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Influence of virtual height exposure on postural reactions to support surface translations

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ABSTRACT

As fear of falling is related to the increased likelihood of falls, it is important to understand the effects of threat-related factors (fear, anxiety and confidence) on dynamic postural reactions. Previous studies designed to examine threat effects on dynamic postural reactions have methodological limitations and lack a comprehensive analysis of simultaneous kinetic, kinematic and electromyographical recordings. The current study addressed these limitations by examining postural reactions of 26 healthy young adults to unpredictable anterior–posterior support-surface translations (acceleration = 0.6 m/s^2, constant velocity = 0.25 m/s, total displacement = 0.75 m) while standing on a narrow virtual surface at Low (0.4 cm) and High (3.2 m) virtual heights. Standing at virtual height increased fear and anxiety, and decreased confidence. Prior to perturbations, threat led to increased tonic muscle activity in tibialis anterior, resulting in a higher co-contraction index between lower leg muscles. For backward perturbations, muscle activity in the lower leg and arm, and center of pressure peak displacements, were earlier and larger when standing at virtual height. In addition, arm flexion significantly increased while leg, trunk and center of mass displacements remained unchanged across heights. When controlling for leaning, threat-related factors can influence the neuro-mechanical responses to an unpredictable perturbation, causing specific characteristics of postural reactions to be facilitated in young adults when their balance is threatened.

1. Introduction

The effects of threat-related factors such as fear, anxiety and arousal on static balance control have been well established through comparisons between fearful and non-fearful subjects [1], and within-subject changes in healthy adults standing in threatening conditions such as elevated surfaces [2,3]. Under threatening conditions, the amplitude and frequency of sway during static balance is altered, and may be associated with concomitant changes in tonic muscle activity of lower leg muscles [3], increased stiffness [3], and increased proprioceptive and vestibular reflex gains [4,5]. The effects of threat on dynamic balance reactions are less clear. A limited number of studies have examined dynamic postural responses of young healthy adults standing at the edge of an elevated platform in response to upper trunk perturbations [6,7], sudden trunk release [8], or support surface rotations [9]. However, comparison across studies is made difficult by inconsistent use of perturbation type and measures (see Table 1), and interpretations are limited by the potential confounding effects of having a direction-specific threat (a single platform edge) and perturbations that are either too small [6,7,9], or are predictable in direction [8]. These methodological limitations can allow subjects to adopt anticipatory postural changes that have the potential to influence a balance reaction. For example, anticipatory leaning to counter a predictable perturbation direction, or move COM away from the edge at height can potentially reduce balance-correcting responses and increase hip displacement [10]. The current study was designed to address these limitations with a comprehensive and controlled analysis of the effects of a postural threat on kinetic, kinematic and muscular responses to a large, unpredictable postural perturbation, which is essential to help consolidate our current understanding of the effects of threat on dynamic balance. Virtual reality (VR) was used to provide a bi-directional threat, by having subjects stand on a virtual

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Table 1
Previous reports of fear and anxiety influences on postural reactions.

		Brown and Frank [6]	Adkin et al. [7]	Sibley et al. [8]	Carpenter et al. [9]	Current study
Methods	Subjects	8	10	10	10	26
	Perturbation	Push	Push	Release	Rotations	Translations
	Height	0.8 m	3.2 m	1.6 m	1.6 m	3.2 m (virtual)
	Pert Dir	Uni	Uni	Uni	Multi	Bi
	Threat Dir	Uni	Uni	Uni	Uni	Bi
Pre	Lean	↑		ns		ns
	BGA			ns	↑ BF	↑ TA,DEL
	CCI					↑ LL; UL/T ns
COP	Amplitude			↑		↑
	Latency			↓		↓
COM	Disp	Amp	↓		↓ (FP); ↑ (BP)	ns
		Lat	ns			ns
	Vel	Amp	ns			ns
		Lat	↓			ns
Segments	Arm Disp.					↑
	Trunk Disp.				↓	ns
	UL Disp.				↓	ns
	LL Disp.				↓	ns
EMG	Amplitude		MG ns	↑ MG	↑ all	↑ MG,DEL
	Latency		MG ns	↓ MG	↓ DEL	↓ MG,OB,DEL
Psych	Confidence		↓		↓	↓
	Fear		↑			↑
	Anxiety		↑	↑	↑	↑

COP = center of pressure; COM = center of mass; EMG = electromyography; Psych = psycho-social variables; Pert Dir = perturbation direction; Disp = displacement; Vel = velocity; UL = upper leg; LL = lower leg; T = trunk; Amp = amplitude; Lat = latency; BGA = background activity; CCI = co-contraction index; MG = medial gastrocnemius; DEL = deltoid; BF = biceps femoris; TA = tibialis anterior; OB = external obliques; FP = forward perturbation; BP = backward perturbation; ns = nonsignificant differences; Empty cells indicate where no measure was reported.

moving platform that had a narrow support surface (with edges equidistant to the front and back of the feet), and could be raised to different virtual heights. Virtual height has been shown to induce emotional and postural changes similar to those experienced in real settings [11], and has been used to study the effects of threat on static balance and gait [11,12], but not, to our knowledge, during dynamic balance reactions.

After controlling for potential confounding effects of leaning and expectation by using bi-directional threat and perturbation, we hypothesized that threat-related increases in stiffness and sensory gain [3–5] would influence dynamic postural responses in terms of (a) larger and earlier peak center of pressure (COP) displacements [8]; (b) reduced center of mass (COM) and leg segment displacements [6,9]; and (c) larger and earlier balance correcting EMG responses, particularly in the arm [8,9].

2. Methods

2.1. Participants

Subjects were 26 healthy young adults (mean ± SD, 23 ± 3 years old, 173 ± 10 cm tall, weighing 153 ± 23 lbs) with no known neurological or musculoskeletal disorders, or claustrophobia based on self-report. All subjects provided informed written consent in accordance with the local university ethics board.

2.2. Apparatus

A head mounted display (HMD) VR system (resolution = 20 pixels/° field of view = 150° × 60°, mass = 1 kg, PiSight, Sensics, USA) was fitted to optimize viewing, and surrounded by a black cloth to occlude vision outside the HMD. In the virtual environment, subjects perceived themselves to be standing within a simulated laboratory, on top of a wheeled scissor-lift capable of translating and elevating from the ground (Vizard, WorldViz, USA, see Fig. 1). Movement of the virtual scene was linked to real-time head position recorded (125 Hz) from a rigid body mounted to the HMD (Optotrak, Northern Digital Canada, CAN). Additional infrared (IRED) markers were used to control an avatar (LiveCharacters, WorldViz, USA), linked to the subject's real-time body movements (MotionBuilder; Autodesk, USA) that could be viewed by the subject in the virtual environment from a first-person perspective.

Subjects stood on a forceplate (40 × 60 cm, model BP 400600-1000, AMTI, USA) fixed to a motorized platform (DRS 120-09-176, H2W Technologies Inc., USA) that translated antero-posterior (AP) in the horizontal plane (acceleration = 0.6 m/s^2, constant velocity = 0.25 m/s, total displacement = 0.75 m). The forceplate was embedded within a larger wooden surround (123 cm long × 60 cm wide; 26 cm high). Subjects' feet were positioned side-by-side with a distance between the lateral borders of the feet equal to their foot length, and marked for reference between conditions. Subjects stood with arms at their side while looking at a visual (virtual) target at eye level 4.2 m away (at each height).

2.3. Procedures

In order to increase the sense of presence within the virtual environment, subjects first performed a 5 min immersion protocol consisting of a series of object search and identification tasks and explored the edges of the real (and corresponding virtual) platform with their feet. Subjects were positioned at a virtual Low height (0.4 m) then a High height (3.2 m) during the experiment. During periods when the platform was raised in the virtual environment, the sounds recorded from a real-life hydraulic lift were played back to the subject via headphones, to further increase their sense of presence.

Subjects experienced 10 practice perturbations (forward and backward directions counter-balanced) at the Low height to become familiar with the protocol and eliminate habituation/first trial effects [13]. During all perturbations (practice and