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Investigation of human body vibration exposures on haul trucks operating at U.S. surface mines/quarries relative to haul truck activity

Alan G. Mayton^{a,*}, William L. Porter^a, Xueyan S. Xu^b, Eric B. Weston^c, Elaine N. Rubenstein^a

^a National Institute for Occupational Safety and Health, Pittsburgh Mining Research Division, Pittsburgh, PA 15236 USA

^b National Institute for Occupational Safety and Health, Health Effects Laboratory Division, Morgantown, WV 26505 USA

^c The Ohio State University, Department of Integrated Systems Engineering, 1971 Neil Avenue, Columbus, OH 43210, USA

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ABSTRACT

Workers who operate mine haul trucks are exposed to whole-body vibration (WBV) on a routine basis. Researchers from the National Institute for Occupational Safety and Health (NIOSH) Pittsburgh Mining Research Division (PMRD) investigated WBV and hand-arm vibration (HAV) exposures for mine/quarry haul truck drivers in relation to the haul truck activities of dumping, loading, and traveling with and without a load. The findings show that WBV measures in weighted root-mean-square accelerations (a_w) and vibration dose value (VDV), when compared to the ISO/ANSI and European Directive 2002/44/EC standards, were mostly below the Exposure Action Value (EAV) identified by the health guidance caution zone (HGCZ). Nevertheless, instances were recorded where the Exposure Limit Value (ELV) was exceeded by more than 500 to 600 percent for VDV_x and a_{wx} , respectively. Researchers determined that these excessive levels occurred during the traveling empty activity, when the haul truck descended down grade into the pit loading area, sliding at times, on a wet and slippery road surface caused by rain and overwatering. WBV levels (not normalized to an 8-h shift) for the four haul truck activities showed mean a_{wz} levels for five of the seven drivers exceeding the ISO/ANSI EAV by 9–53 percent for the traveling empty activity. Mean a_{wx} and a_{wz} levels were generally higher for traveling empty and traveling loaded and lower for loading/dumping activities. HAV for measures taken on the steering wheel and shifter were all below the HGCZ which indicates that HAV is not an issue for these drivers/operators when handling steering and shifting control devices.

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Relevance to industry

Human vibration exposures were investigated for mine/quarry haul trucks during full-shift loading, hauling, and dumping activities to determine the potential impact on tasks that involve safe vehicle ingress/egress. This study advances the reservoir of data and knowledge of whole-body and hand-arm vibration exposure on mine/quarry haul trucks. This data can be used to determine performance metrics for equipment or tools to reduce WBV transmission to equipment operators.

1. Introduction

Workers in the industrial world, particularly those who operate off-road vehicles and earth-moving equipment are commonly

exposed to whole-body vibration (WBV). Jarring or jolting (mechanical shock) is a component of WBV. When transmitted to the human body at the natural frequency of a body part or the body as a whole, WBV may produce a condition known as *resonance*. During resonance, the body or a part of the body will vibrate at a magnitude higher than the applied excitation force. In response, muscles will contract in a voluntary or involuntary way and cause fatigue or a lowering of motor performance capacity (Chaffin and Andersson, 1984). Evidence shows that the operator normally will reduce speed; whereas, experimental data indicates the pain threshold for WBV is 0.8m/s^2 (Langer, 2012). In light of postural elements, WBV is a contributing factor in the development of musculoskeletal disorders of the spine among workers exposed to a vibration environment (Kittusamy and Buchholz, 2004; Kittusamy, 2003, 2002; Bovenzi and Zadini, 1992; Johanning, 1991; Bongers et al., 1988, 1990; Seidel and Heide, 1986). Low-back pain (LBP) is a prominent and unfavorable health effect of WBV. A review by the National Institute for Occupational Safety and Health (NIOSH)

* Corresponding author.

E-mail address: AMayton@cdc.gov (A.G. Mayton).

reported a significant positive association between WBV exposure and LBP in 15 of 19 WBV studies reviewed by assigning the highest ranking descriptor of 'strong evidence' to the WBV–LBP relationship (NIOSH, 1997). A variety of field investigations have reported on WBV exposure for mining and quarry machinery (Smets et al., 2010; Mayton et al., 2009, 2008; Eger et al., 2006; Kumar, 2004; Miller et al., 2000, 2004). Smets et al. (2010) reported on a review of Canadian accident statistics for the Ontario Mining Industry, which showed that 16% of the traumatic injuries were associated with haul truck (HT) operation. Moreover, Kumar in his study of WBV on HTs concluded that HT operator exposure to WBV posed a significant health risk and noted that the exposure limit recommended in ISO 2631 was exceeded for a majority of the exposure time (Kumar, 2004; ISO, 1997).

2. Background

Various health and safety issues affect haul truck operators and include injuries from slips, trips, or falls from equipment, with the potential for high severity. Moore et al. (2009) examined circumstances surrounding injuries attributed to "falls from equipment" in the 2006 and 2007 Mine Safety and Health Administration (MSHA) databases. "Large trucks" accounted for over 20% of all falls from equipment injuries during that period. For the entire sample of falls from equipment injuries, almost 50% occurred during ingress or egress, and approximately 25% occurred while operators were performing maintenance activities during the course of operation such as changing a filter or cleaning a window that had become dirty.

Falls from haul trucks may occur as a result of a number of factors. A fall during the ingress/egress process on haul trucks can result in a drop of 10–12 feet. For mine workers, the tasks of getting on and off vehicles and equipment can be further complicated in that mine workers may carry an object with them such as a lunch box or tools while entering the equipment. Moreover, the issue of access path design has been shown to be an important factor in a person's ability to safely enter and exit mobile equipment (Leskinen et al., 2003). In this study several issues were examined including angle of incline for the ladder handrail placement. Bottoms (1983) examined guidelines for the design of ingress/egress systems. The recommendations Bottoms presents are based on laboratory experiments to establish generally acceptable standards. This work pointed to the need for examining the access system as a whole owing to the interactions between the size and location of steps, handholds, doors, and workplace arrangement. Thus, a variety of standards exist for ladder design on mobile equipment, each with varying recommended geometries, resulting in non-uniform access systems throughout the industry.

Given the above issues, developing solutions to the complicated problems of ingress/egress should involve examination of issues beyond access systems, such as potential decreased capabilities due

to WBV and hand-arm vibration (HAV) exposures. Moreover, exposure to WBV and increased postural requirements of the job have been identified as important risk factors in the development of musculoskeletal disorders for workers exposed to a WBV environment (Kittusamy, 2002, 2003; and Kittusamy and Buchholz, 2004). Although the ingress/egress systems on existing trucks may not be easily changed, the contribution to risk from other sources may be amenable to prevention efforts.

NIOSH researchers have conducted several vibration studies related to surface mine haul trucks and front-end wheel loaders. Mayton et al. (2014, 2008) reported on WBV exposures and influencing factors for quarry haul truck drivers and loader operators and WBV exposures on older and newer haul trucks at an aggregate stone quarry operation. In the former study, Mayton et al. (2014) looked at vibration exposure when traveling with and without a load of material between loading and dumping areas of two quarries. They noted that WBV measured on the floor of the operator's cab (chassis) and on the seat were significantly lower for the loaded compared to the unloaded condition (Mayton et al., 2014). Smets et al. (2010) also reported similar results for haul trucks traveling loaded and unloaded. In this context, researchers considered it important to examine WBV in relation to four primary haul truck activities, which include traveling with and without a load, loading and dumping (ISO/TR 25398, 2006). The objective was to see how haul truck WBV exposure related to a particular activity and whether one or more of the activities posed a higher exposure risk than the others.

3. Methods

NIOSH researchers conducted field studies and collected data of WBV and HAV exposures and GPS for a total of seven vehicles and drivers/operators operating at each of the four surface mines/quarries (Table 1). The HTs were rear-dump, which differed by make/model, age, and capacity. Measurements of vibration were carried out with a Siemens (formerly LMS) SCADAS – SCR05, 16-channel, "front-end" data recorder using PDA type HP iPAQ 214 with a Windows Mobile based Bluetooth connection. Data were written to and stored on 8 or 16 GB flash cards. Two different sampling rates were used with 24-bit resolution: 256 samples per second for WBV measures and the trigger signal and 2048 samples per second for HAV measures. The sensors used to record three orthogonal axes of vibration included four PCB tri-axial accelerometers, as follows:

- chassis WBV – 356B18 (Serial No: 13982)
- seat WBV – 356B40 (Serial No: 17210)
- steering wheel HAV – 356A32 miniature – (Serial No: 92576)
- gear selector HAV – 356A32 miniature – (Serial No: 92575)

WBV and HAV data, in each direction for the floor, seat, steering

Table 1

Description of haul trucks and subjects evaluated for whole-body and hand-arm vibration exposure at four mine/quarry operations.

Commodity	Haul Truck (Make – Model)	Year of Mfr.	Nominal Class (Short Tons)	Operating Hours	Subject #	Age (years)	HT exp. (years)
Limestone	CAT – 777D	1996	100	51,476	1	56	0.25
Sandstone	CAT – 773D	1997	50	18,821	2	57	4
Limestone	CAT – 773D	1997	50	28,208	3	39	3.5
Limestone	CAT – 777D	1997	100	52,676	4	25	0.25
Limestone	CAT – 777D	2005	100	21,403	5	54	22
Copper	Liebherr – T282B	2010	400	4969	6	56	17.5
Copper	Liebherr – T282B	2007	400	21,791	7	52	6.5

HT: haul truck.

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