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Whole-body vibration transmissibility in supine humans: Effects of board litter and neck collar

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ABSTRACT

Whole-body vibration has been identified as a stressor to supine patients during medical transportation. The transmissibility between the input platform acceleration and the output acceleration of the head, sternum, pelvis, head-sternum, and pelvis-sternum of eight supine subjects were investigated. Vibration files were utilized in the fore-aft, lateral, and vertical directions. The power spectral density across the bandwidth of 0.5–20 Hz was approximately flat for each file. A comparison between a baseline rigid-support and a support with a long spinal board strapped to a litter has shown that the latter has considerable effects on the transmitted motion in all directions with a double magnification in the vertical direction around 5 Hz. The results also showed that the neck-collar has increased the relative head-sternum flexion–extension because of the input fore-aft vibration, but reduced the head-sternum extension–compression due to the input vertical vibration.

1. Introduction

In the U.S., there are an estimated 12,000–20,000 new spinal cord injuries each year (Sekhon and Fehlings, 2001; Bernhard et al., 2005), with approximately 20% of deaths and 25% of cases exacerbated prior to arrival at the hospital (Sekhon and Fehlings, 2001; Thurman et al., 1994; Bernhard et al., 2005). The estimated cost of spinal cord injuries exceeds $7 billion (DeVivo, 1997). It is apparent that pre-hospital transportation is a critical period for patients of both civilian and military medical teams, yet healthcare on the battlefield presents some of the most dangerous and controversial methods of providing aid for combat casualties. Advancements in armor and current war tactics have changed the pattern of injury; current research has revealed that a larger proportion of head and neck injuries are emerging, with most due to an explosive mechanism (Owens et al., 2008). Within this harsh environment, pre-hospital transportation has become a topic of growing interest in recent years.

The phases of medical evacuation can be characterized by ground, vehicle, and aerial transport (Kang and Lehman, 2011), and whole-body vibration (Demic and Lukic, 2009; Johanning, 2011) exists in all of these modes. A study (Alberti et al., 2006) on off-road ambulance and hand transportation showed the largest un-weighted average accelerations—1.87 and 1.46 m/s^2, respectively. In addition, helicopter and ambulance accelerations have been recorded in medical transportation (Silbergleit et al., 1991). Due to the lack of safety standards pertaining to supine vibration, whole-body vibration exposure has been studied using International Organization for Standardization (ISO-2631-1) standards for hand transport, ground vehicle transport, and aerial methods relating to a mountain rescue operation, even though these standards apply to seated vibration.

Huang and Griffin (2008a) observed the apparent mass for the semi-supine human body during vertical and longitudinal dual-axis vibration, the apparent mass during longitudinal and horizontal vibration (Huang and Griffin, 2008b), and the apparent mass and transmissibility during vertical vibration for the semi-supine, full supine, and constrained supine postures (Huang and Griffin, 2009). Specific to spinal immobilization, Perry et al. (1999) reported relative neck motions associated with horizontal vibration; the neck motion was deemed clinically significant by a neuroscientist for a potential contribution to spinal cord injury. In civilian applications, the use of a cervical collar is recommended during spinal immobilization (Shade et al., 2002; National Association of Emergency Medical Technicians (US), 2005).

While the transmissibility for seated and standing positions can give valuable information to vibration suppression designers about

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the relationship between the input ground motion and the output motion at different points on the body, it has difficulties providing them with the same level of information for supine positions. In the supine position, the input energy enters the body from different locations (head, torso, pelvis, and legs), and while it looks like each segment is vibrating independently due to the input motion, it is also clear that the motion of each segment is affected by the motion of the neighboring segments. The relative transmissibility is introduced in this work to capture the effect of the input ground motion on the motion of the cervical spine (relative motion between the head and sternum) and on the motion of the lower back (relative motion between the sternum and pelvis).

The objective of the current work is to quantify the effect of a long spinal board strapped to a standard military litter and neck-collar conditions on the transmitted motion to the head, sternum, pelvis, cervical spine, and lower back during whole-body vibration. By understanding the supine human response under these conditions, future developments and designs may be incorporated to reduce the transmitted vibration to the supine patients during transportation.

2. Methods

2.1. Participants

Eight healthy male participants with mean age of 23 years (SD 3.16), mean weight of 81 kg (SD 14.98), and mean height of 182 cm (SD 8.36) voluntarily took part in this study. The participants had no history of musculoskeletal disorders or injury. The study was approved by the University of Iowa Institutional Review Board for human subject studies, and informed consent was obtained for each participant prior to the study.

2.2. Experimental setup

Each participant was placed upon a 6-degree-of-freedom (DOF) vibration platform (Moog-FCS 628 electrical system, Ann Arbor, MI) capable of generating frequencies up to 25 Hz; accelerations up to 15 m/s^2; strokes up to $\pm$40 cm in the longitudinal, lateral and vertical directions; and angular motion up to $\pm 15°$ in the roll, pitch, and yaw directions. Three conditions were used to attach the spinal immobilized, supine subjects. These include: (a) the baseline rigid platform covered by a thin rubber sheet (rigid platform, Fig. 1a); (b) a long spinal board strapped to a standard military litter, secured to the rigid platform (board-litter, Fig. 1b); and (c) a long spinal board-litter with the addition of a cervical collar (board-litter-collar, Fig. 1c).

The cervical collar was fitted properly for each participant so that a neutral head position was maintained. In all cases, a 10-point harness was used to constrain the subjects to the long spinal board or rigid platform. Methods used during spinal immobilization were taken into consideration from commonly used pre-hospital emergency references (Shade et al., 2002; National Association of Emergency Medical Technicians (US), 2005) as well as the local

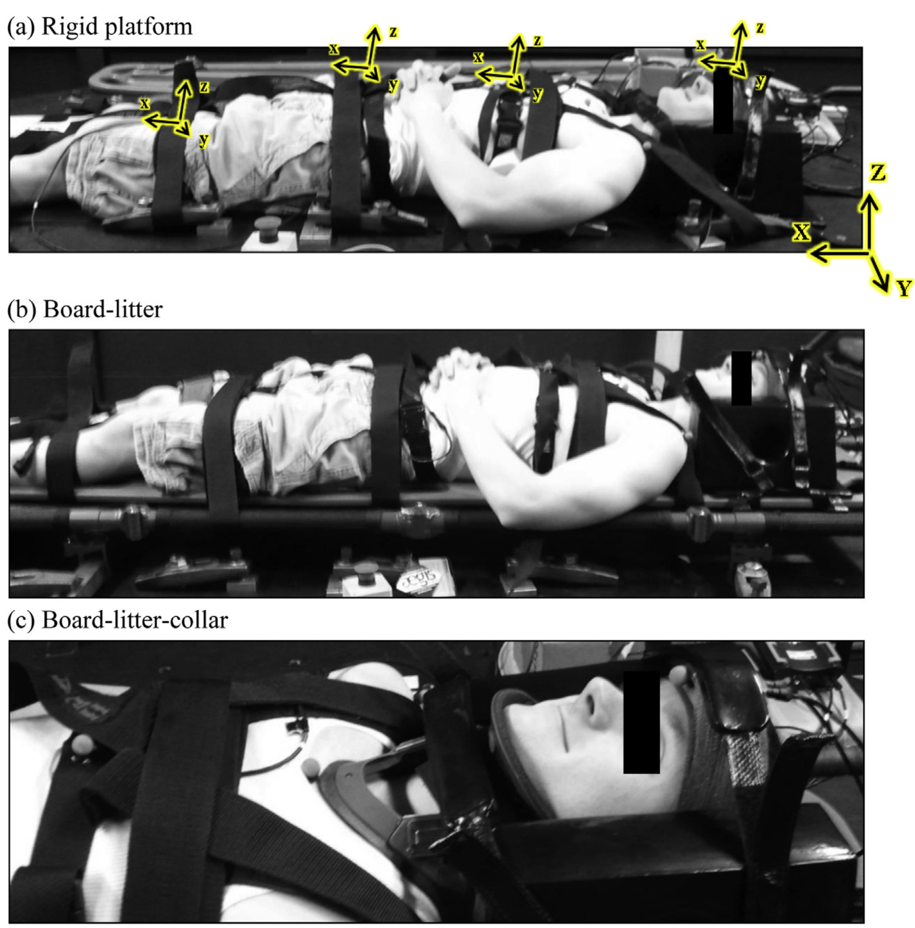

Fig. 1. Example of experimental participant for each of the three support conditions: (a) rigid platform; (b) long spinal board fixed to a military litter; and (c) addition of cervical collar to condition (b). *X*, *Y*, and *Z* represent the directions of the input motion at the rigid-platform level, and *x*, *y*, and *z* represent the directions of the output motion at the head, sternum, pelvis, and legs level.