How on earth moving equipment can ISO 2631.1 be used to evaluate whole body vibration?

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ABSTRACT

Exposure to whole body vibration (WBV) is a hazard for operators of earth-moving equipment. ISO2631.1 "Evaluation of human exposure to whole-body vibration. Part 1 - General Requirements" is referred to within guidance provided to obligation holders such as mine operators and equipment manufacturers. Measurements gathered from dozers in operation at a surface coal mine are examined to both gain insight into the vibration to which operators of this plant are exposed, and to illustrate issues related to the application of ISO 2631.1.

Twenty-six measurements were gathered from ten dozers undertaking a range of activities at a surface coal mine. Unlike most equipment types, the WBV exposure associated with dozers is characterised by vibration in the fore-aft (X) direction which is frequently greater than that measured in the vertical direction (Z). If Z direction vibration expressed as r.m.s. only is considered, the vibration exposure of the dozer operators lies within or below the "Health Guidance Caution Zone" (HGCZ) proposed by ISO2631.1 for an 8 hour exposure to the 26 situations measured. A similar conclusion would be drawn from consideration of the X direction acceleration values. However, if X direction accelerations are multiplied by 1.4 as suggested by ISO2631.1, half of the measurements exceed the HGCZ. If the accelerations in different directions are combined into a Vibration Total Value as defined in ISO2631.1, all except four of the measurements exceeded the HGCZ.

ISO2631.1 is ambiguous regarding which measures should be utilised and its application is problematic. Task-dependent variability in vibration measurements was noted. The implication for equipment manufacturers is that measurements must be taken in the range of realistic operating conditions. The implication for mine operators is that systematic measurement of whole body vibration correlated with information such as the activity being undertaken has potential to assist in the identification of appropriate control measures.

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INTRODUCTION

Long term exposure to whole body vibration (WBV) is a known risk factor for the development of back pain (Bernard, 1997; Bovenzi & Hulshof, 1998). Many operators of earth-moving equipment used in mining are exposed to significant WBV for relatively long periods (Cann et al., 2003; Kumar, 2004; Smets et al., 2010).

The Model Work Health and Safety Act 2010 places an obligation on designers, manufacturers, importers and suppliers of plant to ensure, so far is reasonably practicable, that plant such as earth-moving equipment is without risks to the health of persons who operate the plant. The obligation holders must ensure that appropriate evaluations are conducted to ensure this obligation is met, and are required to communicate the results of these evaluations to purchasers.

Guidance provided to mining companies and mining equipment manufacturers provided by the NSW mine safety regulator in MDG15 "Guideline for Mobile and Transportable Equipment for Use in Mines" (NSW DPI, 2002) 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 AS 2670.1, 'Evaluation of human exposure to whole-body vibration - General requirements'.*

Australian Standard AS2670.1-2001 duplicates ISO2631.1-1997 "Evaluation of human exposure to whole-body vibration. Part 1 - General Requirements" (International Standards Organisation, 1997). While ISO 2631.1 defines methods for the quantification of whole body vibration, as explicitly noted in the introduction, it "does not contain vibration exposure limits". Guidance is provided in clauses 7, 8, and 9, and confusingly, additional guidance is located in "informative" annexes B, C & D regarding the evaluation of possible effects of vibration on health, comfort and perception, and motion sickness, respectively.

The application of the guidance is not straight forward. Several ambiguities and anomalies have been noted in the application of ISO2631 to the evaluation of WBV. For example, Griffin (2004) noted ambiguity regarding the axes to be evaluated for the evaluation of health effects. Griffin (ibid) also noted the anomalous use of a multiplying factor of 1.4 for X and Y-axes when guidance is provided regarding the evaluation of health effects of WBV, but not for the evaluation of the effects of WBV on comfort. For these, and other reasons, obligation holders may encounter difficulties in the use of ISO2631.1.

ISO 2631.1

ISO 2631.1 begins by defining symbols and coordinate systems and nominates acceleration as the primary quantity by which vibration is to be expressed. Instructions are then provided regarding: direction of measurements; the locations for measurements; signal conditioning; and duration of measurements (ie., "sufficient to ensure reasonable statistic precision and to ensure that the vibration is typical of the exposures which are being assessed" p. 5).

Frequency weightings to be applied to the accelerations measured for the evaluation of health effects in the seated position are provided i.e., W_k for the Z direction (approximately vertically through the seated operator), and W_d for the X (forward-backward) and Y (lateral) direction. The peak weighting for the X & Y directions is in the vicinity of 1/8 to 1/4 Hz, decreasing to a minimum weight at 4 Hz. A broader spectrum of frequencies is weighted more highly for the Z direction, with weighting given to frequencies between 1/2 and about 60 Hz, and the maximum weighting of frequencies between 4 and 10 Hz.

ISO 2631.1 clause 6.1 defines the "basic evaluation method" as the calculation of the frequency weighted root-mean-square (r.m.s.) acceleration (ISO 2631.1 equation 1, units m/s^2). ISO 2631.1 clause 6.2 defines a "crest factor" as the ratio of the maximum instantaneous peak value of the frequency-weighted acceleration signal to its r.m.s. value over the period of measurement. It is suggested that if the crest factor is below or equal to 9, then the r.m.s. acceleration values are "normally sufficient" measures of severity for the evaluation of human vibration effects.

Two additional measures of vibration amplitude are described in ISO 2631.1 clause 6.3. These additional measures are suggested for use when high crest factors, or the presence of occasional shocks, mean the basic evaluation method may underestimate vibration effects. The running r.m.s. method defined in ISO2631.1 equation 2 provides a maximum transient vibration value (MTVV) (units = m/s^2) which is sensitive to occasional shocks. The second alternative described in clause 6.3 is the fourth power vibration dose method which uses the fourth power of the acceleration time history and provides a vibration dose value (VDV, units $m/s^{1.75}$) which is sensitive to acceleration peaks.

In addition to the "crest factor" criterion for the use of alternative methods, ISO 2631.1 clause 6.3.3 suggests two additional thresholds for the use of alternative methods for evaluating health or comfort effects of vibration. MTVV is suggested for use if the ratio of the MTVV value to the r.m.s. value exceeds 1.5; VDV is suggested when the ratio of the VDV to the product of the r.m.s. value and the fourth root of the time period of the measurement exceeds 1.75.

A vibration total value (VTV) is defined in clause 6.5 which provides a value of the combined X, Y & Z r.m.s. accelerations (being the square root of the sum of the squared accelerations - weighted by subsequently defined multiplying factors k_x, k_y and k_z). ISO 2631.1 clause 6.5 suggests that the use of the VTV is recommended for assessing comfort, and a note further suggests that VTV has "been proposed for evaluation with respect to health and safety if no dominant axis of vibration exists" (p. 13).

Clause 7 provides guidance regarding the evaluation of health effects. It is proposed that: the frequency weighted r.m.s. shall be determined for each axis (clause 7.2.1); the assessment shall be made independently for each axis, and that the assessment shall be made considering the highest frequency-weighted acceleration determined in any axis (clause 7.2.2); although it is noted the "vector sum" (i.e., VTV) is "sometimes used to estimate health risk" when vibration in two or more axes is comparable. Clause 7.2.3 states "The frequency weightings shall be applied for seated persons as follows with the multiplying factors indicated", defining the multiplying factors (k) as 1.4 for X and Y-axes, and 1 for acceleration in the Z direction.

Further guidance regarding evaluation of the health effects of whole body vibration are provided in Annex B of ISO2631.1. A note in the introduction of this Annex suggests that the guidance is based on the response of seated human to vibration in the Z direction, and that "there is only limited experience in applying the part of ISO2631" to other directions or postures.

In ISO 2631.1 clause B.3.1, Figure B.1 defines two versions of a "health guidance caution zone" (HGCZ) for weighted r.m.s. accelerations of different durations. The different versions are congruent for durations between 4 and 8 hours. For exposures below the HGCZ, 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 acceleration exposures greater than the HGCZ it is suggested that "health risks are likely".

Ambiguity exists in that the "multiplying factors" (k) are not referred to, nor included in the equations in Annex B. Indeed the only equation in ISO 2631.1 in which the "multiplying factors" appear explicitly in relation to health effects is in the definition of VTV, and "k" is not defined in clause 4 "Symbols and subscripts".

While no numerical values are provided by ISO 2631.1 (other than by reference to Figure B.1), the lower and upper bounds of the HGCZ for an 8 hour exposure have been quoted as 0.47 m/s^2 and 0.93 m/s^2 respectively (McPhee et al., 2009).

ISO 2631.1 clause B.3.1 Note 2 suggests that an estimated value for VDV (eVDV) can be inferred from the r.m.s. value (the product of 1.4 times the weighted acceleration and the fourth root of the duration of the measurement) and suggests that eVDV values of 8.5 $m/s^{1.75}$ and 17 $m/s^{1.75}$ correspond to the upper and lower bounds of the HGCZ respectively.

The final clause of ISO 2631.1 Annex 3 is titled "Method of assessment when the basic evaluation method is not sufficient". However, the clause provides no more information than earlier sections, merely referring the reader to earlier clauses (6.2.1, 6.3.1, 6.3.2, and 6.3.3). No guidance regarding the evaluation of MTVV with respect to the HGCZ is provided. No indication is provided regarding whether multiplying factors (k) should be applied to X and Y directions for MTVV evaluation.

Indeed, no explicit guidance is provided in ISO 2631.1 regarding the evaluation of VDV, although it has been generally inferred that the values referred to for eVDV in note 2 of clause B.3.1 may be utilised (Paddan & Griffin, 2002). No indication is provided regarding whether multiplying factors (k) should be applied to X & Y directions for VDV evaluation.

EU DIRECTIVE 2002/44/EC

The European union directive 2002/44/EC (European Parliament, 2002) sets an exposure action value (EAV), above which it requires employers to control the whole-body vibration risks of their workforce and an exposure limit value (ELV) above which workers must not be exposed. Annex B to the directive provides an interpretation of the application of ISO 2631.1 to measure vibration exposure against these values viz:

> *The assessment of the level of exposure to vibration is based on the calculation of daily exposure A(8) expressed as equivalent continuous acceleration over an eight-hour period, calculated as the highest (rms) value, or the highest vibration dose value (VDV) of the frequency-weighted accelerations, determined on three orthogonal axes ($1,4a_{wx}$, $1,4a_{wy}$, a_{wz} for a seated or standing worker) in accordance with Chapters 5, 6 and 7, Annex A and Annex B to ISO standard 2631-1(1997).*

The r.m.s. and VDV threshold values provided for the EAV and ELV are higher than those implicitly provided in ISO 2631.1 Annex B. EU

Directive 2002/44/EC provides EAV thresholds of 0.5 m/s^2 (r.m.s.) or 9.1 m/s$^{1.75}$ (VDV); and ELV thresholds of 1.15 m/s^2 (r.m.s.) or 21 m/s$^{1.75}$ (VDV) respectively. The upper ELV values "above which workers must not be exposed" in particular are significantly less protective that the upper HGCZ values implied within ISO2631.1.

The aim of this paper is to evaluate a sample of 26 WBV measurements from dozers in operation at a surface coal mine to both gain insight into the vibration to which operators of this plant is exposed and to illustrate issues related to the application of ISO 2631.1 to such a situation.

METHOD

Twenty-six measurements were gathered over a 6 month period from ten dozers (9 x Caterpillar D11R, 1 x Caterpillar D10) undertaking a range of activities at a surface coal mine (Table 1). The dozers were operated by 18 different drivers. The A triaxial DeltaTron (seat pad) accelerometer was secured with tape to the seat of each dozer to measure vibration at the seat-buttock interface in the fore-aft (X), lateral (Y) and vertical (Z) dimensions. A DeltaTron uniaxial accelerometer was secured with bees wax to the floor adjacent to the seat to simultaneously measure vibration at the floor in the vertical (Z) direction only. Calibration of the accelerometers was conducted prior to each testing session. The measurement durations ranged from 16 min to 70 min.

A Bruel & Kjaer Human Vibration Analyser Type 447 was applied the frequency weightings defined by ISO2631.1 for health effects in the seated position and calculated r.m.s., MTVV and VDV measurements in the X, Y and Z directions for the seat pad accelerometer, and in the vertical direction for the floor accelerometer. VDV does not provide an average measure of acceleration during the time period measured, but rather this measure increases with measurement duration. Consequently the VDV values are expressed as an 8 hour exposure value [VDV(8)] to allow comparison between measurements of different durations.

The ratio of the accelerations in the Z direction measured at the seat to accelerations in the Z direction measured at the floor provides

Table 1: Summary of whole body vibration measurements taken from 26 dozers undertaking a range of tasks at a surface coal mine.

ID	Dozer	Driver	Activity	Time	X RMS (m/s^2)	Y RMS (m/s^2)	Z RMS (m/s^2)	X VDV(8) (m/s$^{1.75}$)	Y VDV(8) (m/s$^{1.75}$)	Z VDV(8) (m/s$^{1.75}$)
1	A	1	Roads, building ramps, soft dirt	16:07	0.482	0.342	0.446	12.5	8.98	13.9
2	A	2	Building ramps, soft dirt	31:44	0.604	0.452	0.645	13.6	9.61	13.5
3	A	2	Building ramps, soft dirt	23:14	0.506	0.392	0.744	12.3	7.99	19.1
4	B	3	Bulk pushing shale	28:35	0.602	0.555	0.581	12.7	11.5	10.9
5	C	4	Bulk pushing shale	31:57	0.559	0.548	0.557	12.0	11.8	10.9
6	C	3	Bulk pushing shale	38:47	0.549	0.526	0.671	12.6	11.9	12.3
7	D	5	Dragline dozer, including ripping	32:47	0.821	0.710	0.684	16.8	14.2	13.2
8	E	6	Pushing, building ramps, spoil	31:53	0.588	0.435	0.416	13.1	9.13	7.84
9	C	7	Pushing, building ramps, spoil	20:25	0.524	0.431	0.503	12.4	8.78	9.18
10	B	8	Pushing, building ramps, spoil	21:08	0.519	0.371	0.374	12.1	7.50	7.63
11	F	9	Pushing, building ramps, spoil	22:46	0.476	0.349	0.772	11.4	7.41	14.9
12	G	10	Drill benching	29:05	0.624	0.569	0.513	13.8	14.21	9.88
13	B	11	Pushing	24:03	0.861	0.771	0.684	17.4	16.4	13.5
14	D	12	Cutting highwall, pushing to rill	32:49	0.705	0.610	0.527	14.8	12.2	12.5
15	G	13	Ripping, benching	22:20	0.566	0.506	0.492	12.3	10.9	9.06
16	H	14	Pushing, cleaning floor	27:46	0.878	0.802	0.672	17.6	16.5	13.0
17	D	12	Pushing, cutting the key	60:18	0.704	0.584	0.504	15.1	12.0	9.36
18	A	1	Pushing	27:08	0.708	0.608	0.541	14.9	12.9	10.3
19	I	15	Pushing and ripping, digger clean up	46:12	0.781	0.698	0.823	15.7	14.3	16.1
20	A	16	Pushing	25:39	0.754	0.588	0.545	15.9	12.1	10.4
21	J	11	Pushing - some ripping	30:18	0.931	0.826	0.714	18.5	16.4	12.5
22	A	1	Pushing - no ripping	28:09	0.773	0.677	0.521	16.6	14.3	9.40
23	C	4	Ripping and at an angle	32:06	0.680	0.673	0.495	14.3	14.5	10.1
24	D	17	Cutting highwall, clean dragline pad	70:15	0.729	0.586	0.583	16.6	13.4	12.2
25	J	18	Ripping and pushing	23:00	0.748	0.720	0.720	15.8	17.2	13.4
26	G	13	Ripping	23:44	0.626	0.596	0.574	14.6	14.9	11.4

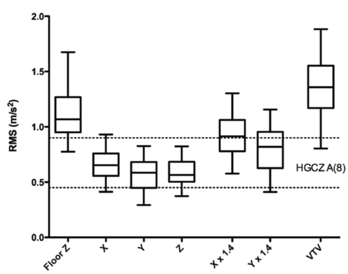
an indication of the effectiveness of the seat in attenuating vibration. Measurement of this Seat Effective Amplitude Transmissibility (SEAT) value was undertaken for both r.m.s. and VDV measures of acceleration.

RESULTS & DISCUSSION

Basic evaluation method

Figure 1 presents the distributions of the basic evaluation method (r.m.s.) for the 26 measurements. The HGCZ for an eight hour exposure as defined in ISO 2631.1 Annex B is indicated.

Figure 1: r.m.s. acceleration magnitudes for 26 WBV measurements from dozers in operation at a surface coal mine.



The Z direction r.m.s. acceleration values at the seat were considerable less than the r.m.s. values measured at the floor, and r.m.s. SEAT values ranged from 0.42 to 0.88. The majority of Z direction r.m.s. acceleration values lay within the eight hour HGCZ, with only 3 of 26 measurements falling below the zone. Based on these Z direction measurements "caution with respect to potential health risks is indicated" for 8 hour exposures. For 21 of the tests, however, the highest r.m.s. values were in the X (forward-backward) direction. When these values were multiplied by 1.4 as required by ISO 2631.1 clause 7.2.3, half of the measurements exceeded the eight hour HGCZ.

Given the relatively similar magnitudes of r.m.s. values for X, Y and Z directions illustrated in Figure 1, it might well be considered that "no dominant axis of vibration" was evident and consequently, as noted in clause 6.5 of ISO 2631.1, the combined accelerations in all directions (VTV) "has been proposed" for the evaluation of health effects. When the VTV was calculated as defined in clause 6.5, all but four of the 26 measurements of dozer operators exceeded the eight hour HGCZ. According to this measure it would be inferred that "health risks are likely" for eight hour exposures in these situations. The ambiguity in whether VTV should be used for the evaluation of health effects is consequently problematic.

Criteria for considering alternative measures

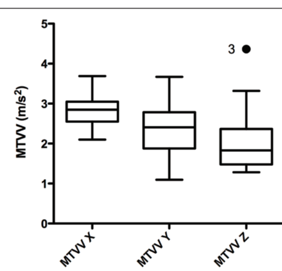
Crest factors for the Z direction calculated ranged from 6.2 to 35.4 (median = 11.5), and 19 of the 26 measurements were greater than 9 (the cut-off suggested by ISO 2631.1 as indicating alternative measures of vibration measurement should be considered).

The crest factor is sensitive to the duration of measurement, in that the longer the measurement duration, the greater the probability of a higher peak value, and consequently its validity as a criterion for the use of alternative measures might be questioned.

The ratio of MTVV to r.m.s. for the Z direction ranged from 2.4 to 5.9 (median = 3.0), and all measurements in all directions exceeded the threshold of 1.5 nominated as the criteria for use of MTVV. The use of this criterion would suggest that MTVV should be utilised in the evaluation of the dozer measurements, although as noted earlier, no guidance is provided regarding how these values should be evaluated.

In contrast, only 3 of the 26 measurements exceeded the VDV threshold criteria of the ratio of the VDV to the product of the r.m.s. value and the fourth root of the time period of the measurement in the Z direction (measurements 1, 3 & 14). Use of this criterion would suggest that the basic evaluation method was sufficient for all other measurements.

Figure 2: MTVV distributions for 26 WBV measurements from dozers in operation at a surface coal mine.



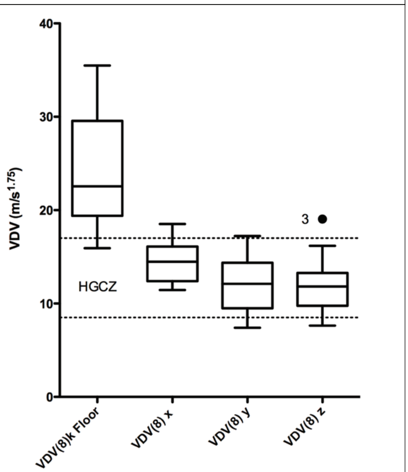
Alternate methods

Figure 2 describes the distributions of MTVV calculated as described in ISO2631.1 equation 2. Again the greatest values for the dozer accelerations are consistently in the fore-aft direction. As noted above, interpretation of these data is difficult because no guidance is provided within ISO 2631.1 regarding the evaluation of MTVV values. It is clear than measurement 3 provided an exceptionally high MTVV value in the Z direction, and might logically be highlighted for further investigation. However, in the absence of evaluation criteria, the utility of the MTVV measure is limited to providing an alternative means of describing different measurements.

Figure 3 describes the distributions of VDV [expressed as 8 hour equivalent VDV (8)] for the floor accelerometer and the three dimensions at the seat. The VDV(8) values are consistent with r.m.s. values in that the X-axis was the greatest value in the majority of trials. Almost all VDV(8) values (without the application of the k multiplier to X and Y directions) were within the HGCZ. If the X and Y directions are increased by 40% (k = 1.4), all except four measurements lie beyond the HGCZ. ISO 2631.1 does not make it clear whether this is an appropriate procedure, however.

As for the r.m.s. values, VDV values at the floor are far greater than those in the Z direction experienced by the dozer operator at the seat.

Figure 3: VDV(8) for Floor and X, Y, & Z directions for 26 WBV dozer measurements of dozers in operation at a surface coal mine.



The VDV SEAT values ranged from 0.16 to 0.86 quantifying the effectiveness of the seat in attenuating accelerations in the Z direction.

Figure 4 (A-C) illustrates the relationship between VDV(8) and r.m.s. measurements for the X, Y and Z directions. The HGCZ for 8 hour exposures to both r.m.s. and VDV are indicated. Measurements which lie in the shaded regions are those for which there was agreement between evaluation methods. A generally high correspondence was evident, the exceptions being measurements 1 and 3, for which an evaluation of the VDV measure in the Z direction suggests a higher risk than r.m.s. This is consistent with the VDV criterion for the use of alternative methods which highlighted these trials (and one other) as trials for which the basic evaluation method may in insufficient.

Utility of ISO 2631.1

While ISO 2631.1 provides a method for describing whole body vibration, given the explicit introductory statement that the standard “does not contain vibration exposure limits”, the ambiguities and anomalies noted by Griffin (2004) and illustrated here, and the caveats contained within the standard (particularly that related to the acknowledged lack of evidence for the evaluation of vibration in the X & Y directions) it is difficult to know how to utilise the standard most appropriately.

The Z-axis is the dominant vibration axis for most equipment types. For example, Cann et al (2003) tested 14 different types of construction equipment and reported that the Z-axis was dominant for all except dozers, excavators, crawler loaders and compactors (where, as here, the X-axis dominated). Where the Z direction is dominant, consideration of the r.m.s. and VDV(8) values is relatively straight forward. In the absence of evidence suggesting otherwise, it seems prudent to utilise the more conservative HGCZ zone values rather than those provided by the EU regulation. Even where the Z-axis is not dominant, it seems prudent to evaluate these values given the potential implication in the development of back pain, in addition to considering the X or Y-axes.

Consideration of vibration in X and Y-axes is complicated by the anomalous “k” factor introduced by ISO2631.1. No rationale for the inclusion of the multiplier is provided, nor any explanation why lateral vibration is weighted more highly when evaluating VTV for health effects rather than comfort. Indeed, evidence exists which suggests that lateral vibrations are reported to be significantly less comfortable than vertical vibrations (Dickey et al., 2002; Griefahn et al., 1999) suggesting that, if anything, the weighting for X & Y directions should be greater for evaluating comfort.

Influence of task

Six of the 26 measurements, including trials 1 and 3, were taken from one Dozer (A). Figure 5 illustrates the range of acceleration magnitudes measured [VDV(8) measurement range from 19.4 to 19 $m/s^{1.75}$]. The highest VDV values were measured whilst the dozer was engaged in "building ramps", while the lower three measurements were associated with "pushing" tasks. Differences in operator technique may also influence vibration amplitudes. Investigation of the situations in which the highest vibration levels were measured may reveal opportunities for reducing the vibration exposure of operators.

These data highlight the important observation that, as well as vehicle design aspects such as suspension and seating, the vibration amplitudes to which earth moving operators are exposed are also a function of a range of other factors such as roadway conditions and vehicle speed and, perhaps particularly in the case of dozers, the operations being performed. The implication for designers, manufacturers, importers and suppliers of plant aiming to meet their obligations to ensure that appropriate evaluations are conducted is that vibration assessments must be conducted while the equipment is performing the range of tasks and operations for which the equipment might reasonably be anticipated to be used; and under the range of conditions which might reasonably be anticipated to be encountered.

The implication for persons conducting a business or obligation holders in control of a workplace where earth moving equipment is used is that short duration measurements taken at irregular intervals are unlikely to provide a reliable indication of the magnitudes of vibrations to which earth moving equipment operators are exposed, and consequently not provide the information required by employers to meet their obligations to, so far as is reasonably practicable, eliminate or minimise risks to health and safety. More systematic measurements at frequent intervals, correlated

Figure 5: Z direction VDV(8) measurements as a function of Z r.m.s. for 6 measurements from Dozer A performing a range of tasks at a surface coal mine.

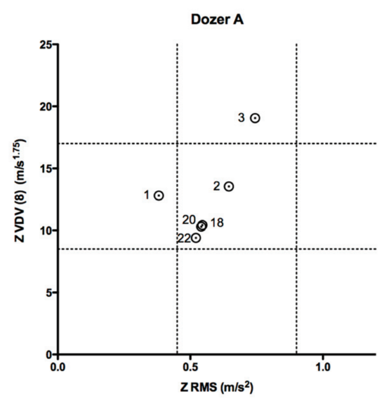
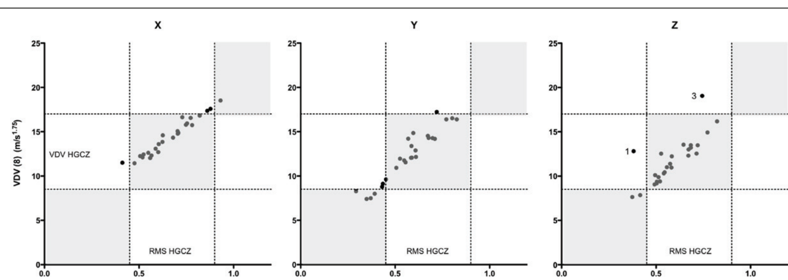


Figure 4: VDV(8) vs r.m.s. measures in X, Y & Z directions for 26 WBV dozer measurements of dozers in operation at a surface coal mine.



with other information such as the activities being undertaken and detailed assessment of other risk factors such as posture, has potential to assist in the identification of appropriate control measures - be they improving shot firing standards; more frequent maintenance of suspension, seating, or roadways; changes to cab design or seating; operator training; or more effective controls such as remote operation or automation.

CONCLUSION

ISO2631.1 is ambiguous and anomalous in a number of respects and its application is consequently problematic. Task-dependent variability in vibration measurements was noted. The implication for equipment manufacturers is that measurements must be taken in the range of realistic operating conditions in order to accurately characterise vibration exposure for design purposes. The implication for mine operators is that systematic measurement of whole body vibration correlated with information such as the activity being undertaken has potential to assist in the identification of appropriate control measures.

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REFRERENCES

Bernard, B.P. (Ed).(1997). *Musculoskeletal disorders and workplace factors: a critical review of epidemiologic evidence for work-related disorders of the neck, upper extremities, and low back*. DHHS (NIOSH) Publication No. 97-141. US Department of Health and Human Services, National Institute of Occupational Safety and Health.

Bovenzi, M. & Hulshof, C.T.J. (1998). An updated review of epidemiologic studies on the relationship between exposure to whole-body vibration and low back pain. *Journal of Sound and Vibration. 215*, 595–611.

Cann, A.P., Salmoni, A.W., Vi, P. & Eger, T.R. (2003). An exploratory study of whole-body vibration exposure and dose while operating heavy equipment in the construction industry. *Applied Occupational and Environmental Hygiene.18*, 999-1005.

Dickey, J.P., Eger, T.R., Oliver, M.L., Boileau. P-E., Trick, L.M. & Edwards, A.M. (2002). Multi-axis sinusoidal whole-body vibrations: Part II - Relationship between Vibration Total Value and discomfort varies between vibration axes. *Journal of low frequency noise, vibration and active control. 26*, 195-204.

European Parliament (2002). Directive 2002/44/EC of the European Parliament and of the council of 25 June 2002 on the minimum health and safety requirements regarding the exposure of workers to the risks arising from physical agents (vibration). *Official Journal of the European Communities. L.177*, 13-18.

Griefahn, B. & Brode, P. (1999). The significance of lateral whole-body vibrations related to separately and simultaneously applied vertical motions. A validation study of ISO 2631. *Applied Ergonomics. 30*, 505-513.

Griffin, M.J. (2004). Minimum health and safety requirements for workers exposed to hand-transmitted vibration and whole-body vibration in the European Union. A review. *Occupational and Environmental Medicine. 61*, 387-397.

International Standards Organisation (1997) Evaluation of human exposure to whole-body vibration. Part 1 - General Requirements. ISO2631.1. Geneva, Switzerland : ISO

Kumar, S. (2004). Vibration in operating heavy haul trucks in overburden mining. *Applied Ergonomics. 35*, 509–520.

NSW Department of Primary Industries. (2002). *Guideline for Mobile and Transportable Equipment for use in mines*. MDG15.

McPhee, B., Foster, G., & Long, A. (2009). Bad Vibrations. 2nd Edition. Sydney: Coal Services Health & Safety Trust.

Paddan, G.S. & Griffin, M.J. (2002). Effect of seating on exposures to whole-body vibration in vehicles. *Journal of Sound and Vibration. 253*, 215-241.

Smets, M.P.H., Eger, T.R., & Grenier, S.G. (2010). Whole-body vibration experienced by haulage truck operators in surface mining operations: A comparison of various analysis methods utilised in the prediction of health risks. *Applied Ergonomics. 41*, 763-770.