

Whole-body vibration exposures at underground coal mining operations

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ABSTRACT

Studies conducted on surface coal mining equipment have identified whole-body vibration as a significant hazard. Operators of underground mobile equipment, particularly shuttle cars and transport vehicles, are also likely to be exposed to significant levels of whole-body vibration. To date, measuring whole-body vibration from underground mining mobile equipment has been difficult due to the guidelines governing the use of electrical equipment in underground mines. This paper presents data obtained from three low-methane coal mines using an iOS application installed on multiple iPod Touch devices. The majority of measurements taken from a range of mobile plant and equipment in use at the underground coal mines exceeded the ISO2631.1 Health Guidance Caution Zone (HGCZ). Further investigations are being undertaken to develop a thorough understanding of whole-body vibration exposures to which operators of mobile equipment used in underground coal mines are exposed and the opportunities for application of this information to assist mine site safety, health and risk management processes.

Keywords: whole-body vibration, underground mining equipment

INTRODUCTION

Long term exposure to high amplitude whole-body vibration is strongly associated with the subsequent development of back pain (Bernard, 1997; Bovenzi & Hulshof, 1998; Sandover, 1983; Wilder & Pope, 1996). Adverse consequences for cardiovascular, respiratory, digestive, reproductive, endocrine and metabolic systems are also possible (Griffin, 1990).

Exposure to high amplitude whole-body vibration has been identified as a significant risk factor in the development of musculoskeletal disorders and associated health problems (Griffin 1990), including loss of visual acuity, loss postural stability and manual control, low-back pain, early spinal degeneration and disc herniation (Bernard, 1997; Bovenzi & Hulshof, 1998; Pope et al., 1998; Sandover 1983; Wilder et al., 1996; Lis et al., 2007). ISO/ANSI standards link whole-body vibration to adverse affects on the digestive, genital/urinary and female reproductive systems (ISO 1997: ANSI 2002).

During the course of their normal work activities operators of mobile plant and transport vehicles used in underground coal mines are exposed to significant high amplitude whole-body vibration. The level of exposure is determined by a number of factors including the equipment (design, suspension and maintenance) (Donati 2002; Pinto & Stacchini 2006); the seat (design, adjustment and maintenance) (Paddan et al.,

2002; Blood et al., 2010); the tyres (Li & Schindler 2014); the roadway surface condition (Lewis & Johnson, 2012), the task (Newell et al., 2006) and operator behaviour (speed, driving pattern) (Tiemessen et al., 2007). Many of these factors are dynamic and vary over different time scales ranging from minutes (eg speed of driving) to hours (task), days (roadway maintenance), months (equipment maintenance) and to years (equipment design). To manage these changing conditions requires systematic and frequent evaluation of whole-body vibration exposures to ensure risk situations are identified and effective risk management strategies implemented (Burgess-Limerick & Lynas 2015).

Measuring whole-body vibration has traditionally involved using expensive equipment where a seat pad mounted accelerometer is connected to an analysis module by a relatively fragile cable. Data collection is cumbersome and the module needs to reset after each measurement is obtained. The complexity of the data interfaces means extensive training is required to enable data collection and interpretation. The combination of complexity, training requirements, and cost of the equipment means mine sites are unlikely to undertake whole-body vibration monitoring on a regular basis. Consequently, ad hoc measurements are unlikely to provide a reliable indication of operator whole-body vibration exposure levels or provide enough information to allow mine sites to effectively manage exposure levels.

Procedures for the evaluation of whole-body vibration are described in ISO2631-1 (ISO, 1997; 2010) where the principle methods of describing frequency-weighted acceleration amplitudes are defined as: (i) the root mean square (r.m.s.); and (ii) the Vibration Dose Value (VDV), with the VDV being a fourth root measure more sensitive to high amplitude jolts and jars. ISO2631-1 provides guidance on the evaluation of health effects, describing a "Health Guidance Caution Zone" (HGCZ). For exposures below this zone it is suggested that no health effects have been clearly documented. For exposures within the HGCZ "caution with respect to potential health risks is indicated" and for measurements exceeding the HGCZ, it is suggested that "health risks are likely". For an eight hour daily exposure, the upper and lower limits of the HGCZ are 0.47m/s² and 0.93 m/s² r.m.s. respectively (McPhee et al., 2009). The corresponding values for the VDV measure expressed as an eight-hour equivalent [VDV(8)] are 8.5 m/s^{1.75} and 17 m/s^{1.75}.

The 5th generation iPod Touch (Apple Inc., Cupertino, CA) (Figure 1) has a factory calibrated accelerometer (Microelectronics, Geneva, Switzerland) providing three dimensional 16 bit data output configured to a range of +/- 2g. An iOS application (WBV) was developed in conjunction with Byteworks (www.byteworks.us) and validated against commercially available whole-body vibration testing devices (Wolfgang & Burgess-Limerick 2014; Wolfgang et al., 2014). Measurements made with the iPod Touch devices have been demonstrated to correspond well measurements obtained via specialised whole-body vibration measurement systems (Wolfgang &

Burgess-Limerick 2014). The accuracy of the iOS application was assessed by obtaining simultaneous pairs of measurements from the iPod Touch and a commercially available measurement device (SV106) during the operation of a range of surface coal mining equipment (Burgess-Limerick & Lynas 2015). Subsequently, the application was installed on multiple iPod devices allowing site based simultaneous collection of long duration measurements.

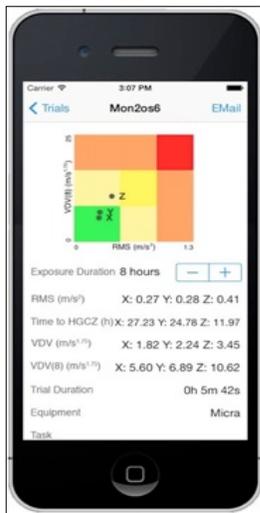


Figure 1. 5th Generation iPod Touch with WBV display

A range of mobile plant and equipment are used in underground coal mines, including shuttle cars and other coal transport vehicles, personnel transport vehicles and Load-Haul-Dump (LHD) vehicles. Collecting occupational whole-body vibration data is challenging whether in surface mining, construction quarrying or underground mining operations, with only a few researchers having collected long duration whole-body vibration measurements. Scarlett and Stayer (2005) collected a single long duration measurement (3-4 hrs) from each of 13 different machines used in mining, quarrying and construction. Eger et al (2006) collected short duration measurements (10-26 min) from fifteen types of underground and surface mining equipment, with reported values for a grader falling within the HGCZ and for a bulldozer exceeding the HGCZ. Smets et al (2010) collected 60 minute duration whole-body vibration measurements from 8 haul trucks operating on surface metalliferous mines in Canada. All 8 VDB(8) measurements were within the HGCZ. In 2012 Burgess-Limerick reported 26 short duration measurements (16-70 min) from dozers working on a range of tasks on an Australian surface coal mine, with only one of the r.m.s measurements lying within the HGCZ and one of the VDV(8) exceeding the HGCZ. Wolfgang and Burgess-Limerick (2014) collected 18-54 minute measurements of haul trucks operating on an Australian surface coal mine, with 20 of the 32 r.m.s measurements falling within the HGCZ. More

recently Burgess-Limerick and Lynas (2016) collected 59 long duration measurements (100 – 460 minutes) from a range of surface coal mining equipment on an Australian mine site. Results indicated that operators of dozers in particular are frequently exposed to vertical whole-body vibration levels that lie within or above the HGCZ. The aim of this research was to explore the whole-body vibration exposures associated with a range of underground coal mining equipment.

METHOD

Whole-body vibration amplitudes were assessed using an iOS application (WBV) installed on multiple fifth-generation iPod Touch devices (Wolfgang et al., 2014a & 2014b; Burgess-Limerick & Lynas 2015). The iPod has an aluminum casing and therefore requires site based electrical safety testing and approval before underground use. The devices were secured in a neoprene casing and tagged with high visibility tape to ensure the device was not misplaced underground. The iPod was placed on the equipment seat, allowing measurements to be taken with the operator in the seated position. The WBV application was pre-set to collect and analyse consecutive 20 minute samples of three-dimensional accelerometer data. Simultaneous use of multiple iPod Touch devices allowed efficient collection of multiple relatively long duration measurements from each equipment type. Measurements of whole-body acceleration were obtained from a range of underground mobile mining equipment in operation across three underground Australian coal mine sites, including shuttle cars, personnel transport vehicles, equipment transport vehicles and Load-Haul-Dump (LHD) vehicles. Data collection was initiated on the iPod Touch devices prior to equipment operator distribution. Equipment operators then took the neoprene encased device to their equipment and placed it on their seat. The devices were collected from the operators at the end of the shift or at task completion. For analysis purposes simultaneous measurements were also obtained for the driver and rear passenger seats in the personnel transport vehicles. The devices were placed on driver and passenger seats and collected at completion of the journey either into and out of the mine. Seventy-seven measurement trials were completed with distribution across equipment types as follows: Shuttle Car (N=37), Personnel Transport (N=26), LHD, etc (N=13), and Continuous Miner (N=1).

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RESULTS AND DISCUSSION

Figure 2 represents data obtained from shuttle cars, as well as a range of other equipment including a personnel transport vehicle, equipment transport vehicles (Brumby and PET), two LHD's (Eimco and CT10), a continuous miner and a coal tram. Vertical direction whole-body vibration VDV(8) is presented as a function of r.m.s. The sample durations selected from each shuttle car measurement represent a single trip from miner to boot end (or the reverse). The range of values recorded from the shuttle cars is large and some measurements lay well above the HGCZ 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 HGCZ, in particular those from the equipment transport vehicles (Brumby and PET). These vehicles are known to have minimal or inadequate suspension, with many operators reporting "bottoming out" on the underground roads. While equipment design including seating and suspension are crucial to reducing operator jarring and exposure to whole-body vibration values within or above the HGCZ, tyre and road maintenance is essential to reduce whole-body vibration exposure. Consideration of the available injury data and relevant literature (NSW Mine Safety Performance Report 2013-2014) indicates injuries associated with personnel transport vehicles most frequently occur to passengers when travelling over rough roads to either access or egress mine operations. The most frequent injuries associated with personnel transport are those caused by hitting potholes or other roadway abnormalities. Older vehicles such as the personnel transport vehicles in this study feature seats facing perpendicular to the direction of travel which have been shown in increase injury potential in the event of an incident or accident. (Dayawansa et al., 2006).

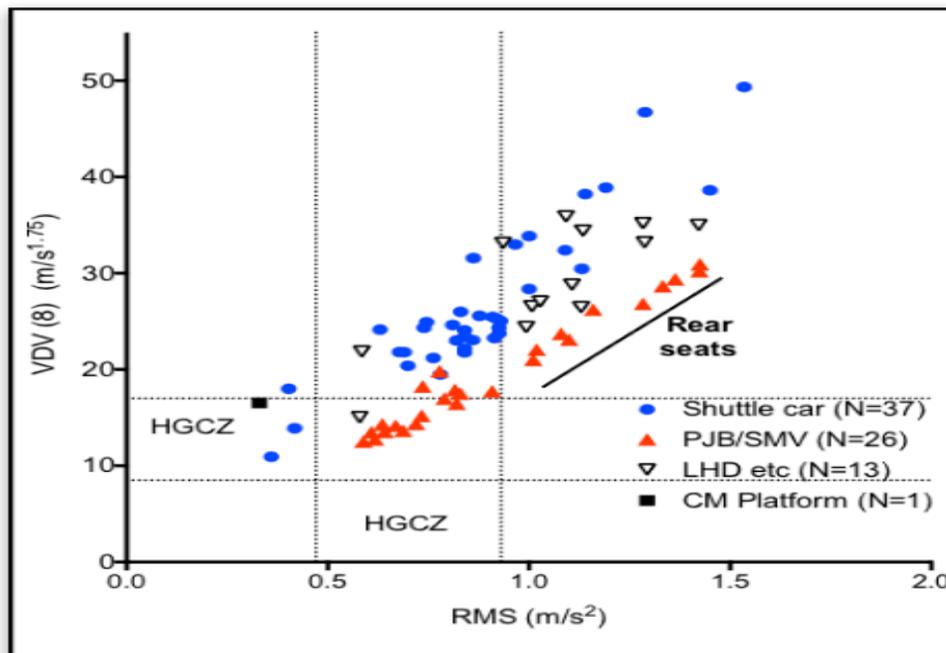


Figure 2: Vertical whole-body vibration samples taken from a range of underground coal mining equipment

The availability of the WBV application facilitates collection of adequate data to allow the identification and understanding of the sources of uncertainty in the evaluation of occupational exposure to whole-body vibration. It is possible to use the iPod Touch device to collect vibration data from mine site equipment in conjunction with other data such as road condition, weather, task, location and speed. The data collected in this study illustrate the potential for timely evaluations of proposed vibration control measures, including provision of information about equipment and road surface maintenance and condition. It allows rapid response to operator feedback or complaints which may assist early detection of problems with equipment and roadways.

Figure 3 illustrates measurements from two personnel vehicles taken at 5 minute intervals during a trip into two of the mines visited. Data indicate vibration levels varied and for each journey were higher for one 5 minute period. The implication is that the data could be used on site to identify portions of the roadway requiring maintenance by undertaking standardised measurements correlated with location, which in turn could be used to develop targeted action response plans (TARPS) to indicate when roadway maintenance is required at a given location. Interestingly it was reported that underground mine site roadway surfaces change with weather conditions – e.g. the need to increase dust suppression management in winter, and summer humidity causing expansion of previously even roadway surfaces to create uneven surfaces.

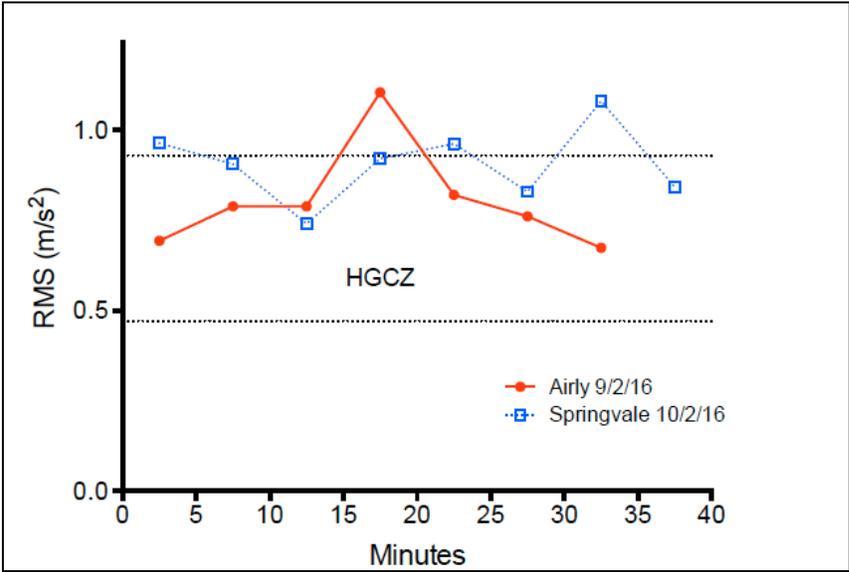


Figure 3: Vertical whole-body vibration samples taken from 2 passenger transport vehicles

In summary, the preliminary results demonstrate that the WBV application and iPod Touch devices may be effectively used to estimate whole-body vibration exposure associated with underground coal mining equipment. The data illustrate the potential for timely evaluations of proposed vibration control measures. The project is still in the preliminary stages of data collection, however further site visits will enable the testing of a number of hypotheses, such as differences between vehicles (e.g. solid fill and pneumatic tyred shuttle cars; PET and Brumby; newly purchased shuttle cars and older models used on site). Whilst on site we are working within normal mine shift routines which challenges collection of some measurements that may be helpful in further understanding operator whole-body exposure (e.g differences in measurements between vehicle drivers, passenger location within the transport vehicle). It is anticipated future site visits will provide the opportunity to test some of these situations.

CONCLUSION

To date, measuring whole-body vibration from underground mining mobile equipment has been difficult due to the strict guidelines governing the use of electrical equipment in underground mines. The simplicity of the WBV application and the relatively low cost of the iPod Touch has the potential to allow routine site based collection of whole-body vibration exposure data. Preliminary data has demonstrated that the WBV iOS application and iPod Touch devices may be effectively used to estimate whole-body vibration exposure associated with both surface and underground coal mining equipment. The majority of measurements taken from a range of mobile plant and equipment in use at the underground coal mines exceeded the ISO2631.1 HGCZ. Subsequent site visits will be undertaken to gather the data required develop a thorough understanding of the whole-body vibration exposures to which operators of mobile equipment used in underground coal mines are exposed.

ACKNOWLEDGEMENTS

We acknowledge support from the Australian Coal Services Health and Safety Trust for project 20638 and Centennial Coal Company Limited underground mine sites (NSW Australia) for site access and on-site assistance with data collection.

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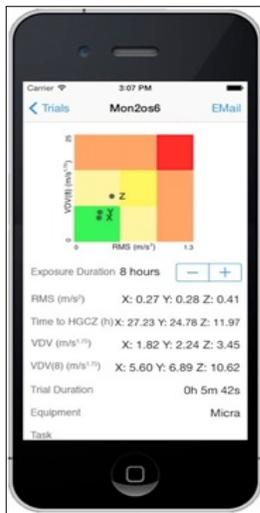


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RESULTS AND DISCUSSION

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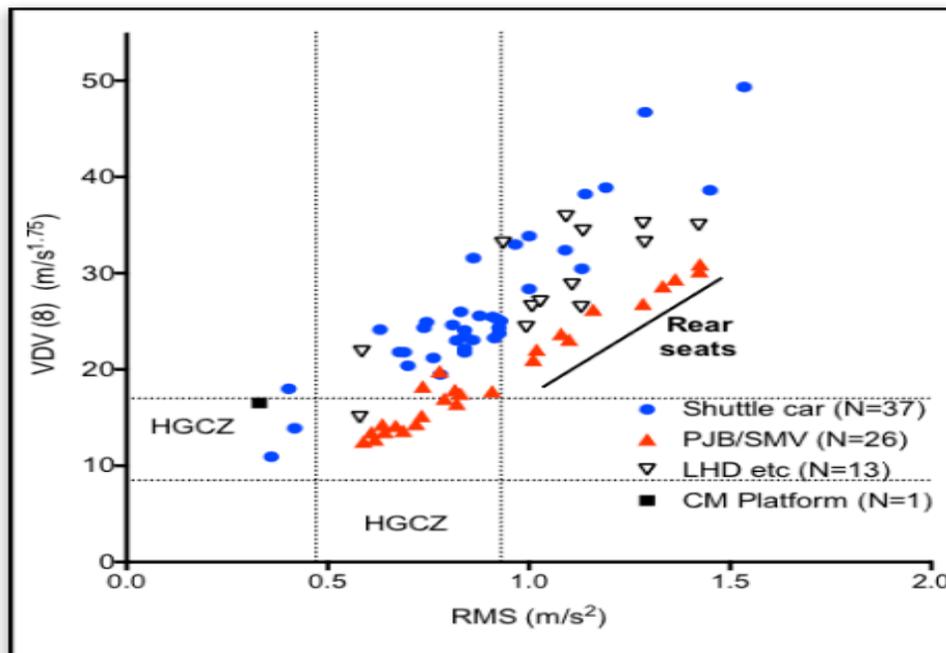


Figure 2: Vertical whole-body vibration samples taken from a range of underground coal mining equipment

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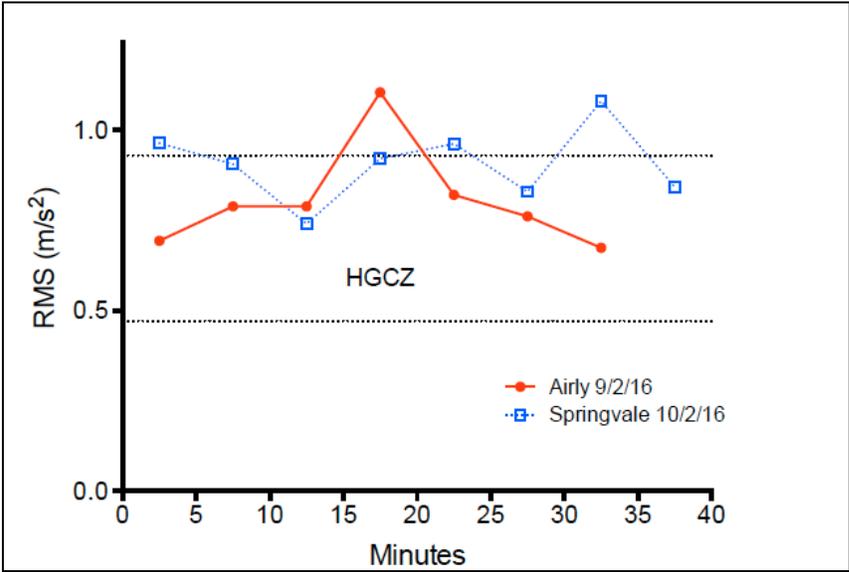


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CONCLUSION

To date, measuring whole-body vibration from underground mining mobile equipment has been difficult due to the strict guidelines governing the use of electrical equipment in underground mines. The simplicity of the WBV application and the relatively low cost of the iPod Touch has the potential to allow routine site based collection of whole-body vibration exposure data. Preliminary data has demonstrated that the WBV iOS application and iPod Touch devices may be effectively used to estimate whole-body vibration exposure associated with both surface and underground coal mining equipment. The majority of measurements taken from a range of mobile plant and equipment in use at the underground coal mines exceeded the ISO2631.1 HGCZ. Subsequent site visits will be undertaken to gather the data required develop a thorough understanding of the whole-body vibration exposures to which operators of mobile equipment used in underground coal mines are exposed.

ACKNOWLEDGEMENTS

We acknowledge support from the Australian Coal Services Health and Safety Trust for project 20638 and Centennial Coal Company Limited underground mine sites (NSW Australia) for site access and on-site assistance with data collection.

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