Available online at www.sciencedirect.com
ScienceDirect
Gait & Posture 28 (2008) 127–134
GAIT & POSTURE
www.elsevier.com/locate/gaitpost

Characterizing head motion in three planes during combined visual and base of support disturbances in healthy and visually sensitive subjects

E.A. Keshner [a,b,*], Y. Dhaher [a,b,c]

[a] Sensory Motor Performance Program, Rehabilitation Institute of Chicago, Chicago, IL 60611, United States
[b] Department of Physical Medicine and Rehabilitation, Feinberg School of Medicine, Northwestern University, Chicago, IL 60611, United States
[c] Biomedical Engineering Department, Northwestern University, Evanston, IL 60208, United States

Received 16 March 2007; received in revised form 31 October 2007; accepted 7 November 2007

Abstract

Multiplanar environmental motion could generate head instability, particularly if the visual surround moves in planes orthogonal to a physical disturbance. We combined sagittal plane surface translations with visual field disturbances in 12 healthy (29–31 years) and 3 visually sensitive (27–57 years) adults. Center of pressure (COP), peak head angles, and RMS values of head motion were calculated and a three-dimensional model of joint motion was developed to examine gross head motion in three planes. We found that subjects standing quietly in front of a visual scene translating in the sagittal plane produced significantly greater ($p < 0.003$) head motion in yaw than when on a translating platform. However, when the platform was translated in the dark or with a visual scene rotating in roll, head motion orthogonal to the plane of platform motion significantly increased ($p < 0.02$). Visually sensitive subjects having no history of vestibular disorder produced large, delayed compensatory head motion. Orthogonal head motions were significantly greater in visually sensitive than in healthy subjects in the dark ($p < 0.05$) and with a stationary scene ($p < 0.01$). We concluded that motion of the visual field could modify compensatory response kinematics of a freely moving head in planes orthogonal to the direction of a physical perturbation. These results suggest that the mechanisms controlling head orientation in space are distinct from those that control trunk orientation in space. These behaviors would have been missed if only COP data were considered. Data suggest that rehabilitation training can be enhanced by combining visual and mechanical perturbation paradigms.

Keywords: Orientation; Virtual environment; Posture; Visual dependence

1. Introduction

Neural control of the head and neck depends upon the goal of the movement [1]. During postural control, one of the primary goals of the neck is to produce a stable base of support for the mass of the head and the visual and vestibular systems. Most studies of postural control have explored the position of the head only in the plane of the disturbance, assuming that the applied forces will constrain the spatial orientation of the postural response. Complex movements such as gait, however, require that postural stabilization occurs in more than one plane [2], and the kinematically redundant joints of the neck need to be controlled in all three planes of motion [3,4].

We have reported previously that when both physical and visual disturbances are simultaneously presented, subjects incorporate the frequency characteristics of both inputs into their postural responses [5]. If postural disturbances are

* Corresponding author. Current address: Department of Physical Therapy, College of Health Professions, Temple University, 3307 N. Broad Street - Jones Hall 600, Philadelphia, PA 19140, United States. Tel.: +1 215 707 4824; fax: +1 215 707 7500.
E-mail address: ekeshner@temple.edu (E.A. Keshner).

0966-6362/$ – see front matter © 2007 Elsevier B.V. All rights reserved.
doi:10.1016/j.gaitpost.2007.11.003

presented in more than one orientation in space, we might expect that the stabilization task will also become more spatially complex and produce compensatory motion in more than one rotational plane. With gaze and arm pointing movements, the problem of minimizing orthogonal motion is solved by the nervous system through constraining the rotation vectors to a 2-D surface [6,7]. This reduction in the number of rotational degrees of freedom is known as Donders' law. In the head, however, Donders' law has been shown to be violated both in monkeys during active gaze saccades [8] and in humans during active head pointing movements [9]. Previous studies of visual motion alone have demonstrated that there were no directionally specific postural responses orthogonal to the displacement of a visual scene [10,11]. The presence or absence of head motion in three rotational planes during whole body instability has not yet been studied.

In this study we applied a three-dimensional model of joint motion [12] to examine compensatory motion of the head with respect to the trunk both when the visual field was stable and when motion of the visual environment occurred in planes other than that of the whole body perturbation. We expected the head to be more unstable in the dark than when a stable visual image was available to assist in orienting the head in space [13]. We hypothesized that if motion of the visual field produced a change in the orientation of the head with respect to the body, then orthogonal head motion would be equal to or greater than that occurring when in the dark. If visual field motion had a directionally specific effect, we predicted that increased head motion would emerge in the plane of the visual motion.

We also examined head motion in three subjects diagnosed with visual sensitivity. These individuals experience dizziness when in visual environments with full field of view repetitive or moving visual patterns [14]. Visual sensitivity is often present in patients with a history of peripheral vestibular disorder, but there is a subset of patients with no history of vestibular disorder and who test negative for vestibular deficit on traditional clinical tests. Visual sensitivity is thought to emerge from their inability to adapt to the visual–vestibular conflict that occurs when both the individual and environment are in motion, thereby making identification of the position of the head in space less accurate [14]. Greater sensitivity to dynamic visual inputs would interfere with their ability to stabilize the head relative to the trunk. We hypothesized that out of plane head motion in these individuals would be greater than that of healthy subjects when the visual scene was moving. Preliminary data from this population has been published [15].

2. Methods

2.1. Subjects

Twelve healthy young (29–31 years) adults (*HS*) and three subjects (27–57 years) with a diagnosis of visual sensitivity (*VS*) participated in these experiments. All subjects provided written consent in accordance with the IRB, Feinberg School of Medicine, Northwestern University. HS were free from musculoskeletal and neurological disorders. Visual sensitivity was diagnosed as a feeling of dizziness or oscillopsia when exposed to full field of view visual motion [14]. One VS subject developed sensitivity to visual stimuli with no known etiology (VS1). ENG and MRI of the brain were normal as was her general neurological examination except for extremely poor smooth visual pursuit. Another experienced dizziness when standing up, performing rapid head movements, walking in a dark room, and in busy sensory environments 2 years after treatment with an intravenous antibiotic (VS2). General neurological examination, ENG testing, and rotatory chair testing was normal. The third VS subject (VS3) had migraine associated vertigo and developed visual sensitivity 2 years post-onset of BPPV. All VS subjects reported being bothered by elevator and motor vehicle travel, and by complex visual environments such as grocery stores.

2.2. Apparatus

Subjects stood barefoot with the feet in parallel and shoulder-width apart on a platform (Neurocom, Inc.) that was anterior translated 5 cm at 5 cm/s. Previously published research describes the hardware and software responsible for generating the virtual environment [5]. In brief, subjects stood approximately 1.25 m in front of a flat screen onto which a virtual environment was back-projected. The virtual environment (scene) consisted of a 30.5 m wide by 6.1 m high by 30.5 m deep room containing round columns with patterned rugs and a painted ceiling. For the stereo-imagery, 7 cm spacing between the centers of projection (approximately equal to the average interpupillary distance) was used to produce field sequential stereo images for each eye. Correct scene perspective was continuously updated by motion capture markers providing head position. Total display system latency from the time of a head motion to the time the new image portrayed the movement in the environment was 25 ms. Stereo update rate of the scene (how quickly a new image was generated by the graphics computer in the frame buffer) was 60 stereo frames/s.

2.3. Procedures

Subjects standing on the platform with their arms positioned at their sides (elbows were flexed to 90° so that markers on the hip were not blocked) were instructed to stand quietly and look straight ahead at the image. All subjects received, in random order, the platform disturbance in the dark (DARK) and with the image projected as natural motion (NM) where the correct scene perspective was continuously updated by motion capture markers providing feedback about head position. The image was also rotated in upward pitch (PITCH) with a constant velocity (30°/s) of optic flow.

Additionally, HS were recorded when the platform was either stationary or translated in the anterior direction with a synchronized scene translation moving toward the subject at 2 m/s to resemble real life perception (FORWARD), and when platform translation was combined with a counterclockwise scene rotation (ROLL) at 30°/s. Each trial contained 10 s of quiet stance before simultaneous triggering of scene and platform motion. Data were collected 10 s prior to and following onset of the two stimuli.