial magnetic stimulation study," *Cortex*, vol. 49, no. 3, pp. 702–10, 2013.

[23] M. Ishida, J. Saitoh, M. Wada, and M. Nagai, "Effects of anticipatory anxiety and visual input on postural sway in an aversive situation," *Neurosci Lett*, vol. 474, no. 1, pp. 1–4, 2010.

[24] J. Shaw, L. Stefanyk, J. Frank, M. Jog, and A. Adkin, "Effects of age and pathology on stance modifications in response to increased postural threat," *Gait Posture*, vol. 35, no. 4, pp. 658–61, 2012.

[25] S. Slobounov, S. Moss, E. Slobounova, and K. Newell, "Aging and time to instability in posture," *J Gerontol A Biol Sci Med Sci*, vol. 53, no. 1, pp. B71–8, 1998.

[26] V. Zatsiorsky and M. Duarte, "Instant equilibrium point and its migration in standing tasks: rambling and trembling components of the stabilogram," *Motor Control*, vol. 3, no. 1, pp. 28–38, 1999.

[27] J. D. Montagu and E. M. Coles, "Mechanism and measurement of the galvanic skin response," *Psychological Bulletin*, vol. 65, no. 5, pp. 261–179, 1966.

[28] D. Mathersul, L. Williams, P. Hopkinson, and A. Kemp, "Investigating models of affect: relationships among eeg alpha asymmetry, depression, and anxiety," *Emotion*, vol. 8, no. 4, pp. 560–72, 2008.

[29] A. Deslandes, H. Moraes, H. Alves, F. Pompeu, H. Silveira, R. Mouta, C. Arcoverde, P. Ribeiro, M. Cagy, R. Piedade, J. Laks, and E. Coutinho, "Effect of aerobic training on eeg alpha asymmetry and depressive symptoms in the elderly: a 1-year follow-up study," *Braz J Med Biol Res*, vol. 43, no. 6, pp. 585–92, 2010.

[30] I. Dziembowska, P. Izdebski, A. Rasmus, J. Brudny, M. Grzelczak, and P. Cysewski, "Effects of heart rate variability biofeedback on eeg alpha asymmetry and anxiety symptoms in male athletes: A pilot study," *Appl Psychophysiol Biofeedback*, 2015.

[31] T. Tossavainen, M. Juhola, I. Pyykk, H. Aalto, and E. Toppila, "Development of virtual reality stimuli for force platform posturography," *Int J Med Inform*, vol. 70, no. 2-3, pp. 277–83, 2003.

[32] T. Tossavainen, E. Toppila, I. Pyykk, P. Forsman, M. Juhola, and J. Starck, "Virtual reality in posturography," *IEEE Trans Inf Technol Biomed*, vol. 10, no. 2, pp. 282–92, 2006.

[33] E. Keshner, J. Streepey, Y. Dhaher, and T. Hain, "Pairing virtual reality with dynamic posturography serves to differentiate between patients experiencing visual vertigo," *J Neuroeng Rehabil*, vol. 4, p. 24, 2007.

[34] H. Surez, A. Surez, and L. Lavinsky, "Postural adaptation in elderly patients with instability and risk of falling after balance training using a virtual-reality system," *Int Tinnitus J*, vol. 12, no. 1, pp. 41–4, 2006.

[35] C. Balaban and J. Thayer, "Neurological bases for balance-anxiety links," *J Anxiety Disorder*, vol. 15, no. 1-2, pp. 53–79, 2001.

[36] C. Balaban, "Vestibular nucleus projections to the parabrachial nucleus in rabbits: implications for vestibular influences on the autonomic nervous system," *Exp Brain Res*, vol. 108, no. 3, pp. 367–381, 1996.

[37] S. Shefer, C. Gordon, K. Avraham, and M. Mintz, "Balance deficit enhances anxiety and balance training decreases anxiety in vestibular mutant mice," *Behav Brain Res.*, vol. 276, pp. 76–83, 2015.

[38] S. Seinfeld, I. Bergstrom, A. Pomes, J. Arroyo-Palacios, F. Vico, M. Slater, and M. Sanchez-Vives, "Influence of music on anxiety induced by fear of heights in virtual reality," *Front Psychol.*, 2016. [Online]. Available: http://dx.doi.org/10.3389/fpsyg.2015.01969

[39] M. Pavlou, R. Kanegaonkar, D. Swapp, D. Bamiou, M. Slater, and L. Luxon, "The effect of virtual reality on visual vertigo symptoms in patients with peripheral vestibular dysfunction: a pilot study," *J Vestib Res.*, vol. 22, no. 5-6, pp. 273–281, 2012.

[40] B. Eftekharsadat, A. Babaei-Ghazani, M. Mohammadzadeh, M. Talebi, F. Eslamian, and E. Azari, "Effect of virtual reality-based balance training in multiple sclerosis," *Neurol Res.*, vol. 37, no. 6, pp. 539–544, 2015.

[41] R. Sumec, P. Filip, K. Sheardova, and M. Bares, "Psychological benefits of nonpharmacological methods aimed for improving balance in parkinson?s disease: A systematic review," *Behavioural Neurology*, 2015. [Online]. Available: http://dx.doi.org/10.1155/2015/620674