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Clinical Study

Visual afference mediates head and trunk stability in vestibular hypofunction

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ABSTRACT

Humans must maintain head and trunk stability while walking. The purpose of this study was to compare the kinematics of healthy controls and patients with vestibular hypofunction (VH) when walking and making head rotations of different frequencies in both light and dark conditions. We recruited eight individuals with VH and nine healthy control subjects to perform four tasks at their preferred gait speed, being normal walk, walking and making yaw head rotations at 1.5 Hz and 2 Hz, and walking in the dark and making yaw head rotations at 1.5 Hz. Linear kinematics as well as head, trunk, and pelvis angular velocities were captured using the Vicon motion analysis system (Vicon Motion Systems, Oxford, UK). We found no difference in walking velocities for any of the four walking conditions across groups. The lateral displacement of the center of mass was increased in VH patients. In the dark, patients had more head instability in pitch (larger amplitudes and velocities) even though they were walking and making active yaw head rotations. Patients also had a smaller relative phase angle (mean 3.50 ± standard deviation 2.13°) than controls (mean 10.31 ± standard deviation 2.70°) ($p < 0.01$). Our data suggest that patients with VH have difficulty walking with a straight trajectory when turning their head. Additionally, patients with VH have an abnormal excursion of spontaneous pitch head rotation while walking and making active yaw head turns, which is dependent on vision. Rehabilitation for these patients should consider applying unique head rotation frequencies when training gait with head turns as well as alternating their exposure to light.

1. Introduction

Walking is an essential function of everyday life. To maintain balance and spatial orientation when walking, sensory afference from the vestibular system is critical. Among its numerous functions, the vestibular system detects head position within the gravitational vector to provide a sense of spatial awareness. In addition, the vestibular system contributes to stabilizing the eyes in space (vestibulo-ocular reflex) and the head on the trunk (vestibulocolic reflex) to maintain the stability of the center of mass (COM) of the body during movement [1].

In addition to maintaining head, gaze, and postural stability the vestibular system contributes to the integration of human navigation during locomotion [2–4]. Using a three-dimensional motion analysis system, Glasauer demonstrated that although subjects with bilateral vestibular hypofunction (BVH) are able to perform goal-directed locomotion towards a memorized target when blind-folded, they use larger amplitude head and trunk rotations [5]. Arthur et al. showed that patients with unilateral vestibular hypofunction (UVH) underestimated self-motion compared with healthy controls and thus have an impaired ability to accurately integrate and estimate the distance of a linear path [6].

Patients with vestibular hypofunction (VH) often report imbalance and display ataxia while walking and turning the head. Their inability to walk steadily and engage in functional activities has been shown to be a crucial factor in determining whether these patients can conduct activities independently in professional, social, and domestic domains [7]. Although patients with VH commonly report difficulty walking in darkness or walking and making head rotation, little data quantifying such common life requirements in this patient population are available. A small number of studies have investigated the spatio-temporal kinematic relationship between the head, trunk, and pelvis while walking in patients

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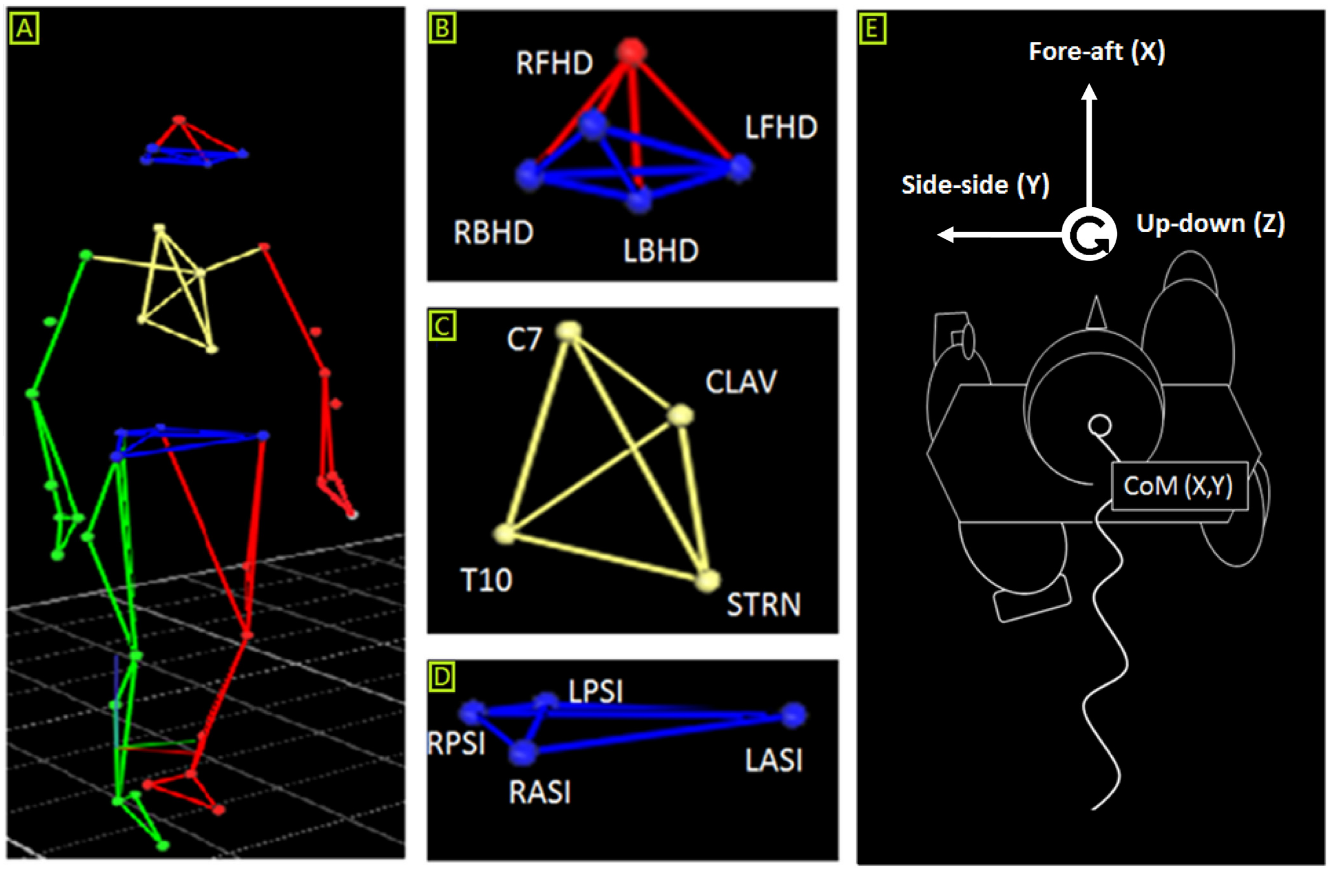

Fig. 1. We used the Global Coordinate System (A) to capture linear kinematics of the head (B), trunk (C), and pelvis (D). (E) Walking trajectories with reference to the motion laboratory in fore-aft (X), and side-side (Y) and up-down (Z) axes. C7 = spinous process of the seventh cervical vertebrae, CLAV = jugular notch where the clavicles meet the sternum, CoM = center of mass, LASI = placed directly over the left anterior superior iliac spine, LBHD = left back head = located on the back of the head roughly in line (horizontal plane) of the front head markers, LFHD = left front head, located over the left temple, LPSI = placed directly over the left posterior superior iliac spine, RASI = placed directly over the right anterior superior iliac spine, RBHD = right back head = located on the back of the head as in LBHD, RFHD = right front head, located over the right temple, RPSI = placed directly over the right posterior superior iliac spine, STRN = xiphoid process of the sternum, T10 = spinous process of the tenth thoracic vertebrae.

with VH. Mamoto found that patients with VH reduced their lateral trunk and hip translation in order to stabilize head motion [8]. Pazzo similarly reported that vestibular patients held their head stiffly but found this was related to a reduced trunk motion not an increased one [5]. A more recent study quantified locomotion with eyes open and closed in subjects with acute/subacute unilateral vestibular deafferentation [9]. These authors reported that the source of locomotion anomalies in the VH patients (described as greater magnitude gait trajectory, varied step frequency, varied step length, and varied step velocity) were related to both increased gait speed and absence of vision. While these studies include data that appear incongruent, one unifying suggestion is that patients with VH adopt unique strategies to maintain coordination of their head, trunk and pelvis.

To our knowledge no studies have quantified the kinematic result of altered vision and head rotation while walking in patients with chronic VH beyond 3 months. The purpose of this study was to investigate the kinematics of healthy controls and VH patients when walking and making head rotations of different frequencies in light and dark conditions.

2. Method

2.1. Participants

Eight patients with the diagnosis of chronic (>1 year) VH (four with right UVH, four with BVH) and nine age-matched healthy adult controls participated in this study. The diagnosis of VH was based on positive clinical head impulse test, a positive clinical horizontal head shaking nystagmus test, and an abnormal caloric (electronystagmography) examination (AIRSTAR, Micromedical Technologies, IL, USA). Exclusion criteria included history of cerebrovascular disease, reduced limb muscle strength, increased tendon reflexes, speech/swallowing difficulties, post-traumatic vertigo, degenerative neurological disease, whiplash injury, neck pain, or cognitive impairment. All participants were asked to sign an informed consent form which was reviewed and approved by the Taipei Veterans General Hospital Institutional Review Board.

2.2. Instrumentation

The experiments were conducted in a gait laboratory ($8 \times 8 \times 2.6$ m) using the Vicon computer-assisted video motion analysis system (Vicon Motion Systems, Oxford, UK) with a sampling rate of 100 Hz. Thirty-seven reflective markers (14 mm diameter) were placed at anatomical landmarks to detail segmental kinematic behavior, according to the Plug-in-Gait marker array. Linear kinematics and angular velocities of the head, trunk, and pelvis as well as walking trajectories in the fore-aft, side-side, and up-down directions were determined by using the global coordinate system (Fig. 1).

2.3. Experimental procedures

Each subject participated in four walking tasks at their preferred gait speed: Condition 1, normal walk; Condition 2, walk