WHOLE-BODY VIBRATION EXPOSURES IN UNDERGROUND COAL MINING OPERATIONS

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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 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 strict guidelines governing the use of electrical equipment in underground mines. This paper presents data obtained from two low-methane coal mines using an iOS application installed on 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. 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.

INTRODUCTION

Exposure to high amplitude whole-body vibration has been identified as significant risk factor in the development of musculoskeletal disorders and associated health problems (Griffin 1990). Identified health problems associated with whole-body vibration include 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).

Operators of mobile plant and transport vehicles used in underground coal mines are exposed to significant high amplitude whole-body vibration during the course of their normal work activities. 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 an expensive piece of equipment in which a seat pad mounted accelerometer is connected to an analysis module by a relatively fragile cable. Data collection is cumbersome due to the complexity of the data interfaces and the need to reset the module after each measurement is obtained. The combination of complexity, training required, and cost of the equipment means mine sites are unlikely to undertake whole-body vibration monitoring on a regular basis.

Procedures for the evaluation of whole-body vibration are described in ISO2631-1 (ISO, 1997; 2010) where principle methods of describing frequency-weighted acceleration amplitudes are defined: (i) the root mean square (r.m.s.); and (ii) the Vibration Dose Value (VDV). The VDV is a fourth root measure that is more sensitive to high amplitude jolts and jars. ISO2631-1 provides guidance on the evaluation of health effects, describing a “Health Guidance Caution Zone”. For exposures below this zone it is suggested that no health effects have been clearly documented. For exposures within the Health Guidance Caution Zone “caution with respect to potential health risks is indicated” and for measurements exceeding the Health Guidance Caution Zone, it is suggested that “health risks are likely”. For an eight hour daily exposure, the upper and lower bounds of the Health Guidance Caution Zone 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/s¹.⁷⁵ and 17 m/s¹.⁷⁵.

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. 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; Burgess-Limerick & Lynas 2015).
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. NIOSH (Mayton et al., 2008) has investigated seating designs for low- and mid-seam shuttle cars in underground coal mines to determine optimal seating design to assist reduction in exposure to whole-body vibration health related risks for operators of underground shuttle cars. Active research has also been conducted into whole-body vibration exposures for operators of underground mining equipment, and off-road heavy vehicles in mines/quarries and farming operations (Paschold & Mayton 2011). However, only a few researchers have 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 with measurements for a face shovel loading being within the Health Guidance Caution Health Zone and a bulldozer working on civil construction exceeding the guidelines. 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 Health Guidance Caution Zone and for a bulldozer exceeding the Health Guidance Caution Zone. 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 Health Guidance Caution Zone. 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, only one of the r.m.s measurements lying within the Health Guidance Caution Zone and one of the VDV(8) exceeded the Health Guidance Caution Zone. 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 Health Guidance Caution Zone. 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 Health Guidance Caution Zone. 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 devices were secured in a neoprene casing which was tagged with high visibility taping to ensue the device was not misplaced underground. The iPod has an aluminum casing therefore the devices required mine site electrical safety testing before being taken underground. The iPod was placed on the seat of the equipment, 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 at two underground Australian coal mine sites. Equipment included 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. The 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 obtained for the driver and rear passenger seats in the personnel transport vehicles. The devices were placed on the driver and passenger seats and collected at completion of the journey either into and out of the mine. Fifteen measurement trials were completed with distribution across equipment types as follows: Shuttle Car (N=4), Personnel Transport (N=8), Equipment Transport (N=3), and LHD (N=2).

The raw accelerometer data gathered in each 20 minute sample were visually inspected and samples corresponding to the period prior to equipment operation commencing were discarded. Samples were also discarded which recorded negligible acceleration levels (less than 0.1m/s² peak to peak) corresponding to no recorded equipment movement for greater than ten minutes. These measurements were collected over 2 consecutive days.

RESULTS and DISCUSSION

Figure 2 represents a selected segment of the data collected simultaneously from the front and rear seats of one of the

Figure 1. 5th Generation iPod Touch with WBV display.
personnel transport vehicles (PJB) when transporting personnel into the mine. The greyed out section of the raw accelerometer traces indicate portions of the sample that have been excluded from calculations. Data obtained simultaneously from the front and rear seats of personnel transport vehicles (PJB & SMV) indicate significant differences between the two seat locations in the vehicle. The passenger seating for both the PJB and the SMV is perpendicular to the direction of travel.

All seats are provided with seat belts which vehicle occupants were wearing at the time of measurement. 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. According to the ISO standard, “caution with respect to potential health risks is indicated” for values within the Health Guidance Caution Zone, and for values above the zone “health risks are likely”.

The sample durations selected from each shuttle car were short, representing a single trip from miner to boot end (or the reverse) with average shuttle car trip duration from miner to boot end was recorded as: right hand side car 2.6min, left hand side car 2.85 min and centre car 2.20min. Nevertheless, the range of values recorded from the shuttle cars is 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, including values well above the Health Guidance Caution Zone, in particular 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 Health Guidance Caution Zone, 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](image_url)

**Figure 2. Simultaneous measurements sample from driver and passenger seats in PJB personnel transport vehicle during trip into the mine.**

![Figure 3](image_url)

**Figure 3: 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.

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. For example, regularly undertaking a standardised measurement of vibration correlated with vehicle location within the mine road system, and combining this with up to date information about roadway condition, targeted action response plans (TARPS) could then be developed to indicate when roadway maintenance is indicated at any given location. 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 Health Guidance Caution Zone. 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.

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REFERENCES


