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Human head–neck models in whole-body vibration: Effect of posture

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ABSTRACT

This work presents passive and muscle-based models to predict the biodynamical response of the human head–neck under fore-aft and combined-axis whole-body vibration considering four head–neck postures: neutral, flexion, lateral flexion, and lateral rotation. The passive model consists of one link, a three-rotational-degrees-of-freedom joint, and traditional spring-mass-damper elements. The muscle-based model is similar to the passive model but has additional muscle components. The additional muscle component comprises spring-mass-damper elements to capture the effects of changes in displacement, velocity, acceleration, and jerk. Eleven male participants were tested under white-noise random vibration input signals at the seat level with a frequency range of 0.5–10 Hz and magnitudes of 1.5 m/s^2 RMS for the fore-aft condition and 1.0 m/s^2 RMS in each direction for the combined-axis condition. The proposed models were able to reasonably predict the frequency content and acceleration of the head–neck for the postures under investigation, with the muscle-based model performing better.

1. Introduction

Studies on human response to whole-body vibration (WBV) have identified the neck and trunk areas of seated humans as two major sources of discomfort and potential risk for long-term injury (Rehn et al., 2005; Eger et al., 2008; Courtney and Cahn, 1999). Experiments have added a considerable amount of knowledge and understanding of the human response to the WBV environment, with most recent studies highlighting the critical role of human postures on the biodynamic response (Kittusamy and Buchholz, 2004; Mansfield and Maeda, 2005; Wang et al., 2006; Smith, 2000; Rahmatalla and DeShaw, 2011a and 2011b; Mandapuram et al., 2011). In a study on 14 Swedish helicopter pilots with neutral neck positions and neck flexing at 20°, Thuresson et al. (2005) found that neck position seemed to have a greater influence on the induced load and neck extensor muscle activity levels than an increase in the mass of head-worn equipment.

Many attempts have also been made to develop computer human models in WBV (Amirouche et al., 1994; Zheng et al., 2011; Seidel and Griffin, 2001; Pankoke et al., 2001; Boileau et al., 1997; Boileau and Rakheja, 1998; Bazrgari et al., 2008; Griffin, 2001). Computer human models present an inexpensive and safe venue in which to perform unlimited testing, with the goal of predicting injury risk or developing better seat design, but posture was not a key issue in these models.

While detailed biomechanical models may provide comprehensive information about the system response and its physiological characteristics, simple mechanisms with muscle components may also offer a good approach to characterizing system behavior (Berthoz et al., 1992; Fritz, 1998; Luo and Goldsmith, 1991). In a recent article, Nikooyan and Zadpoor (2011) presented an overview on the advantages and disadvantages of single-body and multiple-body passive and active spring-mass-damper systems in modeling the soft tissue and muscles of the human body.

It appears that most existing models for seated positions in WBV are limited to the analysis of vertical vibrations (Amirouche et al., 1994; Boileau and Rakheja, 1998; Bazrgari et al., 2008; Wang et al., 2010), with a handful of models considering fore-aft vibration (Fard et al., 2003a and 2003b; Rahmatalla and Liu, 2012). Also, the head–neck system is often modeled as inverted pendulums (Fard et al., 2003a and 2003b; Fard et al., 2004), mostly as a planar passive system, and postures were not considered.

The objective of this work is to develop human head–neck models with the capability of predicting the head–neck biodynamic response under fore-aft and combined-axis WBV when the person takes different head–neck postures. Experimental data were acquired from human subjects and were used in the frequency domain to characterize the stiffness and damping properties of the head–neck region.

2. Methodology

2.1. Participants

Eleven healthy male subjects participated in this study. They had height of 181.2 ± 11.2 cm, age of 24.2 ± 11.8 years, and

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weight of 76.39 ± 14.61 kg. Subjects reported no prior neck, shoulder, or head injuries, nor any neurological conditions. Written informed consent, as approved by the University of Iowa Institutional Review Board, was obtained prior to testing. Subjects were seated in an uncushioned, rigid seat mounted to a vibration platform. The data from the first nine subjects were used in the system parameters identification; the data from the tenth and eleventh subjects were used in the model validation.

2.2. Experiments

A 12-camera Vicon system (infrared SVcam cameras with a resolution of 0.3 megapixels per frame and a peak capture rate of 200 Hz) was used to collect position data of passive reflective markers. Fifteen reflective markers were attached to the subject's skin (Figs. 1(a) and (b)). The markers on the head were placed just superior and lateral to each eyebrow, as well as on each side of the back of the head. For the neck, three markers were placed on C_7-T_1, three markers were placed on C_4-C_5, and one marker was placed on each side at C_1-C_2. Additional markers and accelerometers were placed on the rigid platform to measure the input vibration to the system. The finite difference method was used to calculate the velocity and acceleration from the position-based markers (Rahmatalla and DeShaw, 2011a). Input vibration was generated using a six-degree-of-freedom man-rated vibration platform (Moog-FCS, Ann Arbor, MI, USA). Experiments were conducted where the subjects sat with their backs leaning and strapped to the seat-back and their arms on their laps (Fig. 1a–c). Subjects were exposed to white-noise random vibration signals at the rigid-platform level with a frequency range of 0.5–10 Hz. Unweighted vibration magnitude of 1.5 m/s^2 RMS was used for the fore-aft condition and 1.0 m/s^2 RMS in each direction for the multiple-axis condition. Each file ran for 30 s. The subjects were instructed to relax and take four different postures: neutral, flexion, lateral flexion, and lateral rotation (Fig. 1c–f). The postures were maintained during the experiments by instructing the subjects to look at fixed pictures on the walls of the lab.

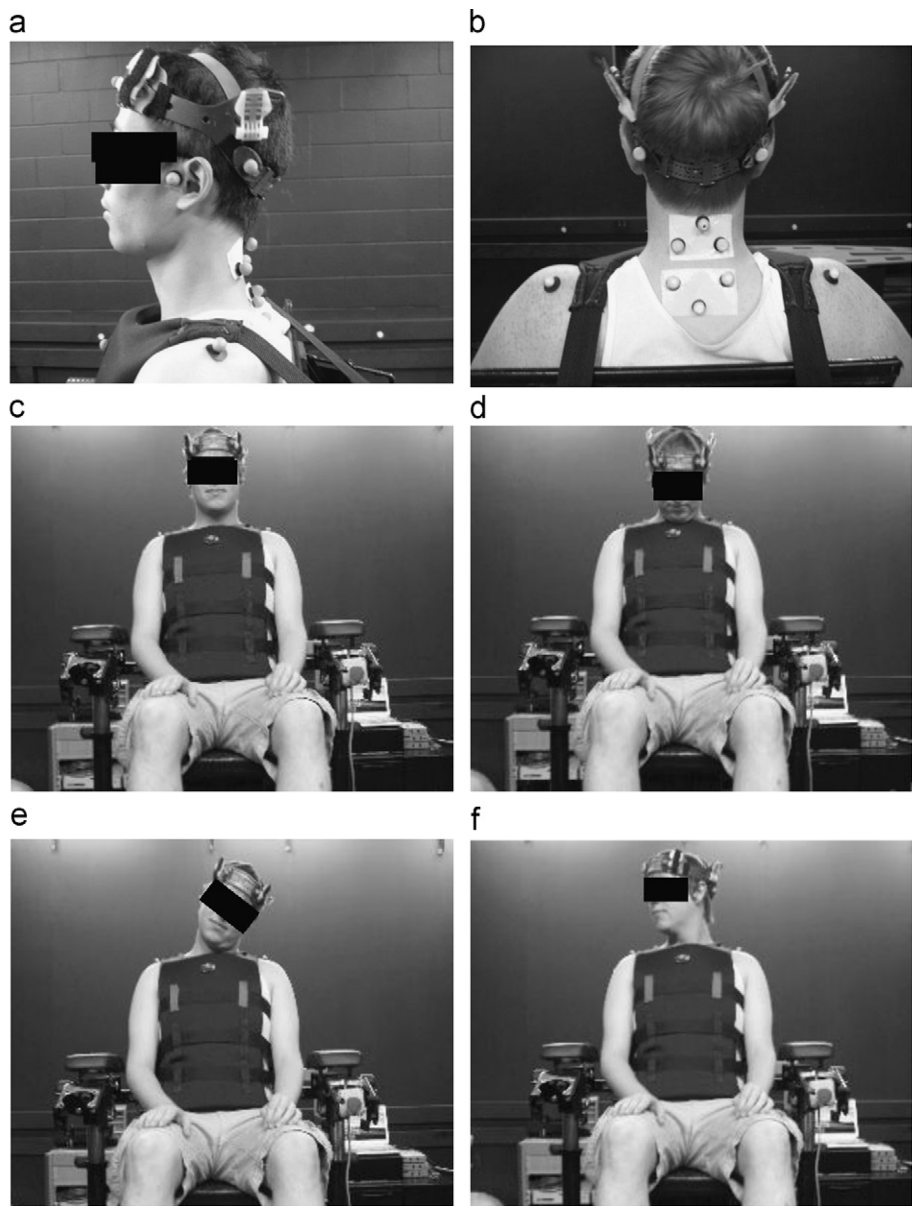

Fig. 1. Marker protocol and subject's seated postures during testing: (a) side view of marker locations on the head–neck, (b) back view of marker locations on the head–neck, (c) neutral posture, (d) flexion posture, (e) lateral flexion posture, (f) lateral rotation posture.