

Whole-body vibration associated with surface coal mining equipment

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Significant whole-body vibration levels have previously been associated with earth-moving equipment used at surface coal mines, however variability in vibration amplitudes has been noted even within the same equipment type operated at the same site. Previous measurements have been undertaken for relatively short durations. Fifty-nine measurements were collected from a range of earth-moving equipment in operation at a surface coal mine. Measurement durations ranged from 100 minutes to 460 minutes (median = 340 minutes). The results confirm that operators of dozers and off-road haul trucks, in particular, are frequently exposed to vertical whole-body vibration levels which lie within, or above, the Health Guidance Caution Zone defined by ISO2631.1. Further investigations are justified to identify opportunities for reducing operators' exposure to high amplitude vibrations.

Practitioner Summary: Whole body vibration is confirmed as a hazard at surface coal mines. Variability in amplitudes varies in equipment of the same type. Identifying the sources of the variability is the key to determining appropriate control measures.

Keywords: Whole-body vibration, mining, earth-moving equipment.

1. Introduction

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

ISO2631-1 (ISO, 1997; 2010) describes procedures for the evaluation of whole-body vibration. Two principle methods of describing frequency-weighted acceleration amplitudes are defined in the standard: (i) the root mean square (r.m.s.); and (ii) the Vibration Dose Value (VDV). The VDV is a fourth root measure which is more sensitive to high amplitude jolts and jars. ISO2631-1 provides guidance regarding the evaluation of health effects, defining a "Health Guidance Caution Zone". For exposures below the Health Guidance Caution 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 accelerations greater than 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 0.47 m/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}.

A range of mobile plant and equipment such as dozers, haul trucks, water trucks, excavators and graders are used at surface coal mines. Data previously collected from such equipment suggests that the vibration amplitudes to which operators are exposed may lie within or above the ISO2631.1 Health Guidance Caution Zone. Dozers in particular have been identified as sometimes being associated with very high whole-body vibration levels. Off-road haul trucks have also been identified as being a source of elevated vibration levels.

For example, Scarlett & Stayner (2005) collected a single long duration measurement (3-4 hours) from each of 13 different types of machines used in mining, construction and quarrying. Vertical r.m.s acceleration values and VDV(8) values reported included: 0.22 m/s² and 11.7 m/s^{1.75} for an excavator (both measures below the Health Guidance Caution Zone); 0.37 m/s² and 14.8 m/s^{1.75} for an 80 Tonne Rigid Dump Truck (below the Health Guidance Caution Zone for the r.m.s measure and within the Health Guidance Caution Zone for the VDV(8) measure); 0.61 m/s² and 15.4 m/s^{1.75} for a face shovel loading trucks (within the Health Guidance Caution Zone for both measures); and 1.45 m/s² and 26 m/s^{1.75} for a Bulldozer undertaking civil-construction activities (exceeds the Health Guidance Caution Zone for both measures). These are the only published long duration measurements (greater than 90 minutes) of whole-body acceleration during mining equipment operation which we have been able to locate.

Eger et al (2006) collected short duration measurements (10 to 36 minutes) from fifteen types of surface and underground mining equipment. Vertical r.m.s acceleration values reported included 0.37 m/s² for a 150 tonne surface haul truck (below the Health Guidance Caution Zone), 0.79 m/s² for a grader (within the Health Guidance Caution Zone) and 1.64 m/s² from a bulldozer (exceeds the Health Guidance Caution Zone).

Smets et al. (2010) collected 60 minute duration whole-body vibration measurements from eight haul trucks of varying capacities during normal operation at metalliferous surface mines in Canada. The vertical accelerations measured as r.m.s. ranged from 0.44 m/s² to 0.82 m/s² r.m.s. The VDV(8) measurements ranged from 8.8 m/s^{1.75} to 16.4 m/s^{1.75}. Seven of the eight r.m.s. measurements were within the ISO2631.1 Health Guidance Caution Zone. All eight VDV(8) measurements were within the Health Guidance Caution Zone.

An investigation of whole-body vibration amplitudes recorded during 18 to 54 minute measurements of haul trucks in operation at an Australian surface coal mine (Wolfgang & Burgess-Limerick, 2014a) concluded that 20 of 32 r.m.s. measurements were within Health Guidance Caution Zone while 30 of 32 VDV(8) measurements were within the Health Guidance Caution Zone. The vertical whole-body vibration amplitude measurements ranged from 0.27 m/s² to 0.74 m/s² and the VDV(8) measurements ranged from 7.9 m/s^{1.75} to 15.3 m/s^{1.75}.

Burgess-Limerick (2012) reported 26 short duration measurements (16 to 70 minutes) from dozers performing a range of tasks at a surface coal mine in Australia. The vertical acceleration values ranged from 0.37 to 0.82 m/s² r.m.s, and from 7.6 to 19.1 m/s^{1.75} VDV(8). Only one of the r.m.s. measurements lay within the Health Guidance Caution Zone. None of the VDV(8) measurements was below the Health Guidance Caution Zone, and one VDV(8) measurement exceeded the Health Guidance Caution Zone.

The measurements collected from dozers and haul trucks has highlighted considerable variability in vibration levels, even within measurements taken from the same equipment types operating at the same site. This variability suggests that, if the sources of the variability could be identified, it may be possible to put in place control measures to reduce the vibration amplitude experienced by operators.

However, it is also possible that the apparent variability arises as a consequence of the relatively short duration measurements. That is, it may be that the variability is an artefact, and that the real exposure levels of operators would be lower (and more consistent) if averaged across a whole shift. Consequently, the aim of this research was to obtain relatively long duration measurements from a range of earth-moving equipment in operation at a surface coal mining site, and in particular, to obtain multiple long duration measurements from bulldozers and haul trucks to compare with previous observations.

2. Method

Whole-body vibration amplitudes were assessed using an iOS application (WBV, Burgess-Limerick & Lynas, in press) installed on multiple fifth-generation iPod Touch devices. The application collects and analyses data from the iPod Touch accelerometer. Measurements made with the iPod Touch devices have been demonstrated to correspond well to measurements obtain via specialised whole-body vibration measurement systems (Burgess-Limerick & Lynas, in press; Wolfgang & Burgess-Limerick, 2014b; Wolfgang et al., 2014). The devices were placed in a pouch sewn onto a neoprene square which was placed on an equipment operator's seat during normal operations. The WBV application was set to collect and analyse consecutive 20 minute measurements of three-dimensional accelerometer data.

The simultaneous use of multiple iPod Touch devices allowed the efficient collection of multiple relatively long duration measurements from each equipment type. Fifty-nine measurements of whole-body acceleration were obtained from a range of earth-moving equipment types in operation at a surface coal mine. Haul trucks and dozers were of primary interest. Twenty-nine measurements were obtained from sixteen haul trucks, and fifteen measurements were obtained from seven dozers. A further seven measurements were obtained from excavators, five from water-trucks, and three from graders. Trial durations ranged from 100 minutes to 460 minutes (median = 340 minutes). The measurements were collected during two measurement periods of four consecutive 12 hour shifts. The two measurement periods were separated by 4 weeks.

The WBV application applied the Wd and Wk frequency weightings specified by ISO2631.1 to horizontal and vertical accelerations respectively, before calculating r.m.s and VDV amplitudes of the frequency-weighted accelerations for each period. Average r.m.s values were calculated for the whole duration of each of the 44 measurements, while the VDV measure were expressed for each measurement were extrapolated to an eight-hour exposure as VDV(8).

3. Results and Discussion

Figure 1 illustrates the r.m.s. acceleration values for fore-aft (X), lateral (Y), and vertical (Z) directions recorded during the fifty-nine long duration measurements. Accelerations in the vertical direction were greater than the horizontal directions for all equipment types except excavators. A range of values were recorded, even for the same equipment types in operation at the same site. This was particularly true for dozers, and four measurements from dozers provided extremely high vertical whole-body acceleration measurements.

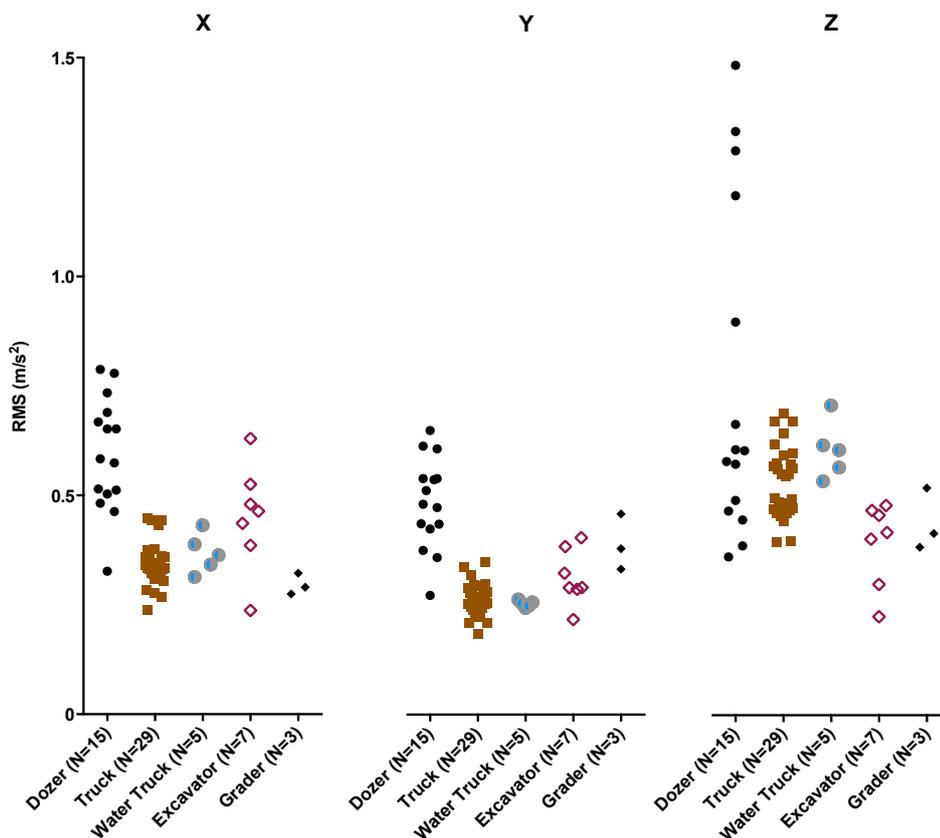


Figure 1: Horizontal (X, Y) and vertical (Z) whole-body vibration amplitude measurements (root-mean-square) of earth-moving equipment during operation at a surface coal mine. Measurement duration ranges from 100 to 460 minutes (median = 340 minutes).

Figure 2 illustrates vertical direction whole-body vibration VDV(8) as a function of r.m.s for the 29 long duration measurements gathered from haul trucks during this research, and 32 shorter duration measurements previously obtained (Wolfgang & Burgess-Limerick, 2014) from a different surface coal mine. Figure 3 illustrates vertical whole-body vibration VDV(8) as a function of r.m.s for 15 long duration measurements obtained from dozers, and 26 shorter duration measurements previously reported from dozers at a different surface coal mine (Burgess-Limerick, 2012). Table 1 summarises the variability of each group of measurements.

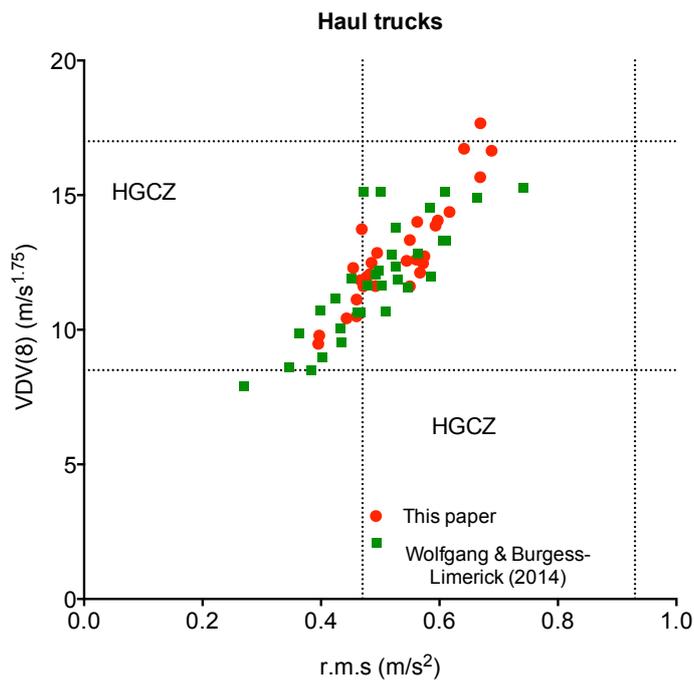


Figure 2: Vertical whole-body vibration VDV(8) plotted as a function of r.m.s for 29 long duration measurements obtained from haul trucks (this paper) and 32 shorter duration measurements (Wolfgang & Burgess-Limerick, 2014) obtained from haul trucks at a different surface coal mine. The dotted lines indicate the lower and upper boundaries of the Health Guidance Caution Zone defined by ISO2631.1 for r.m.s and VDV measures.

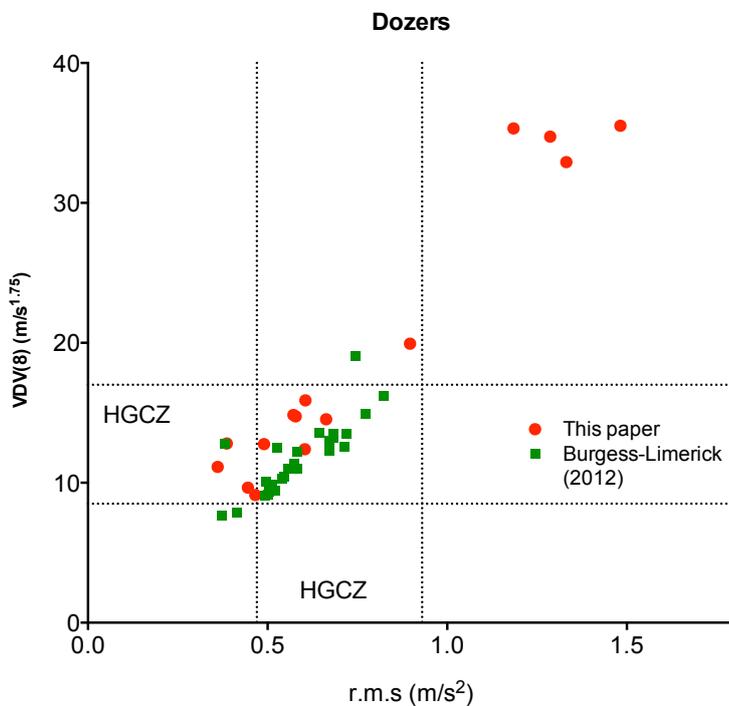


Figure 3: Vertical whole-body vibration VDV(8) plotted as a function of r.m.s for 15 long duration measurements obtained from dozers in operation (this paper) and 26 shorter duration measurements (Burgess-Limerick, 2012) obtained from dozers in operation at a different surface coal mine. The dotted lines indicate the lower and upper boundaries of the Health Guidance Caution Zone defined by ISO2631.1 for r.m.s and VDV measures.

Table 1: Summary variability measures for vertical whole-body vibration measurements obtained from haul trucks and dozers during operation at surface coal mines.

Measure	Haul Trucks		Dozers	
	29 long duration measurements	32 short duration measurements (Wolfgang & Burgess-Limerick, 2014)	15 long duration measurements	26 short duration measurements (Burgess-Limerick, 2012)
r.m.s				
range	0.29 m/s ²	0.47 m/s ²	1.14 m/s ²	0.45 m/s ²
SD	0.08 m/s ²	0.10 m/s ²	0.38 m/s ²	0.12 m/s ²
VDV(8)				
range	8.2 m/s ^{1.75}	7.4 m/s ^{1.75}	26.4 m/s ^{1.75}	11.5 m/s ^{1.75}
SD	2.0 m/s ^{1.75}	2.1 m/s ^{1.75}	10.0 m/s ^{1.75}	2.6 m/s ^{1.75}

The range of vertical r.m.s. measurements obtained from the long duration measurements of haul trucks long duration measurements was lower than the range obtained during the previous short duration measurements. However the range of the long duration VDV(8) measurements was slightly greater than the range of the short duration measurements and the standard deviations of the haul truck measurements were similar. In contrast, the variability of the long duration measurements obtained from a sample of dozers was considerably greater than that previously obtained.

Although the measurements were taken from equipment in operation at different surface coal mines, the variability of the long duration measurements reported here suggests that the variability previously observed is not an artefact of the relatively short duration measurements. The data also suggest that a substantial proportion of haul truck whole-body vibration exposures at the surface coal mine are within the Health Guidance Caution Zone when measured as r.m.s. and that almost all exposures are within, or above the Health Guidance Caution Zone when expressed as VDV(8). As previously noted (Wolfgang & Burgess-Limerick, 2012a), this is of concern given that 12 hour shifts are common in the industry, and haul truck drivers may spend 10 hours a day exposed to these vibration levels. The finding of similar results from haul trucks in operation at different mines in different states operated by different companies also suggests that the exposure to the hazard is likely not to be isolated to an individual mines, and may be common across Australian surface coal mines.

The data also confirm that dozers are the item of equipment which deserves attention by surface coal mine operators. The fifteen long duration measurements ranged from exposures close to the lower bound of the Health Guidance Caution Zone to a group of four extremely high vertical vibration measurements. The duration of these four measurements ranged from 100 minutes to 420 minutes (average 295 minutes), and yielded VDV measurements which exceeded the Health Guidance Caution Zone for the durations measured, let alone that extrapolated for an eight hour exposure. It is critical that the conditions associated with such extreme vibration exposures are identified and opportunities for preventing such exposures are developed and implemented.

4. Conclusion

Multiple long duration measurements of whole-body vibration taken during the operation of earth-moving equipment at a surface coal mine suggests that the ranges of measurements previously observed are not an artefact of the relatively short durations of the previous measurements. The long duration measurements confirm that operators of dozers and off-road haul trucks in use at surface coal mines are frequently exposed to vertical whole-body vibration levels which lie within, or above, the Health Guidance Caution Zone defined by ISO2631.1.

Further investigations to correlate vibration measurements with other data such as roadway condition and driver behaviour are required to identify the sources of variability in whole-body vibration exposures and, consequently, to identify opportunities for reducing the exposure to high amplitude vibrations.

Acknowledgements

The project was funded by the Australian Coal Association Research Program (C23022).

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