WHOLE-BODY-VIBRATION EXPOSURE EXPERIENCED DURING THE OPERATION OF SMALL AND LARGE LOAD-HAUL-DUMP VEHICLES

Tammy Eger
School of Human Kinetics, Laurentian University
Sudbury, Ontario, Canada, P3E 2C6. teger@laurentian.ca
Martin Smets
BEK Lab, School of Human Kinetics, Laurentian University, Sudbury, Ontario, Canada
Sylvain Grenier
School of Human Kinetics, Laurentian University, Sudbury, Ontario, Canada
Vibration Research Group
(Laurentian University, IRSST, Queen's University, University of Western Ontario, Mines and Aggregates Safety and Health Association and Construction Safety Association of Ontario)

Abstract
The body harmlessly attenuates most vibration, however frequencies between 1 and 20 Hz cause the body (pelvis and spine) to resonate (Kitazaki & Griffin, 1998; Thalheimer, 1996) leading eventually to structural damage and health problems including lower-back pain, spinal degeneration, gastro-intestinal track problems, sleep problems, headaches, neck problems, autonomic nervous system dysfunction, hearing loss, and nausea (Scutter et al., 1997; Seidel, 1993; Thalheimer, 1996). Despite the health concerns related to WBV exposure, little attention has been given to understanding the levels of WBV experienced by mining equipment operators. The primary purpose of the present study was to measure WBV exposure levels at the vehicle seat interface and the operator seat interface, during the operation of both small and larger LHD vehicles. Results were compared to the ISO 2631-1 health guidance caution zones to determine safe exposure durations. Preliminary test results indicated that LHD operators were exposed to whole-body vibration levels putting them at risk for injury. ISO 2631-1 exposure guidelines for the health caution zone were exceeded during the operation of several different vehicles. Some seats were also found to amplify the vibration signal resulting in a reduction in the recommended exposure duration.

Key words: Whole-body vibration, ISO 2631-1, LHD vehicle

EXPOSITION AUX VIBRATIONS GLOBALES DU CORPS ÉPROUVÉES PAR LES CONDUCTEURS DE PETITE OU GROSSE CHARGEUSE-DÉCHARGEUSE

Résumé
Même si le corps atténue sans danger la plus grande partie des vibrations, les fréquences qui se situent entre 1 et 20 Hz occasionnent une résonance au corps (bassin et colonne vertébrale) (Kitazaki & Griffin, 1998; Thalheimer, 1996), ce qui peut entraîner des troubles structurels et des problèmes de santé comme : douleur lombaire, dégénérescence rachidienne, troubles gastro-intestinaux, troubles de sommeil, maux de tête, cervicalgie, trouble neurologique, perte de l'ouie et nausées (Scutter et autres, 1997; Seidel, 1993; Thalheimer, 1996). Malgré les préoccupations pour la santé liées à l'exposition des vibrations globales du corps, très peu d'attention a été portée à la compréhension des vibrations globales du corps éprouvées par les conducteurs de matériel d'exploitation des mines. L'objectif premier de la présente étude visait à mesurer les taux d'exposition aux vibrations globales du corps à l'interface du siège du véhicule et l'interface du siège du conducteur lors de l'opération d'une petite ou grosse chargeuse-déchargeuse. Les résultats ont été comparés aux zones de risques pour la santé afin de déterminer les durées d'exposition sécuritaire. Les résultats de tests préliminaires ont indiqué que les conducteurs de

chargeuse-déchargeuse sont exposés à des taux de vibrations globales du corps risquant d'entraîner des blessures. Les directives de risques pour la santé de l'ISO 2631-1 ont été dépassées lors de l'opération de plusieurs véhicules différents. On a également remarqué que certains sièges amplifiaient le signal de vibrations donnant lieu à une diminution de la durée d'exposition recommandée.

Mots clés : vibrations globales du corps, ISO 2631–1, chargeuse-déchargeuse

INTRODUCTION

Increased mechanization in mining has resulted in a larger number of workers exposed to longer durations of whole-body vibration, WBV, and the trend towards extended shift lengths (10+ hrs) has resulted in longer durations of exposure. Adverse health outcomes associated with WBV exposure have been well documented and include damage to the nervous, circulatory, and digestive systems. Degenerative changes to the spine are also a concern as they are linked with increased rates of low-back pain and injury (Scutter et al., 1997; Seidel, 1993; Thalheimer, 1996). Research has also shown that health concerns are more likely if the vibration experienced is in the resonance zone which is 4-8 hz for the z-axis and 1-2 hz for the x, y axes (ISO 2631-1). The amount of vibration experienced by an operator of mobile equipment is also determined by driving speed, road condition, vehicle maintenance, vehicle load, vehicle suspension, vehicle size and seat type (Ozkaya et al., 1994; Village et al., 1989; Bush and Hubbard, 2000; Eger et al., 2004).

In a 1989 study by Village, Morrison, and Leong WBV experienced by LHD vehicle operators was measured (11 vehicles, 8 operators, and 4 work locations). The variables of interest were LHD size (3.5 to 8 yard capacities), task (mucking, dumping, driving full, driving empty), and driving speed. Attempts were made to control for operator experience (all experienced), tire pressure, seat suspension (all seats the same), and road conditions (all vehicles driven over the same terrain). The study found that WBV exposure was higher when driving (empty or full) than under all other conditions. The authors also reported higher values of exposure when driving at higher speeds and for smaller capacity LHD vehicles. The present study builds on these results. WBV was measured during the operation of small and large haulage capacity LHDs, while performing three tasks (tramming full, tramming empty and mucking) under similar underground mining terrain. However, WBV exposure levels were measured at the vehicle floor/seatbase interface and the seatpad/operator interface in order to determine the effectiveness of the seat.

METHODOLOGY

WBV Measurement

Whole-body vibration was measured in accordance with the guidelines set out in the 1997 ISO 2631-1 standard. A tri-axial seat-pad accelerometer was used to measure vibration exposure at the seatpad/operator interface and a tri-axial accelerometer mounted with a large magnet was placed on the floor at the base of the seat in order to measure WBV at the vehicle floor/seatbase interface. Measured vibration values were compared to the 1997 ISO 2631-1 Health Guidance Caution Zones (HGCZ) in

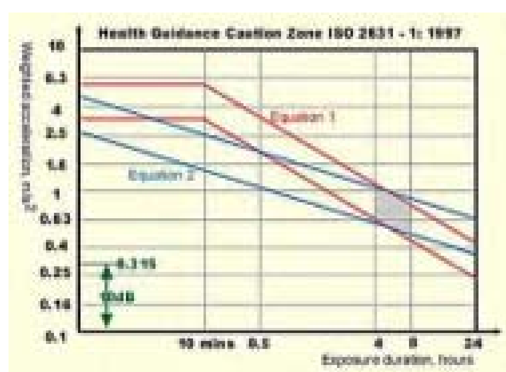

Fig. 1 Health guidance caution zone (ISO 2631-1)

order to determine recommended exposure durations (Fig. 1). No crest factors were measured above 9 therefore frequency weighted RMS acceleration values were used when making comparisons to the HGCZ.

Test Sites and LHD Vehicles

WBV measurements were conducted at 8 underground mine sites in Ontario on 16 different LHD vehicle models. WBV levels were recorded during tramming (loaded and unloaded) and mucking tasks.

RESULTS AND DISCUSSION

Preliminary Results

Preliminary results are shown for two LHD vehicles tested in Table 1. For Model A (10 yard haulage capacity), the highest vibration magnitudes were observed in the z-axis, the seat acted to increase the magnitude of the vibration signal in all axes and the maximum vibration magnitudes fell between 0.89-1.18 m/s/s. The vibration levels experienced fell in the HGCZ indicating harmful health effects are likely. Moreover the seat installed in the vehicle was not appropriate for the vibration experienced in the underground mining environment. For Model B (6 yard haulage capacity), the highest vibration magnitudes were observed in the x-axis, the seat acted to increase the magnitude of the vibration signal, and the maximum vibration magnitudes fell between 0.55-0.64 m/s/s. The vibration levels experienced fell within the zone of caution with respect to health effects and the seat was not appropriate for the vibration experienced in the underground environment.

Control Strategies

Preliminary results from this study support the findings of Village et al., (1989) and Eger et al., (2004). Vibration levels were found to be higher when the vehicles were operated with the buckets empty and WBV exposure measured at the seatpad/operator interface indicated increased health risks for the LHD operators. In order to reduce harmful levels of WBV exposure mining companies were encouraged to maintain equipment (will result in less mechanical vibration), maintain roadways (regular care will act to reduce the peak values in the vibration signal) and operators were encouraged to reduce driving speeds (decreased rate of travel will decrease the magnitude of vibration).

Future Research Directions

Further research is required to evaluate the effectiveness of seating used in underground mining vehicles (for maximum damping, the seat's resonant frequency needs to be smaller than the frequencies produced by the vehicle or amplification of the vibration can occur). In order to tackle this issue the authors of this paper will conduct controlled experiments (reproducing WBV measured in the field) in a laboratory environment in order to evaluate current seat design in an effort to identify seat characteristics required for mining applications.

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Table1. Frequency weighted RMS acceleration for the X, Y, and Z axis for two LHD models. Measured crest factors were less than 9 for all measured reported. Recommendations based on the ISO 2631-1 health guidance caution zone are reported.

Machine Model	Haulage Capacity and Activity	Frequency Weighted RMS Acceleration Values (m/s/s)						Recommendation based on ISO-2631-1 HGCZ
		LHD Floor/Seatbase Interface			LHD Seatpad/Operator Interface			
		X-axis	Y-axis	Z-axis	X-axis	Y-axis	Z-axis	
Model A	• 10 yard haulage capacity • Tramming with a fully loaded bucket	0.54	0.43	0.86	0.51	0.61	0.89	Caution with respect to health risks is necessary. Interventions should be put in place.
Model A	• 10 yard haulage capacity • Tramming with an EMPTY bucket	0.51	0.46	0.78	0.57	0.58	1.00	Health effects are likely. Operator should not be exposed to vibration of this magnitude for 8 hour periods. Therefore the duration of exposure should be reduced or vibration magnitude attenuated.
Model A	• 10 yard haulage capacity • Mucking (process to load the bucket)	0.65	0.61	1.47	0.64	0.78	1.18	Health effects are likely. Operators should not be exposed to vibration of this magnitude for 8 hour periods. Therefore the duration of exposure should be reduced or vibration magnitude attenuated
Model B	• 6 yard haulage capacity • Tramming with a fully loaded bucket	0.39	0.24	0.44	0.51	0.30	0.55	Caution with respect to health risks is necessary. Interventions should be put in place.
Model B	• 6 yard haulage capacity • Tramming with an EMPTY bucket	0.81	0.56	1.07	0.59	0.46	0.46	Caution with respect to health risks is necessary. Interventions should be put in place.
Model B	• 6 yard haulage capacity • Mucking (process to load the bucket)	0.41	0.34	0.73	0.64	0.55	0.54	Caution with respect to health risks is necessary. Interventions should be put in place.

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