# Coal Services Health & Safety Trust project 20638

# Assessing the whole-body vibration exposures of underground coal miners

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# Executive Summary

Prolonged exposure to high amplitude whole-body vibration is known to be strongly associated with spinal degeneration and the subsequent development of back pain. The outcome of CSHST project 20624 was the development and validation of an iOS application that allows an iPod Touch to be used to estimate whole-body vibration exposures. The devices have successfully been used at a central Queensland surface coal mine as part of ACARP project C23022 to describe the exposures associated with surface coal mining equipment.

Operators of mobile plant used at underground coal mines such as LHDs, shuttle cars, and personnel transport are also exposed to whole-body vibration for long periods. However, the amplitude and frequency characteristics of the exposures associated with such equipment have not previously been comprehensively assessed. The aim of this project is to determine the suitability of the WBV application for use at underground coal mines and provide an improved understanding of the whole-body vibration exposures to which operators of mobile equipment used in underground coal mines are exposed. The sites for the investigations are Centennial Coal's Airly, Springvale and Clarence mines.

Whole-body vibration data were collected underground at Centennial Springvale and Centennial Airly mines over multiple shifts from November 23 to 25, 2015 and February 9-11, 2016. Long duration measurements were collected simultaneously using the WBV application installed on multiple iPOD Touch devices.  A range of mobile plant including personnel transport, shuttle cars and LHDs and other materials transport equipment were measured. Additional data were collected at Centennial Clarence from May 30 to June 2, 2016. A total of 62 measurements were obtained, including one experimental measurement of the vibration exposure at the feet while standing on a continuous mining machine platform.

The data collected confirm that high whole-body vibration levels are associated with a range of underground equipment. Vibration levels which exceed the ISO2631.1 health guidance caution zone were measured from shuttle cars, rear seat passengers in personnel transport, as well as some measurements obtained from materials transport vehicles. The variability in measurements obtained from shuttle cars, and the high values obtained during some measurement periods, highlights these equipment as deserving of further investigation to identify and evaluate potential control measures. Although the duration of exposure for rear seat passengers in personnel transport vehicles is typically relatively short, attention to these exposures is also justified. The potential use of the WBV iOS application within a Trigger Action Response Plan regime to manage roadway standards was also highlighted.

The project has confirmed the feasibility of utilising the WBV iOS application to measure the whole-body vibration exposures associated with underground coal mining equipment and identified further opportunities for research aimed at improving the long-term health of underground coal miners.

## Introduction

Drivers and passengers of mobile plant, equipment or vehicles are exposed to vibration transmitted through the seat. Vibration frequencies between 1 and 20 Hz correspond with the resonant frequencies of body tissues in the trunk. Long term exposure to high amplitude accelerations at these frequencies have been identified as a significant contributor to the subsequent development of back pain (Bernard 1997; Bovenzi and Hulshof, 1998; Sandover, 1983; Wilder and Pope, 1996). Such exposures have also been directly or indirectly linked as a contributor to adverse health consequences for the cardiovascular, nervous, digestive, metabolic, endocrine and reproductive systems (Griffin, 1990; Thalheimer, 1996). The effects of whole-body vibration are cumulative, often taking a number of years for associated health changes to occur.

A range of mobile plant and equipment are used at underground mining operations including shuttle cars, load-haul-dump, and personnel transport vehicles. Exposure to hazardous levels of whole-body vibration has been recognised by the mining industry as a significant issue. Both the Australian Coal Association Research Program and the Coal Services Health and Safety Trust have identified management of whole-body vibration exposure as a priority area for research. The NSW Department of Industry, Mining Design Guideline 1009 "*Managing road and vehicle operating areas in underground coal mines*" makes specific mention of operator exposure to whole-body vibration. Guidance has also been provided to mining companies and mining equipment manufacturers by the NSW mine safety regulator in MDG15 "*Guidelines for Mobile and Transportable Equipment for Use in Mines*" which stipulates in clause 3.6.3 that:

> *Adequate preventative measures shall be taken to prevent excessive vibration being transmitted to the Operator during the operation of any equipment. The transmitted vibration during operations shall not exceed the levels specified by AS2670.1. 'Evaluation of human exposure to whole-body vibration- General requirements'.*

The NSW Department of Industry, Division of Resources and Energy requires all mines sites to have in place a Health Management System and the management of whole-body vibration exposure is one of the priority areas that require site specific management plan submission.

Whole-body vibration exposures experienced by mining equipment operators are a function of many variables including equipment design; seat design, condition, and adjustment; roadway conditions; vehicle maintenance; activity undertaken; and driver behaviour. Many of these variables are dynamic in nature, varying over time periods ranging from hours (activity undertaken), days (roadway conditions, seat adjustment), months (vehicle maintenance), or years (equipment design). Managing such a dynamic hazard is currently challenging for underground mine sites because frequent and systematic measurement of whole-body vibration has not been feasible with existing technology.

ISO 2631-1 / AS2670.1 (ISO, 1997; 2010) describes procedures for the evaluation of whole-body vibration. Two principal methods of describing frequency-weighted acceleration amplitudes are identified in the standard: (i) the root mean square (r.m.s.); and (ii) the Vibration Dose Value (VDV). The standard identifies acceleration as the primary quantity by which to measure vibration and provides direction regarding measurement calculations. The basic evaluation method is the calculation of the weighted root-mean-square (r.m.s) acceleration in units $m/s^2$. The Vibration Dose Value (VDV) is an alternative fourth root measure which is more sensitive to high amplitude jolts and jars and provides a better indicator of health risks of vibrations containing transient high acceleration values. No measurement durations are specified, however, the standard indicates measurement should be "sufficient to ensure reasonable statistical precision and to ensure that the vibration is typical of the exposures that are being assessed". Similarly, the standard does not specify exposure limits, instead providing guidance regarding the evaluation of health effects, in the form of  a "Health Caution Guidance Zone". For exposures below this zone it is suggested no health effects have been clearly documented.  For exposures within the Health Care Guidance Zone "caution with respect to potential health risks is indicated". For acceleration values greater than the Health Care Guidance Zone it is suggested that "health risks are likely".

Conventional measurement of whole-body vibration involves a three-dimensional accelerometer mounted in a seat padconnected by a cable to a data analysis and storage module.  Obtaining sufficient whole-body vibration measurements at underground coal mines to manage exposure to the hazard has previously been difficult because of the complexity, expense, and relative fragility of the measurement equipment. Consequently, relatively few measurements of whole-body vibration are routinely undertaken at underground coal mines. Such *ad hoc* measurements are unlikely to reliably capture the varying degrees of whole-body vibration exposure experienced by equipment operators or provide the information required to effectively manage operator whole-body vibration exposures. CSHST project 20624 funded the development of an iOS application (WBV) which allows an iPod Touch to be used to record and analyse whole-body vibration exposures (Wolfgang & Burgess-Limerick, 2014; Wolfgang et al., 2014). Subsequent work demonstrated the accuracy of the WBV application and it's utility within surface coal mining operations (Burgess-Limerick & Lynas, 2015; 2016a; 2016b). The aim of this project is to assess the suitability of the WBV application for use at underground coal mines and provide an enhanced understanding of the whole-body vibration amplitudes to which underground coal miners are exposed.

## Whole-body vibration measurements at underground coal mines

*Preliminary data*

An initial visit was undertaken to Centennial Coal's Springvale and Airly mines during November 23-25, 2015. Short duration whole-body vibration measurements were obtained from a range of underground equipment including personnel transport, shuttle cars and other materials transport equipment using the WBV iOS application installed on multiple iPOD touch devices.  The differences between measurements taken simultaneous from font and rear seats of personnel transport were stark (Figure 1). All of the vertical vibration values obtained from the rear seat position exceed the ISO2631.1 Health Guidance Caution Zone (HGCZ) for an 8 hour daily exposure, while the front seat values lie within (or very close to) the Health Guidance Caution Zone.

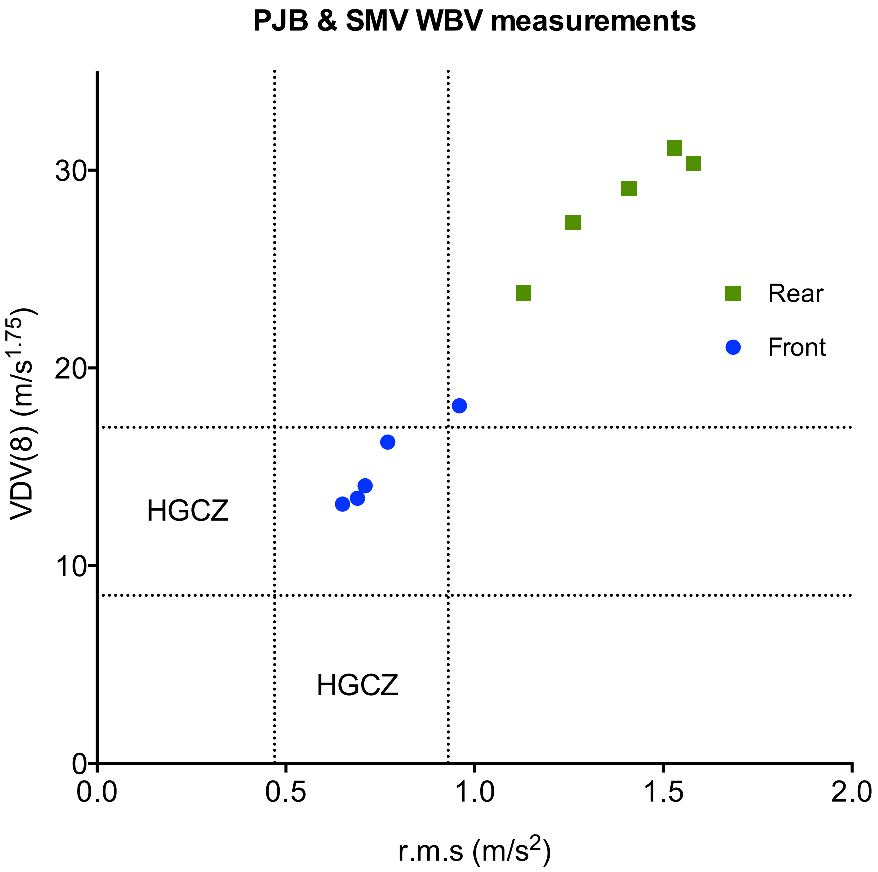


*Figure 1: VDV(8) and RMS values for vertical vibration measurements taken simultaneously from front and rear seats of underground personnel transport.*

Figure 2 illustrates fifteen measurements taken from a range of equipment types at the site including shuttle cars and Load-Haul-Dump vehicles. The sample durations selected for analysis from shuttle car measurements were short, representing a single trip from miner to boot end (or the reverse), and further data are required before any conclusions may be drawn. However, the range of values recorded from the shuttle cars was found to be large and some measurements lay well above the Health Guidance Caution Zone for both RMS and VDV(8) measurements. A large range of values were also obtained from the other materials transport vehicles measured, again including values well above the Health Guidance Caution Zone.

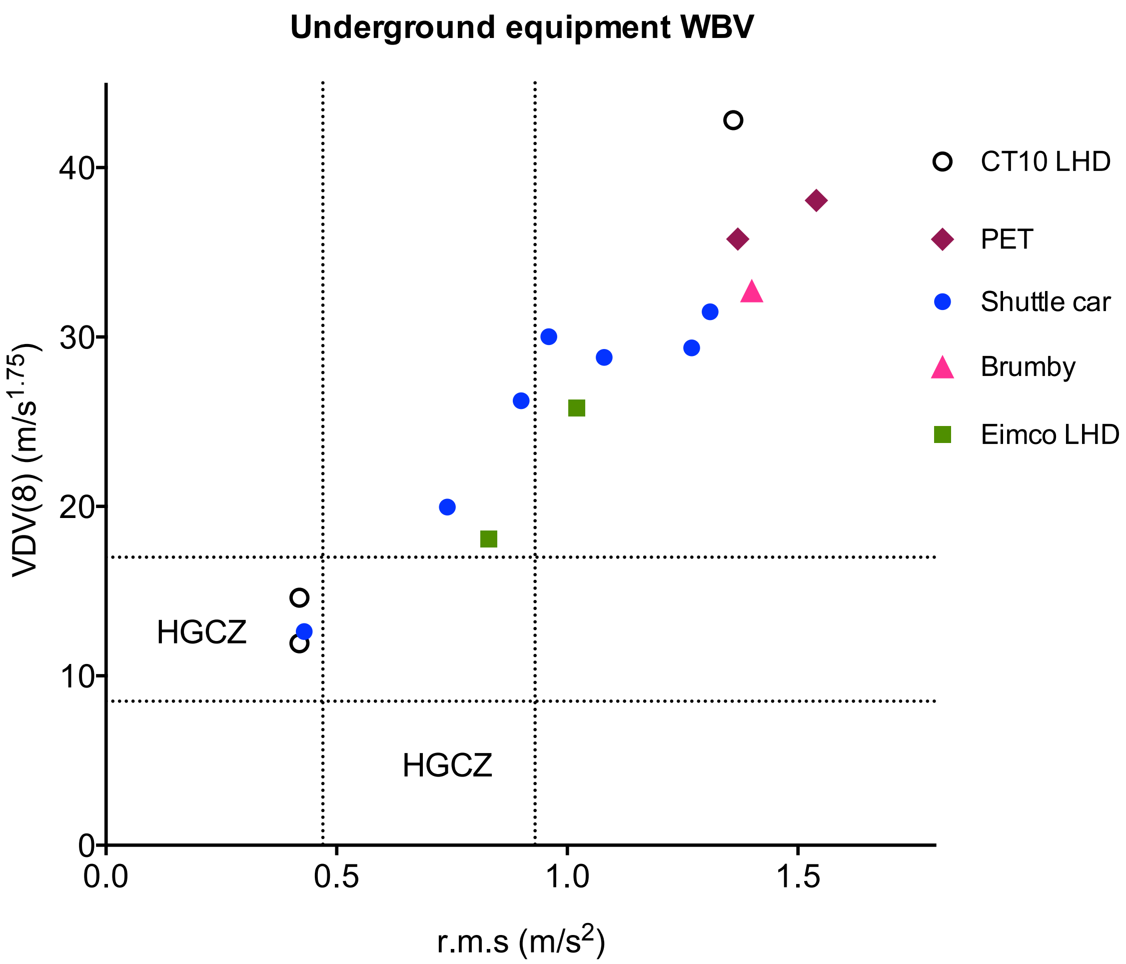


*Figure 2: Vertical whole-body vibration samples taken from a range of underground coal mining equipment.*

In summary, the preliminary visit to Centennial Coal's Airly and Springvale mines demonstrated that the WBV iOS application and iPOD Touch devices may be effectively used to estimate whole-body vibration exposure associated with underground coal mining equipment and that further investigation was justified.

*Subsequent visits*

Further visits were undertaken to Centennial Coal's Springvale and Airly mines during Feb 9-11, 2016, and to Centennial Coal Clarence mine from May 30 to June 3, 2016. Sixty-two measurements of whole-body vibration data were obtained from a range of underground equipment (Shuttle cars, N=22; PJB/SMV, N=26; LHD etc N=13, CM platform, N=1) using the WBV iOS application installed on multiple iPOD touch devices. Measurement durations ranged from 15 to 268 minutes (mean= 71 minutes). Figure 3 illustrates examples of frequency weighted acceleration data from a sample of different equipment. Figure 4 illustrates the corresponding frequency spectra for the equipment.

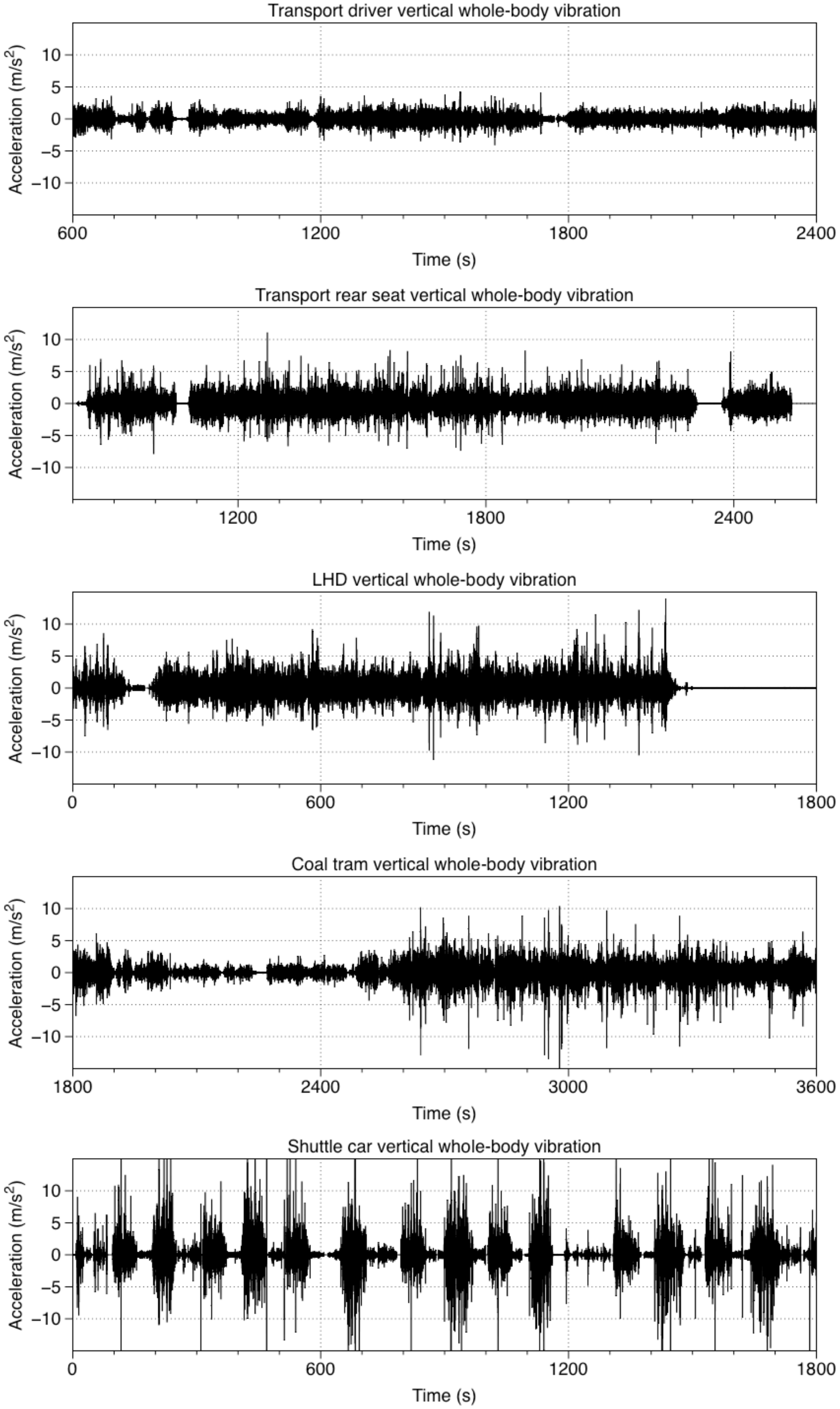


*Figure 3: Frequency weighted vertical whole-body vibration samples taken from a range of underground coal mining equipment.*

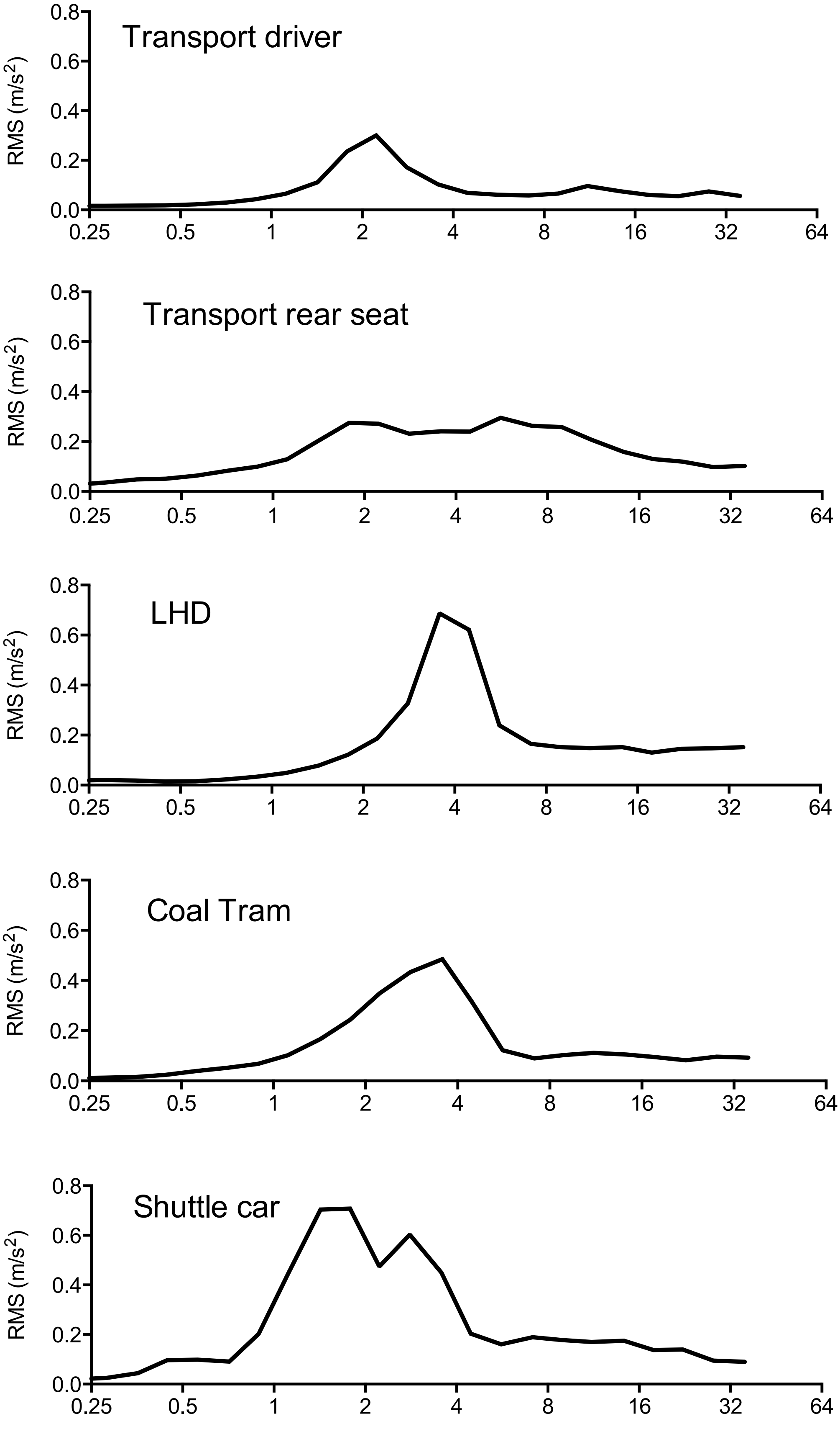


*Figure 4: Frequency spectra for vertical whole-body acceleration measurements taken from a range of underground coal mining equipment.*

Figure 5 illustrates the vertical vibration levels expressed with respect to the Health Guidance Caution Zone for an eight hour exposure defined by ISO2631.1. The majority of measurements exceeded the Health Guidance Caution Zone. The highest values were measurements obtained from Shuttle cars, and LHD, Brumby, PET and Coal Tram equipment, as well as some rear seat transport measurements.

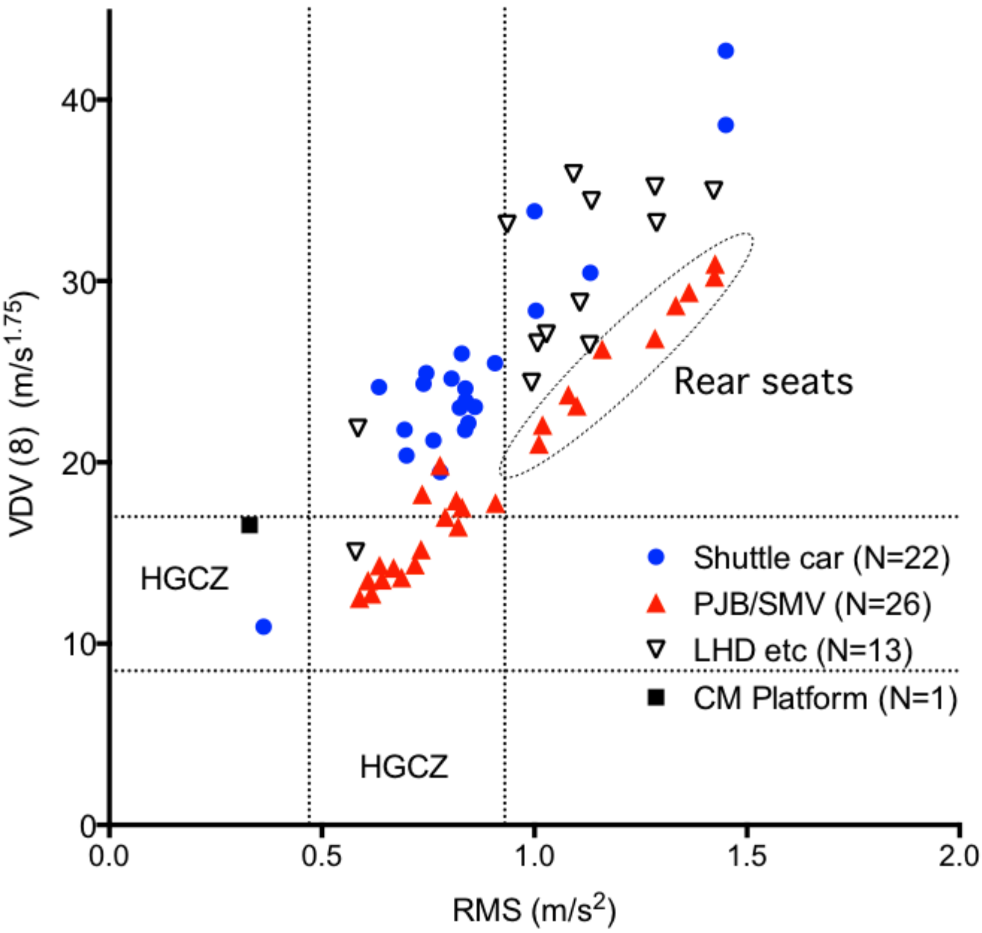


*Figure 5: VDV(8) and RMS values for vertical vibration measurements from a range of underground coal mining equipment in use at Centennial Coal's Airly, Springvale and Clarence mines.*

The large range of values obtained from shuttle cars, and the high values obtained during some measurement periods, highlights these equipment as deserving of further investigation to identify and evaluate potential control measures. Interest was expressed by the sites in gaining a better understanding of the consequences of different tyre choices (solid vs air) and determining whether improved shuttle car seating or suspension may reduce vibration exposures associated with shuttle cars. Planning for future work is underway.

It was also notable that measurements from personnel transport which exceeded the HGCZ were all taken from the rear seats of the transport vehicles. Although the duration of exposure is typically relatively short, attention to these exposures is also justified. Improved roadway standards are a potential means of achieving this. As well as reducing cumulative injuries associated with long term vibration exposure, improved roadway standards are also important to avoid instantaneous injuries which occur as a consequence of rear passengers being thrown into the roof when transport vehicles travel into pot-holes at speed.

Figure 6 illustrates measurements from two personnel transport vehicles taken at five minute intervals during a trip into two of the mines. The data indicate that, in each case, the vibration levels varied, and were higher during one of the five minute segments of travel than any other. The implication is that the data could be used to identify portions of the roadway requiring maintenance. The data illustrate the potential for timely evaluations of proposed vibration control measures, and for the provision of information about roadway condition though regularly undertaking a standardised measurement of vibration correlated with location. TARPS could then be developed to indicate when roadway maintenance is indicated at any given location.

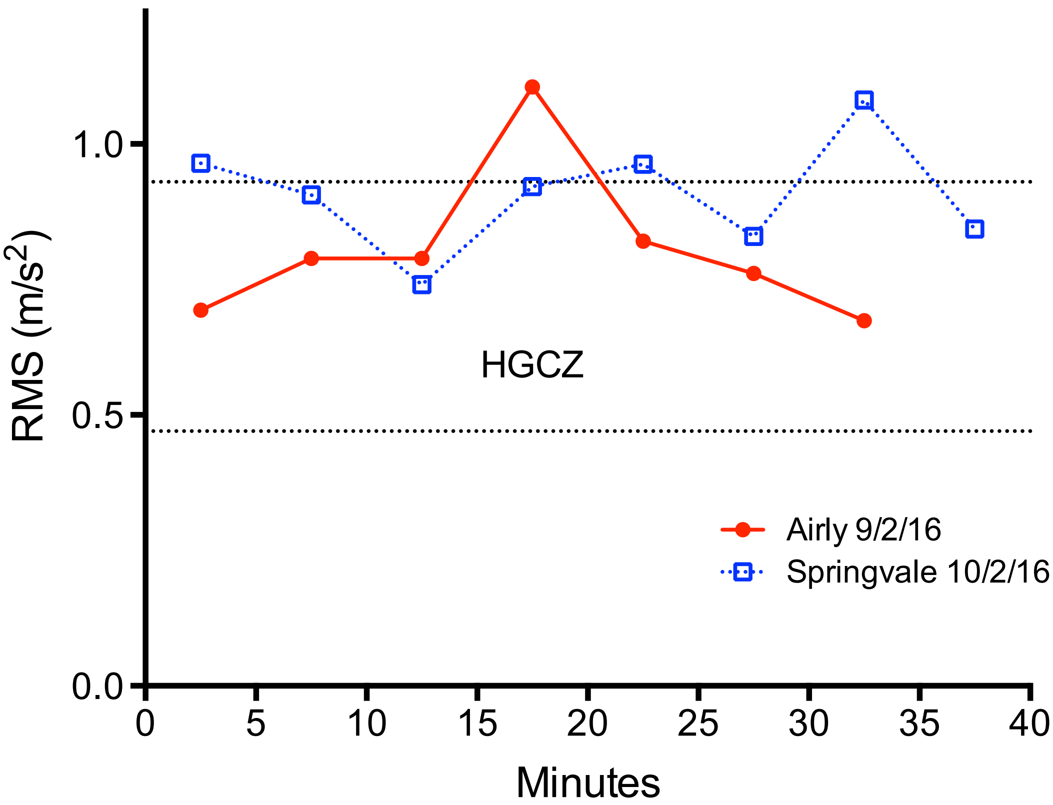


*Figure 5: Vertical vibration RMS at five minute intervals taken from personnel transport during trips into at Centennial Coal's Airly and Springvale mines.*

## Conclusion

High whole-body vibration levels are associated with a range of underground coal mining equipment. Vibration levels which exceed the ISO2631.1 health guidance caution zone were measured from shuttle cars, rear seat passengers in personnel transport, as well as materials transport equipment. The variability in measurements obtained from shuttle cars, and the high values obtained during some measurement periods, highlights these equipment as deserving of further investigation to identify and evaluate potential design control measures. Although the duration of exposure for rear seat passengers in personnel transport vehicles is typically relatively short, attention to these exposures is also justified. The potential use of the WBV iOS application within a Trigger Action Response Plan regime to manage roadway standards was also highlighted.

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