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The effect of vibration exposure during haul truck operation on grip strength, touch sensation, and balance

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ABSTRACT

Falls from mobile equipment are reported at surface mine quarry operations each year in considerable numbers. Research shows that a preponderance of falls occur while getting on/off mobile equipment. Contributing factors to the risk of falls include the usage of ladders, exiting onto a slippery surface, and foot or hand slippage. Balance issues may also contribute to fall risks for mobile equipment operators who are exposed to whole-body vibration (WBV). For this reason, the National Institute for Occupational Safety and Health, Office of Mine Safety and Health Research conducted a study at four participating mine sites with seven haul truck operators. The purpose was to ascertain whether WBV and hand-arm vibration (HAV) exposures for quarry haul truck operators were linked to short-term decreases in performance in relation to postural stability, touch sensation threshold, and grip strength that are of crucial importance when getting on/off the trucks. WBV measures of frequency-weighted RMS accelerations (wRMS) and vibration dose value (VDV), when compared to the ISO/ANSI standards, were mostly below levels identified for the Health Guidance Caution Zone (HGCZ), although there were instances where the levels were within and above the specified Exposure Action Value. Comparably, all mean HAV levels, when compared to the ISO/ANSI standards, were below the HGCZ. For the existing conditions and equipment, no significant correlation could be identified between the WBV, HAV, postural stability, touch sensation threshold, and grip strength measures taken during this study.

Relevance to industry

Whole-body and hand-arm vibration exposures were investigated for quarry haul trucks to determine their effects on short-term changes in postural stability, touch sensation threshold, and grip strength. No significant effects could be identified between the measures examined during this study.

1. Introduction

A significant number of falls from mobile equipment are reported at surface mines each year. Mobile equipment operators may fall when performing a variety of activities including mounting and dismounting their equipment, routine or emergency maintenance and repair tasks, or cleaning tasks on their equipment (Moore et al., 2009; Shibuya et al., 2010). Research has shown the majority of falls to occur while egressing from mobile equipment (Moore et al., 2009; Lin and Cohen, 1997). Several factors have been identified which may contribute to this fall risk. The usage of ladders, exiting onto a slippery surface, and foot or hand slippage are likely contributors (Moore et al., 2009). Balance disturbances may also contribute to fall risks in mobile equipment operators, with exposures to whole-body vibration (WBV) contributing to these disturbances (Ahuja et al., 2005; Gauchard et al., 2001; Oullier et al., 2009; Santos et al., 2010).

Mobile equipment operators are typically exposed to WBV and HAV due to the movement of their vehicles over rough ground conditions. WBV is transmitted through the frame of the truck to the operator through the operator's seat. Operators are exposed to HAV through both the steering column and the gear shift lever which transmit vibration from the engine as well as from the

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movement of the equipment. Both types of vibration contribute to fatigue and can have detrimental effects on health and job performance (Goglia et al., 2003). The effects of WBV exposure on postural stability have been examined in laboratory studies, and results show inconsistent effects on balance (Cornelius et al., 1994; Mannin and Ekblom, 1984; Santos et al., 2008a). Cornelius et al. (1994) exposed six male participants to uniaxial (vertical) WBV levels which were simulated to represent values measured from an underground mining shuttle car. The researchers were unable to find any statistically significant changes in balance measures following vibration exposure and argued that the relationship between WBV and postural stability may depend on both frequency and duration. Mannin and Ekblom (1984) exposed ten male participants to noise, vibration, or a combination of both. Results showed an increase in body sway when exposed to noise alone, vibration alone, and a combination of noise and vibration. Santos et al. (2008a) exposed twelve male participants to 60 min of vertical random WBV or no vibration. No statistically significant changes were found in many of the 36 center of pressure (COP) movements examined following WBV exposure. One measure, the median frequency of the COP movement in the anterior-posterior direction, was shown to decrease following vibration exposure.

Limited research is available showing the detrimental effects of real-life vibration exposures on balance (Oullier et al., 2009; Ahuja et al., 2005; Martin et al., 1980). Oullier et al. (2009) studied a group of 12 apprentice bulldozer operators and 12 non-operator participants. Results showed no change in performance for the non-operator participants and a significant change for the operators. There was a destabilizing effect found after being exposed to bulldozer vibration which was evident during upright stance and when transferring from bipedal to unipedal stance. The sensorimotor treatment was found to be effective at re-stabilization. Ahuja et al. (2005) studied nine long haul freight drivers. Results showed a significant change in antero-posterior and medio-lateral sway in the "eyes open" condition after the 2.5-hour driving exposure. The authors concluded that postural stability may be impacted by WBV exposure similar to those experienced by long haul freight drivers. Martin et al. (1980) focused on quantifying the balance changes due to long-term helicopter vibration exposure and to determine the source of these changes. The researchers exposed ten participants to 30 min of seated vibration exposure. The authors reported vibration exposure to the body and legs to have a negative effect on postural control.

The effect of WBV exposure on postural stability has been variable across studies. Postural stability, however, is but one measure which likely contributes to fall risk when egressing from mobile mining equipment. Many of the ingress/egress systems on mobile equipment in mining feature vertical ladders. These ladders would require the use of the feet as well as the hands to safely egress from the equipment. The hands must constantly exert force to prevent falling from a ladder and these hand forces vary widely when descending a ladder (Armstrong et al., 2009; Young et al., 2011). As such, the ability to create and maintain hand forces are vital to safely ingressing and egressing from mobile mining equipment. Similarly to postural stability, the performance of the hands may also be affected by vibration exposure due to operating mobile mining equipment. Long-term exposure to HAV has been shown to result in vascular, neurological, and osteoarticular symptoms such as white fingers, cold intolerance, numbness, stiff fingers, decreased touch sensation, and decreased grip strength (Bernard et al., 1998; Bovenzi, 1998; Cenderlund et al., 2001; Ho and Yu, 1986; Widia and Md Dawal, 2010). Hand-Arm Vibration Syndrome (HAVS) is a name given to a host of vascular symptoms brought on by high-level exposure to HAV, typically from hand-held vibrating tools. These symptoms include a vascular component typically evident by vibration-induced white finger, a neurological component typically evident by sensory impairment, and an osteoarticular component which includes bone and joint degeneration (Bovenzi, 1998).

Widia and Md Dawal (2010) measured muscle activation at the arm and shoulder as well as grip strength before and after seven participants used electric and bench drills to drill through wood for 5- and 15-minute periods. Results showed a decrease in grip strength for all trials, with greater reductions in grip strength associated with higher vibration levels and longer exposure durations. Ho and Yu (1986) examined the effect of HAV exposure on the median and ulnar nerves and found a significant dose/effect correlation between duration of exposure and nerve conduction velocity. Longer exposures times were associated with reduced nerve conduction velocities. A reduction in median or ulnar nerve conduction velocities would decrease a person's ability to detect touch, known as touch sensation threshold, and also decrease their grip strength (Metter et al., 1998).

Touch sensation threshold and grip strength show decreases with age and with the decline of motor nerve function (Metter et al., 1998). In the elderly, touch sensation thresholds are significantly reduced and thought to be caused by the decreased density and distribution of mechano-receptor fibers in the skin and an overall decrease in the number of nerve fibers (Thornbury and Mistretta, 1981; Bruce, 1980). Similar changes are also common to HAVS. Changes in finger touch sensation threshold are found among dentists and dental technicians who commonly use tools with vibration levels exceeding 1000 Hz (Lundström and Lindmark, 1982). The reduction in grip strength associated with HAV exposure has been well documented in short-term studies where participants use vibrating hand tools as well as from epidemiological studies of more long-term effects (Widia and Md Dawal, 2010; Widia and Md Dawal, 2011; Gaidhane and Patil, 2012; Nyantumbua et al., 2007). Vibration dose, the product of vibration level and exposure time, is a critical factor for developing HAVS and a strong relationship has been shown between the severity of HAVS and the exposure time (Bernard et al., 1998; Bovenzi, 1998). There is a clear association between HAV and the reduction of hand performance evident by decreased grip strength and reduced tactile sensitivity.

Previous research has examined the effects of whole-body vibration on balance and also the effects of hand-arm vibration on grip strength. No study has examined the short-term effects of whole-body and hand-arm vibration on haul truck operators over the course of their typical workday while measuring their vibration exposure. The aim of this research was to determine the acute, time-sensitive effects of surface mining haul truck vibration exposure on balance, grip strength, and touch sensation threshold of haul truck operators over the course of two workdays. HAV and WBV exposures were measured for the duration of the shift, and relevant balance, grip strength, and touch sensation threshold measurements were taken pre-, mid-, and post-shift.

2. Materials and methods

Four mine sites participated in this study resulting in seven male participants. The mine and participant demographics and shift durations are provided in Table 1. Data collection occurred over two days due to the need to conduct measurements soon after vibration exposure had ended. As such, grip strength and touch sensation threshold testing occurred on one day, while balance testing occurred on a different day. The order of these testing days was randomized. WBV and HAV exposures were measured each day. All subjects read and signed an informed consent form approved by the NIOSH Institutional Review Board.