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INCREASED GAIN OF VESTIBULOSPINAL POTENTIALS EVOKED IN NECK AND LEG MUSCLES WHEN STANDING UNDER HEIGHT-INDUCED POSTURAL THREAT

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Abstract—*Objective:* To measure changes in amplitudes of vestibular evoked myogenic potentials (VEMPs) elicited from neck, upper and lower limb muscles during a quiet standing task with increased postural threat achieved by manipulating surface height. *Methods:* Twenty eight subjects were tested while standing on a platform raised to 0.8 m and 3.2 m from the ground. Surface electromyography was recorded from the ipsilateral sternocleidomastoid (SCM), biceps brachii (BB), flexor carpi radialis (FCR), soleus (SOL) and medial gastrocnemius (MG) muscles. Stimulation was with air-conducted short tone bursts (4 ms). After controlling for background muscle activity, VEMP amplitudes were compared between heights and correlated with changes in state anxiety, fear and arousal. *Results:* VEMP amplitude significantly increased in SCM (9%) and SOL (12.7%) with increased surface height ($p < 0.05$). These modest increases in SCM VEMP amplitude were significantly correlated with anxiety (*Rho* = 0.57, $p = 0.004$) and confidence (*Rho* = −0.38, $p = 0.047$) and those for SOL were significantly correlated with anxiety (*Rho* = 0.33, $p = 0.049$) and fear (*Rho* = 0.36, $p = 0.037$). *Conclusion:* Postural threat significantly increased vestibulospinal reflex (VSR) gains. Results demonstrate that VEMPs can be used to test different VSR pathways simultaneously during stance. Since fear and anxiety are prevalent with vestibular disorders, they should be considered as potential contributing factors for clinical vestibular outcome measures.

Key words: fear, anxiety, arousal, vestibular evoked myogenic potential, vestibulospinal reflex, standing.

INTRODUCTION

Previous research on animal models has provided neuroanatomical evidence for a potential relationship between vestibular function and threat-related responses such as fear, anxiety, arousal and vigilance. Potential neural substrates for threat-related changes in vestibular function include excitatory projections to the vestibular nuclei from regions processing fear and anxiety through the parabrachial nucleus, the raphe nucleus obscurus and the locus coeruleus (Balaban and Thayer, 2001; Balaban, 2002; Staab et al., 2013) and vigilance through the central histaminergic system (de Waele et al., 1992; Serafin et al., 1993; Yabe et al., 1993; Peng et al., 2013). Although direct evidence of these neural links in humans is limited, there is indirect evidence to support a relationship between threat-related changes and vestibular function.

Previous studies examining the association between threat and the vestibular function have focused primarily on changes in the vestibulo-ocular reflex (VOR) in patients with chronic anxiety or panic disorders (Furman et al., 2006). The major limitation of these studies was the inability to determine a causal relationship between anxiety and vestibular function, and to control for subjects' anxiety levels at the time of VOR assessment. Experiments that have attempted to induce mental stress and arousal through mental arithmetic have demonstrated significant increases in VOR gain with increases in arousal (Yardley et al., 1995). Likewise, vigilance, which is defined as sustained state of attention or tonic alertness, but includes an element of arousal (Oken et al., 2006), has been manipulated through sleep deprivation (Collins, 1988; Quarck et al., 2006) or amphetamine administration (Collins and Poe, 1962) and shown to significantly increase VOR gain, amplitude or duration. However, in these studies, the levels of anxiety, arousal or vigilance were not directly measured nor controlled. Despite these limitations, this research has provided converging evidence of a relationship between threat-related changes and VOR gain. However, less is known about the effects of state anxiety and arousal on the vestibulospinal reflexes (VSRs), which have a direct influence on balance control and involve different nuclei and pathways than those of the VOR.

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Abbreviations: BB, biceps brachii; BGA, muscle background activity; cVEMP, cervical vestibular evoked myogenic potential; EDA, electrodermal activity; EMG, electromyography; FCR, flexor carpi radialis; GVS, galvanic vestibular stimulation; MG, medial gastrocnemius; SCM, sternocleidomastoid; SOL, soleus; SVS, stochastic vestibular stimulation; VEMP, vestibular evoked myogenic potential; VOR, vestibulo-ocular reflex; VSR, vestibulospinal reflex.

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When subjects are standing on high elevated surfaces, a postural threat is generated, which is known to increase the levels of anxiety, fear of falling and arousal (Carpenter et al., 2001). Vigilance, or a sustained state of attention or tonic alertness, is also likely increased during these threat conditions, in which a degree of arousal is implied (Oken et al., 2006). Therefore, real heights have been used as a method to manipulate fear, anxiety state and autonomic arousal (Carpenter et al., 2001; Davis et al., 2009; Horslen et al., 2014), in order to examine the relationship between changes in static and dynamic postural control, sensorimotor function (Horslen et al., 2013, 2014) and sense of vertigo (Brandt and Huppert, 2014). Horslen et al. (2014), recently investigated ground reaction forces evoked with Stochastic Vestibular Stimulation (SVS) in subjects standing at different heights. These results demonstrated an increase in VSR gain during height-induced states of fear and anxiety, expressed by an increased gain and coherence between the galvanic input and the ground reaction forces and moments. These results contrast the findings of Osler et al. (2013) that reported no significant height-related changes in the early kinematic response to square-wave Galvanic Vestibular stimulation (GVS). The contrasting findings may be explained by methodological differences between both studies (Horslen et al., 2014; Osler et al., 2013).

An alternative method to probe the vestibulospinal system is to use vestibular-evoked myogenic potentials (VEMPs). Unlike galvanic stimulation, VEMPs probe the vestibular system directly by activating the hair cells at the end-organs and not indirectly at the vestibular nerve. A VEMP is usually defined as a short-latency potential most commonly recorded through electromyography (EMG) from tonically contracted neck muscles (i.e. sternocleidomastoid (SCM)) in response to auditory air-conducted clicks or short tone-bursts or bone-conducted stimuli (Welgampola and Colebatch, 2005). VEMPs have also been elicited from distal limb muscles in the leg and arm that are engaged in a postural task, including the soleus (SOL) (Watson and Colebatch, 1998), medial gastrocnemius (MG) (Rusidill and Hain, 2008), and triceps brachii (Cherchi et al., 2009). Thus, VEMPs provide a reliable and robust screening test for assessing vestibulospinal pathways extending to all levels of the spinal cord (see Fig. 1). The clinical interpretation of VEMPs elicited in cervical muscles (cVEMPs) is based in the assumption that these originate in the saccule (Welgampola and Colebatch, 2005), with vestibular function disorders having absent or severely decreased myogenic potentials (Murofushi et al., 1999). The evoked potential is projected to the medial and lateral vestibular nuclei neurons that induce inhibitory postsynaptic potentials to the ipsilateral SCM motorneurons (Colebatch and Rothwell, 2004). However, to our knowledge, no studies to date have elicited VEMPs from neck, arm and leg muscles simultaneously during stance.

The objective of this study was to measure the effects of height-induced threat on the amplitude of VEMPs used as a measure of VSR gain to different muscles. Based on previous research we hypothesized that VEMP amplitudes would increase with increased threat, and correlate with threat-related changes in fear, anxiety, arousal and confidence.

EXPERIMENTAL PROCEDURES

Twenty eight healthy individuals (10 females; age = 27.3 ± 5.4; height = 168.9 ± 12.5 cm; weight = 70.4 ± 11.6 kg) volunteered for the study. All subjects were free from any neurological or orthopedic balance deficits, hearing or cognitive impairments, extreme fear of heights, frequent or severe headaches, pregnancy and/or history of low blood pressure or fainting, history of chronic neck pain or/and whiplash-associated balance deficits, or abnormal neck movement restrictions, as verified by self-report. Before participating, all subjects read and signed an informed consent form approved by the Clinical Research Ethics Board of the University of British Columbia.

Experimental set-up

Subjects stood sideways to and at the edge of a hydraulic lift (M419-207B10H01D, Pentalift, Guelph, Ontario, Canada) on a force plate (#K00407, Bertec, Columbus, Ohio, USA). Their feet were placed shoulder-width apart. The elevation of the hydraulic lift was either 0.8 m (Low condition) or 3.2 m above the ground (High condition). Standing at 3.2 m has been shown to cause significant increases in anxiety, fear and arousal, and decreases in balance confidence and perceived stability in young adults (Adkin et al., 2000; Davis et al., 2009). In the Low condition, a table was placed in front of and flushed with the force plate, in order to mimic standing at ground level (Davis et al., 2009).

Participants were secured with a harness attached to the ceiling that prevented them from falling, and an experimenter remained next to them during the trials to aid in case of a fall and to ensure that the experimental protocol was followed correctly. Trials were always presented in an ascending order of height conditions in order to maximize the effect of height (Adkin et al., 2000).

EMG was recorded from the following right-sided muscles ipsilateral to the side of stimulation: SCM, biceps brachii (BB), flexor carpi radialis (FCR), SOL, and MG. All muscles were tonically active during the experiments to ensure a VEMP response was elicited. The right SCM was activated by having the subjects voluntarily maintain a yaw head rotation 60° to the left (looking over the edge of the platform). A laser pointer attached on top of the head provided participants with visual feedback to maintain the head rotation throughout each height condition. BB and FCR were activated by holding a 1-kg bar in both hands, while maintaining the elbows flexed at 90° and the wrists in the neutral position. SOL and MG were activated by elevating both heels with a 30° wedge under each foot. The subject's lower leg position was monitored during both height conditions to ensure similar lower leg muscle background activity (BGA) throughout the trials (see Fig. 2).