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Exposure to Whole Body Vibration for Drivers and Passengers in Mining Vehicles

Part 2

Report of findings at four Underground Mines
To be read in conjunction with Part 1 - Open-cut mines and a coal loader

1997 to 2000

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EXPOSURE TO WHOLE BODY VIBRATION FOR DRIVERS AND PASSENGERS IN MINING VEHICLES – PART 2

REPORT TO THE JOINT COAL BOARD HEALTH AND SAFETY TRUST

1. EXECUTIVE SUMMARY

1.1 Introduction

In NSW a significant number of Workers' Compensation claims are for back and neck injuries believed to arise directly or indirectly from exposure to what are commonly referred to as 'rough rides'. These rides include jolts and jars as well as 'steady state' vibration and are measured in terms of whole-body vibration (WBV). There has been surprisingly little research into the long-term effects on humans of exposure to WBV. Similarly there is very limited information on the extent and nature of WBV exposure in mining personnel in Australia.

This is Part 2 of a Report of on exposures of coal mine workers to WBV. The study was conducted in NSW open-cut and underground mines and a coal loading facility. Part 2 deals with the results from the four underground mines, which commenced in 1997. It should be read in conjunction with Part 1 of the Report which contains results from four open-cut mines and a coal loader, a literature review; an explanation of the different WBV Standards used; the Study questionnaires and checklists; and research papers written before May 2000.

1.2 Methods

Measurements were made on different vehicles undertaking a range of activities under normal operational conditions. Factors that might influence the ride of a vehicle were recorded. As a random sample this study provides a 'snapshot' in time of vibration exposures in coal mine workers from 1996 to 2000.

Participants in the study were either operators or passengers on four machine types of different ages:

- personnel and materials transport vehicles both free steered and rail
- load-haul-dump vehicles (LHDs)
- skid steer vehicles
- a shuttle car (test run on the surface).

Vibration exposures for operators and passengers were measured with custom-built equipment. Information was sought from operators and passengers on their ratings of rides, their opinions of the cab and seat, symptoms of sprains, strains, aches and pains experienced within the previous year, and whether they considered any of these to be related to their work. Information gathered from operators on the ride quality has been directly compared with the vibration recordings that were made.

Recommended vibration exposures were determined according to the Australian, British and the new International Standards, which include limits for comfort, fatigue and health. How well the seat damped vibration for the operator was calculated using a formula devised in Britain called SEAT (Seat Effective Amplitude Transmissibility).

1.3 Findings

Forty-two participants from the four underground mines took part in the study and 68 sample rides were analysed. Thirty-six participants answered questions about themselves.

The current Australian (AS 2670-1990) and British (BS 6841:1987) and the new International Standards (ISO 2631-1, 1997), give widely varying exposure time limits depending on the type of exposure and how the analysis is carried out.

The Australian Standard assessed most vehicle rides in this study as acceptable for exposure time limits of 16 hours. Four different Free Steered Vehicles (FSVs) and one Load Haul Dump (LHD) machine were acceptable for 4-hour exposure periods. The roughest ride was experienced by passengers of one FSV without suspension that had a permissible exposure period of 2.5 hours. These assessments may, however, underestimate the ride roughness particularly where jolts and jars are frequent.

The International Standard has incorporated methods (Vibration Dose Value or VDV) to better assess WBV exposures that include jolts and jars. It is generally much more stringent and recommends much lower exposure periods than the Australian Standard for typical mine vehicle rides. Under the International Standard all vehicle rides, except those in rail personnel carriers, locos, Dollycars and FSV 4WD Type 1 vehicles (driver), reach the likely health risk zone in less than an 8-hour exposure period. The worst rides in some FSVs reached this zone in only 12 minutes.

The British Standard yielded similar results to the International Standard.

The VDV used in the International Standard is a sensitive indicator of ride roughness. However, most operators and passengers appeared to underrate the roughness of their rides.

Thirty-two of the 36 participants (88.8%) reported some musculoskeletal disorders (sprains and strains, aches and pains) in the previous 12 months. Low back pain (27 or ~~69%~~ 75%) and/or neck pain (18 or ~~46%~~ 50%) were the most commonly reported disorders. (Tables 6, 7, Results). Over 44% and 19% reported back and neck pain respectively in the last seven days. Over 72% (back pain) and nearly 42% (neck pain) thought these disorders were related to what they do at work.

There was a wide performance range for various seats. The ability of the seat to cushion vibration generally tended to decrease as the roughness of the ride increased. No seats performed consistently well in all three axes

A large percentage of participants rated cab design as good or acceptable. This included displays (65%), controls (90%), visibility from the cab (71%); and vehicle seat suitability (65%). However, some vehicles, most notably some makes of LHD were rated as poor due to the lack of cab space, inadequate seating, poor location of displays and controls and a sideways facing seat. There was evidence that poor cab design increased operators' complaints of discomfort.

Factors such as the type, age, design and make of vehicle especially the cab, vehicle suspension, seat suspension, road and work surfaces, activity, speed of operation and driver skills all appeared to contribute to what participants considered to be rougher rides with higher VDV values.

1.4 Proposed strategies for reducing exposures to vibration

It is likely that acceptable levels of exposure could be achieved through a combination of design and administrative controls and each mine will need to consider what works for them. Controls come under the following categories:

- Training of operators to recognise damaging levels of vibration and in driving skills
- Limiting speed
- Prompt communication and correction of specific road problems

- ❑ Timely and effective road maintenance programs
- ❑ Appropriate design of vehicles including cab and seat design, lighting and visibility
- ❑ Effective maintenance of vehicles particularly suspension systems and seats

The relative contribution of each of these solutions needs to be explored further to determine the most cost-effective approach. In the short term administrative and maintenance controls could be applied. In the long-term design aspects of vehicles needs to be considered and addressed.

5.5 Conclusions

A significant number of low back and neck injuries have been precipitated by "rough rides" in mining vehicles of all types. The current Australian and British Standards, and the new International Standard for whole-body vibration exposure give widely varying time limits depending on the type of exposure and how the analysis is carried out.

The current Australian Standard appears to be inadequate for assessing jolts and jars commonly experienced in mining vehicles. It is not suitable for rides containing jolts and jars (shocks) and underestimates the risk of vibration exposures in such rides. It appears to provide little guidance to equipment manufacturers, employers and employees on what are 'safe' limits, particularly in relation to sprains and strains.

However, the new International Standard, which is based on more recent research, has been designed to assess these jolts and jars and appears better for evaluating such vibration exposures. As a result reduces the allowable exposures to these.

If the new International Standard is adopted in Australia, recommended exposures would drop significantly. This has wide implications for the industry. In particular some equipment will need to be redesigned and different approaches to reducing vibration exposure and improving operator comfort, such as cab redesign and isolation, may need to be considered.

As a cross sectional study this project cannot and does not attempt to provide answers on how the cause (exposure levels) and effect (outcomes such as back pain) may be linked. Nor can it identify which are the most important contributing factors to vibration exposures. However, it does identify rides that could be hazardous, factors that may contribute to risks of injury and actions that might be taken to minimise risks to the health of mine workers.

2. INTRODUCTION

In the coal industry in NSW a significant number of Workers' Compensation claims are for back and neck injuries arising directly from rough rides. Further unknown numbers of back injuries also could be attributable, in part, to exposure to vibration.

The two main types of vibration exposure are whole-body (WBV) and local. WBV occurs when the body is supported on a surface that is vibrating, be it sitting on a vibrating seat, standing on a vibrating floor, or lying on a vibrating bed. WBV is usually said to occur when the whole environment is undergoing motion and the effect of interest is not limited to one particular point of contact. Local vibration occurs when one or more limbs are (or the head) are in contact with a vibrating surface. For instance, the terms 'hand-arm' or ' hand –transmitted' are often used if a vibrating device is held in the hands and the effect of interest is local to that source of vibration.

While much is known about the effects on humans of local vibration, such as hand-arm, there has been surprisingly little research into the long-term effects of WBV on humans. It is now believed that it is a risk factor for the development of low back pain.

There is very limited information on the extent and nature of WBV exposure in mining personnel in Australia. The few studies that have been conducted indicate that, for some workers, it is above that recommended in the current Australian Standard (AS 2670-1990). Unfortunately, it appears that the Australian Standard does not adequately assess jolts and jars commonly experienced in 'off-road' vehicles. However, the new International Standard (ISO 2631-1, 1997), which is based on more recent research, has been designed to assess jolts and jars and appears more reasonable for evaluating vibration exposures in mining than the Australian Standard.

This study of WBV exposure in coal miners in NSW commenced in 1995. Vibration exposure measurements were made on a range of vehicles at open-cut and underground mines and a coal loader. Where possible, measurements were made under operational conditions in a cross section of vehicle types undertaking a range of activities. A range of factors that might influence the ride of a vehicle also was recorded.

This is Part 2 of the Report and deals with the results from the four underground mines, which commenced in 1997. It should be read in conjunction with Part 1 of the Report which contains results from four open-cut mines and a coal loader, a literature review; an explanation of the different WBV Standards used; the Study questionnaires and checklists; and research papers written before May 2000.

As a random sample this study provides a 'snapshot' in time of vibration exposures in open-cut mines in 1996 and 1997 and may not reflect the situation in 2000. As a cross sectional study it cannot and does not attempt to provide answers on cause (exposure levels) and effect (outcomes such as back pain). Nor can it identify which are the most important contributing factors to vibration exposures. However, it does provide a basis for further study and action in areas where exposures might be higher than appears to be desirable.

The Joint Coal Board Health and Safety Trust and Worksafe Australia have funded the study conducted originally through researchers at Worksafe Australia. They were: Barbara McPhee (Principal Investigator), Gary Foster (Occupational Hygienist), Airdrie Long (Biomedical Engineer) and Gerard Fay (Research Assistant for nine months). Since 1996 Barbara McPhee and Airdrie Long have participated as independent researchers.

External collaborators were Michael Harrap, Murat Tahtali and Andrew Roberts at the Acoustic and Vibration Centre, Australian Defence Force Academy, Canberra who developed the software and some hardware in consultation with the researchers. Anthony Rose of AR Technologies developed the data logger.

3. AIMS OF THE STUDY

The study aimed to achieve the following:

1. develop an intrinsically safe system for measurement and analysis of Whole-Body Vibration (WBV) in mining;

2. measure and analyse WBV exposure levels in a sample of workers, in a range of mining vehicles, under operational conditions, in underground and open-cut coal mines using the Australian, British and new International Standards;

3. record individual's (operators and passengers) ratings of rides in association with the objective measures;

4. record musculoskeletal symptoms of those participating;

5. develop and publish guidelines on how to reduce exposure to harmful WBV in the mining industry.

The following research questions were posed:

i. Do any exposures to WBV for operators or passengers exceed the Australian, British and new International Standards recommended levels?
ii. Which Standard best reflects the actual WBV exposure levels and participant's responses to a 'rough ride'?
iii. What is the pattern of sprains and strains (musculoskeletal symptoms), especially low back pain, amongst participants?
iv. Do participants relate any of these symptoms to what they do at work?
v. What are the vibration damping characteristics of seating presently used in mining vehicles?
vi. What range of factors might influence WBV exposure in mining industry workers?

4. METHODS AND INSTRUMENTATION

4.1 Selection of mines/facilities and participants

The organisations that took part in the Study were recruited either through a contact at the facility or by a direct approach. In several cases the company personnel approached the research team to take part. Copies of a general information sheet prepared for the mines/facilities was sent to all interested personnel before final participation was confirmed. Additional information was provided on request. Participation in the Study was voluntary for individuals and mines/facilities and they were free to withdraw at any time.

The main mining union representing participants (the Mining Division of the Construction, Forestry, Mining and Energy Union, CFMEU) was approached and information on the project was distributed to it through union representatives.

Another information sheet was prepared for individual participants and was distributed, along with a small talk about the Study, before they gave their written consent to take part.

A coal loading facility, four open-cut and four underground mines agreed to take part in the Study.

There was a random selection of participants and it depended on which vehicles were being operated on a particular shift at each site. While many operators expressed a wish to participate, some could not be included because of the limitations placed on the researchers by time and logistics.

At the end of the data collection in underground mines 42 participants had taken part in the Study, and 68 useable recordings had been made ranging from 5 to 60 minutes in length. No operators had refused the invitation. The research team spent up to nine days at each facility over a three-year period. Data were collected over one to three days at each visit. This report describes these data and discusses them. An earlier report (Part 1 – May 2000) described and discussed data from the open-cut mines and gave some detail on the background of the Study.

4.2 Questionnaire and checklist design

The wording of the questionnaires and checklists was carefully developed so that the researchers conducting the interview would obtain fairly uniform information and in order to minimise misunderstandings for operators.

Most of the information from the questionnaires and checklists has been compiled for the report and the guidelines about vibration and factors important in its control. Some data, such as information on operators' age, height and weight, experience in the operation of plant and equipment, and the occurrence of sprains and strains were compiled to establish a 'snap shot' of the people who participated and their musculoskeletal symptoms (sprains and strains).

Information was also gathered independently on vehicles and seats from knowledgeable people on site.

A full set of questionnaires and checklists used in the study is included in Appendix 3 in Part 1 of the Report.

4.3 Instrumentation

Instrumentation and software were developed in collaboration with the Acoustic and Vibration Centre (AVC), Canberra, to measure, analyse and assess vibration exposures in accordance with the Australian, British and later, the new International Standards. AR Technologies in Sydney built a custom designed data logger. The whole measurement system was calibrated at the CSIRO Measurement Laboratory, Lindfield.

The measurement system consisted of two sets of triaxial accelerometers (sensors), the purpose built data logger, a laptop computer and a magneto-optical disk drive for data storage.

4.3.1 The data logger

The data logger has the capacity to store up to 60 minutes of raw vibration data; it is compact in size and is housed in a stainless steel enclosure enabling it to withstand the rough conditions found in mines. Six input channels are available for the x-, y- and z-axes from two sets of triaxial accelerometers.

Raw vibration signals from the sensors are stored on a series of DRAM chips in the data logger giving a total of 48 Mbyte recording capacity at a sampling rate of 1kHz. The sampling frequency and anti-alias cut-off frequency can be independently selected on the data logger. The anti-alias filter is implemented as an 8th order Butterworth switched capacitor filter with appropriate noise limiting filters. For this application, the unit was configured for a low-pass cut-off frequency of 160 Hz. This satisfies the requirements of the Australian, British and ISO Standards. The recording system has a low noise floor and a 14 bit analogue to digital converter giving a dynamic range of 84dB which allows high peak levels to be captured along with low continuous vibration signals.

The seat pad, which contains the accelerometers, is made from non-static polyurethane material. The floor accelerometers are mounted on a metal plate which is bolted or clamped to the floor of each test vehicle.

4.3.2 'HVIBE' Data analysis program

Data collected was analysed using the 'HVIBE' software, which was specifically written for this purpose as part of the project. This 'Windows'-based software provides a number of unique analysis features that are not available in existing human vibration analysis packages known to the authors. In particular, the HVIBE software allows complete data analysis according to AS 2670, ISO 2631-1 and BS 6841.

A key objective in the design of the HVIBE software was to provide the user with the flexibility of a research tool whilst maintaining ease of use. The program makes use of a graphical user interface which provides the user with facilities for previewing raw data: specifying analysis sequences: monitoring calculations as they progress and viewing results. The results may be exported in graphical or numerical forms.

Many of the human vibration calculations described by AS 2670, ISO 2631-1 and BS 6841 require vibration signals to be frequency weighted using prescribed filters. This process is analogous to the various frequency weightings used in the analysis of sound signals. For example, the 'A' weighting curve used in 'dB(A)' sound pressure level measurements. The human vibration filters required by the two standards are implemented numerically in the HVIBE program. All digital filters are within tolerances prescribed in the standards.

Narrowband spectra used in the calculation of the transmissibility, r.m.s. spectra and r.m.q. spectra are calculated using a fast fourier transform (FFT). The nominal data sampling rate of 1kHz leads to a narrowband spectra with a resolution of less than 1Hz. The r.m.q. spectrum calculation is a unique feature of this software. It allows for a comparison to be made with the r.m.s. spectrum to identify the frequencies contributing to the result obtained using the various standards.

4.3.3 Measurements

Measurement of vibration was made in three orthogonal axes, fore to aft (x), side to side (y) and up and down (z), simultaneously on the floor and the seat (Figure 1). The seat accelerometer (sensor) was used to measure the whole-body vibration exposure of the operator or passenger. The floor accelerometer was attached firmly to the cab frame, usually the floor, with a metal plate that was screwed on with G clamps. Data signals from the accelerometers were stored on the data logger, which was positioned inside the vehicle cabin. The two accelerometers allowed an assessment to be made of the performance of the seats presently in use. Vibration levels on the floor of the vehicle were compared with those measured on the seat. From these data the seat vibration damping characteristics or 'seat transmissibility' were evaluated.

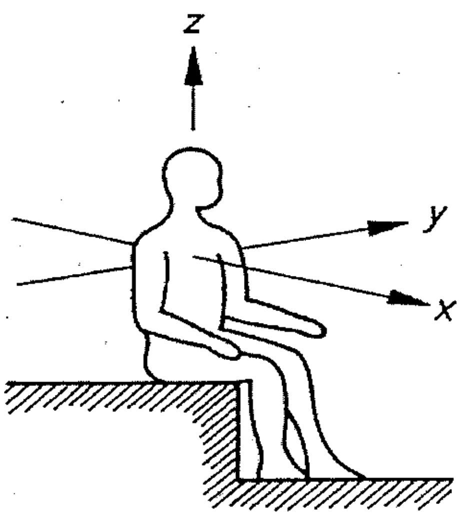


Figure 1. Vibration Axes

Source: Australian Standard AS 2670-1990, Evaluation of human exposure to whole-body vibration

4.4 Data collection

After each test run the data collected were downloaded onto a laptop computer.

Researchers interviewed the operator or passenger about:

- the ride that they were experiencing,
- any musculoskeletal symptoms (sprains and strains) they might have, and
- their opinions on the design and maintenance of the vehicle, the cab, the seat, the roads and the work conditions etc.

This took about half to three-quarters of an hour. In cases when it was no possible to accompany the driver on the test run the interviews were made immediately after the measurement period.

For each exposure measurement the interview was used to survey an individual's work history, estimated past vibration exposures, back pain experience and other related symptoms. The symptom history over the last seven days and the last 12 months was recorded on a form based on the Nordic Questionnaire, commonly used throughout the world to gather basic information on sprains and strains. The operator's opinion of the roughness of the ride being recorded was also sought. Information on the types of vehicles driven regularly was recorded in order to get a more accurate picture of exposure patterns.

Information on other factors associated with each ride were recorded. These included work patterns during the measurement period, design of the cab and the seat, sitting postures, seat and vehicle suspension, condition of the vehicle being driven, condition of the road and visibility.

4.5 Types of vehicles selected for measurement

Measurements of whole-body vibration levels were conducted on a range of vehicles. These were personnel and equipment transport (both free-steered and rail), load-haul-dump (LHD) machines, and skid steer vehicles. Unfortunately shuttle cars could not be measured underground due to the stringent intrinsic safety requirements for the measuring equipment. A shuttle car was measured on the surface and this could be used as base-line data for further measurements at a later date.

The vehicles measured were considered to give a variety of rides from "rough" to "good". They were selected after consultation with users and others on site. Vehicles were fitted with a range of seats.

The vehicles selected for measurement on any day varied depending on the availability of vehicles and operators. The following combinations were included:

- ◊ same driver - different vehicles
- ◊ different drivers - same vehicle
- ◊ same driver - same vehicle - different speeds or different work areas
- ◊ 'best' vehicles - 'worst' vehicles
- ◊ 'before and after' measurements e.g. installation of a new seat.

4.6 Data analysis

Whole-body vibration exposure levels were determined according to the Australian, British and the new International Standards.

4.6.1 Seat vibration isolation efficiency

Two methods were used to indicate seat vibration isolation efficiency

4.6.1.1 Transmissibility

The vibration that is transmitted through the seat to the driver is assessed using the vibration transmissibility characteristics for each axis over a frequency range from 1-20 Hz. A typical transmissibility charts for a FSV without suspension is shown in Figure 13, Discussion. The seat reduces the vibration level at those frequencies where the transmissibility value is below 1.0. Transmissibilities above 1.0 indicate that the seat is actually amplifying the vibration level. This commonly occurs at 2-3 Hz in the z-axis and is due to the natural resonance of the seat suspension system.

4.6.1.2 Seat Effective Amplitude Transmissibility (SEAT)

The seat vibration isolation efficiency (how well the seat reduces harmful vibration) was also assessed in terms of the "SEAT" value (Seat Effective Amplitude Transmissibility). This value is calculated from the ratio of seat/floor vibration dose values and is a single number representation of the seat performance over a range of frequencies. A SEAT value below 1.00 indicates that, over all frequencies, the seat suspension is decreasing the vibration level in a particular axis. A positive SEAT value (above 1.00) means that the seat is actually increasing the vibration transmitted to the driver at certain frequencies. SEAT values are listed in Table 5.1 and 5.2 in the Results Section and Tables A5.1 to A5.4 in Appendix 1.

4.6.2 Whole-body vibration standards

At present Standards are in a state of change. It has been recognised that the current Australian Standard does not properly assess the risks of whole-body vibration especially if exposures include shocks or jolts and jars.

Whole-body vibration is measured as the acceleration (m/s^2) in three translational axes: x-axis (back to chest, or fore and aft), y-axis (right to left or side to side) and the z-axis (foot to head or vertical axis).

There is limited relevant scientific information on the effects of whole-body vibration on the human body (see papers in Appendix 2, Part 1 of the Report). Most exposure studies relate to the z-axis and were conducted in laboratories. The contribution of vibration in the x- and y-axes to back pain and other symptoms is not known. Also, it is not possible at the moment to specify, with any precision, the type or probability of injury caused by vibration exposure. Some anecdotal and statistical evidence and limited biomechanical research indicates that jarring in vehicles is the direct precipitator of some vibration related back problems. None of the current standards addresses these aspects or the effects of intermittent exposures to vibration or the influence of work breaks.

Vibration measurements from this study were analysed according to three different Standards (as described below) to compare their suitability for assessing whole-body vibration exposure of mine workers. It should be noted that each Standard uses different frequency weightings in the assessment of r.m.s vibration acceleration and as a consequence, the r.m.s values will vary between Standards.

It is important to understand the aims and limitations of these methods before trying to understand the results.

4.6.2.1 Australian Standard

The Australian Standard *AS 2670-1990, Evaluation of human exposure to whole-body vibration* duplicates the previous International Standard (ISO 2631-1985). It provides exposure limits for three criteria boundaries:

- *Reduced comfort boundary* - (comfort) applies mainly to vibration in transport and nearby machinery. The standard states..."In the transport industry, the reduced comfort boundary is related to difficulties of carrying out such operations as eating reading and writing". This boundary may not be relevant to the mining industry.

- *Fatigue decreased proficiency boundary* - (fatigue) "The boundary specifies a limit beyond which exposure to vibration can be regarded as carrying a significant risk of impaired working efficiency in many kinds of tasks, particularly those in which time-dependent effects ("fatigue") are known to worsen performance as, for example, in vehicle driving."

- *Exposure boundary* - (health) - preservation of health and safety. "The exposure limit is set at approximately half the level considered to be the threshold of pain (or limit of voluntary tolerance) for healthy human subjects restrained to a vibrating seat". These limits are based on laboratory studies on male subjects.

The Australian Standard gives no guidance on whether the 'health' or the 'fatigue' criteria should be applied, to satisfy statutory Occupational Health and Safety (OH&S) requirements. If tested in court, it is likely that OH&S regulations would be based on the health criteria. However, the fatigue criteria are probably much more useful as an indication of potential health and safety problems and are commonly used for guidance on worker exposure.

The major limitation with the Australian Standard is that it is not applicable to vibration exposures that exceed a crest factor of six. The crest factor is a measure of the impulsiveness of the signal and is the ratio of the peak value to the r.m.s. value. This is particularly significant for assessment of whole-body vibration in coal mines because jolts and jars often produce crest factors that exceed this value. Therefore the Australian Standard underestimates the risks to health of vibration exposures that contain shocks.

Exposure Time Limits

The boundary time limits are 24 hours, 16 hours, 8 hours, 4 hours, 2.5 hours, 1 hour, 25 minutes, 16 minutes and 1 minute. It is common practice to express test results as 'the boundary exceeded'. The Standard does not make it clear if the boundary exceeded should be taken as the permissible exposure time for that particular ride. An approximate interpolation (estimation) between boundaries may be made to determine more accurately the permissible exposure duration for practical purposes. However, a strict interpretation of the Standard in law may be that the permissible exposure duration should be taken as the next lower boundary from the boundary exceeded. For example, if the 8-hour boundary were exceeded, the permissible exposure time would be 4 hours. A flaw in this method is the fact that even if the 8-hour boundary were only just exceeded, the exposure limit would still be taken as 4 hours. Fatigue and health limits are given in the Results Section (Tables 2.1 to 2.3) and Appendix 1 (Tables A2.1 to A2.4).

Two methods of evaluation described in AS 2670

The Australian Standard describes two different ways to evaluate vibration exposure. These are the third-octave and the overall r.m.s. methods. Results of the third-octave method have been provided in this report, as this is the preferred method in the Standard.

Third-octave method

This is the recommended method for assessing exposure limits in this Standard and the most commonly used. These limits are evaluated by comparing the unweighted third-octave spectrum levels with a set of criteria curves for each axis. The permissible exposure time is established from the lowest boundary exceeded. The criteria curves are drawn to give emphasis to those frequencies which are more damaging to the human body i.e. z-axis (4-8 Hz), x- and y-axes (1-2 Hz) (Figure 2).

In the example given in Figure 2, the lowest boundary exceeded is 2.5 hours for the 4Hz frequency band.

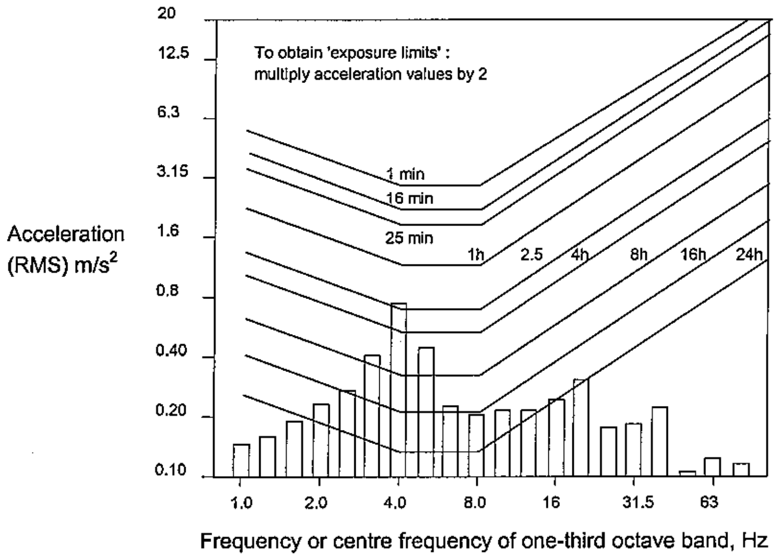


Figure 2. Australian Standard Vibration Time Limits for Z Axis: Fatigue-decreased deficiency boundary ('fatigue')

Overall RMS method

The standard also prescribes an alternative method of assessment when it is not possible to use the third octave method. The weighted, overall root mean square (r.m.s.) may be used to assess comfort and performance but is not recommended for health and safety exposure criteria and was not used in this study.

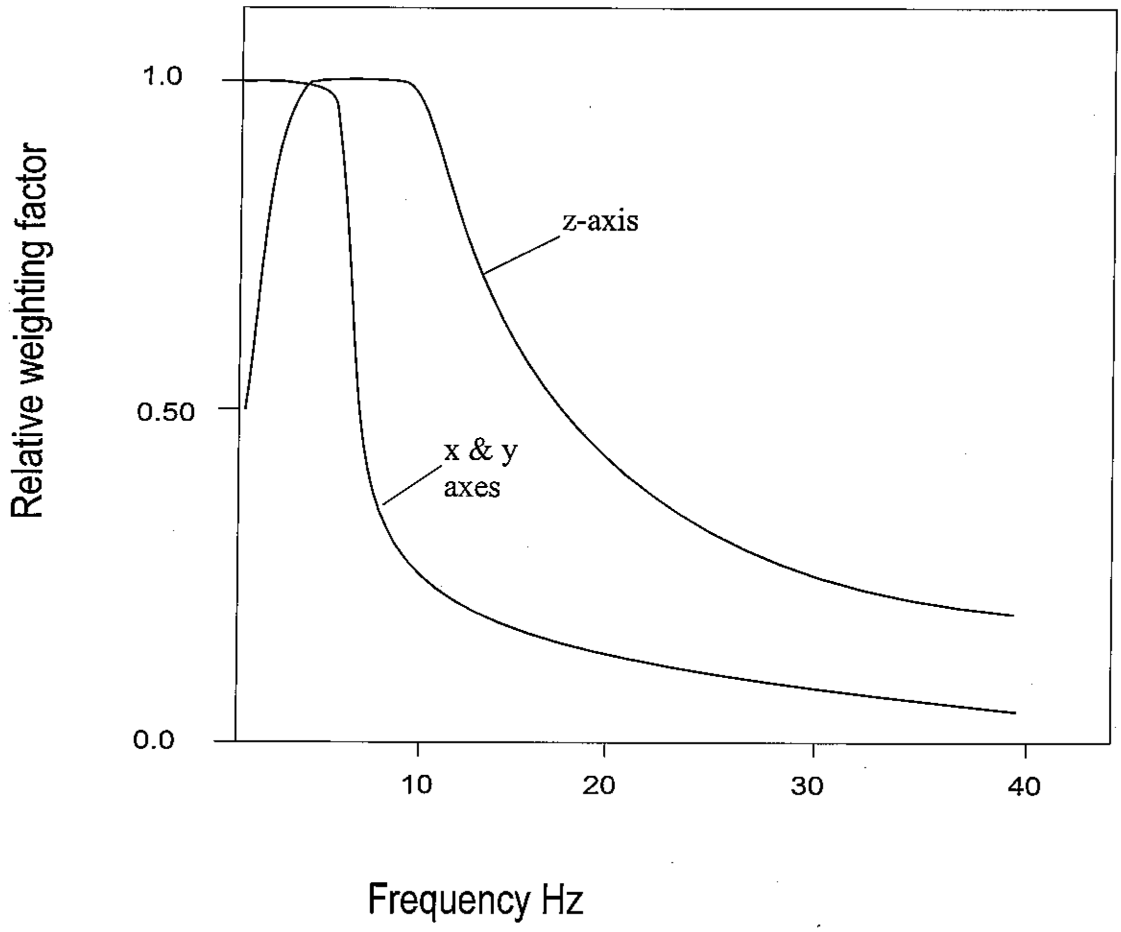


Figure 3. Australian Standard (AS2670.1, 1990): Frequency Weighting Factors for x, y, and z-axes.

Note:

The Australian Standard is only suitable for evaluating vibration exposures that are fairly continuous without jolts and jars. Unfortunately in the mining industry whole-body vibration exposure is not continuous but contains many jolts and jars.

An indication of the extent of jolts and jars in a vibration measurement is given by the 'crest factor', which is the ratio of the peak level to the r.m.s. level. The Australian Standard is recommended only for vibration exposures with crest factors up to 6. Mine vehicles commonly exceeded this limit.

4.6.2.2 British Standard

The British Standard BS.6841-1987, *Guide to measurement and evaluation of human exposure to whole-body mechanical vibration and shock*, addresses the issue of jolts and jars by incorporating a vibration dose value (VDV). The vibration dose value is based on the fourth power instead of the second power used in the r.m.s averaging method. Being a fourth power function, the VDV is more sensitive to peaks and therefore a better indicator of rides that contain shocks or jolts and jars. The VDV calculates an accumulated vibration dose for the exposure period.

The British Standard gives preference to the VDV method and states that, "Since vibration conditions which may impair health will often have high crest factors it is necessary to define a procedure which is applicable to such motions. The preferred method (VDV) may be used with all types of vibration and repeated shock. The approximated method (estimated VDV) may be used with low crest factor vibration (less than 6)".

The estimated vibration dose value (eVDV) is calculated using the r.m.s. acceleration value as follows:

$$eVDV = 1.4 \times \text{r.m.s. value} \times (\text{duration})^{1/4}$$

In this report all British Standard assessments were based on the VDV rather than the eVDV.

An 'action level ' of 15 $m/sec^{1.75}$ is recommended. Rides that produce vibration doses in the region of this level will usually cause severe discomfort according to the Standard. According to the Standard...."It is reasonable to assume that increased exposure to vibration will be accompanied by increased risk of injury".

The British Standard provides for assessment of vibration exposure in three axes on the seat, backrest and floor as well as rotational axes, giving a total of 12 axes. In this study, only seat and floor axes were measured due to equipment limitations. In the great majority of cases, assessment based on vibration exposure transmitted through the seat is sufficient.

4.6.2.3 New International Standard

The new International Standard ISO 2631-1, 1997, *Mechanical vibration and shock - Evaluation of human exposure to whole-body vibration,* is quite different to the previous ISO standard. It has abandoned the third-octave band method and uses the *overall, weighted r.m.s.* value to evaluate the average vibration exposure in what the Standard refers to as the 'basic' evaluation method. The frequency weighting emphasises the more damaging frequencies for humans in a similar way to the Australian and British Standards.

The Standard uses a 'caution zone' for classifying vibration exposures that lie between specified limits depending on the exposure duration (Figure 4). Exposures above this caution zone are considered to be in a 'likely health risk zone'. Recommendations are based mainly on exposures in the range 4-8 hours and there is limited research evidence outside this range.

The caution zone could be viewed as an 'action level' where intervention to control exposure is necessary. Exposures in the 'likely health risk zone' would likely to be considered unacceptably high even in a court of law but there also may be a case for applying caution zone criteria to exposure regulations. The new criteria were, however, not meant to be 'exposure limits' but more as 'guidance' for assessing vibration exposures.

Combined Axes

In cases where all axes contribute substantially to the vibration exposure, provision is made to combine these values to give the total vibration exposure value. This combined value is often necessary for dozers and loaders because there is substantial vibration in all axes. Vehicles' activity causes this, particularly the pushing and ripping (x-axis) and turning (y-axis) phases.

Assessment of shocks

The new International Standard has recognised that the health effects caused by high peaks or shocks may be underestimated by r.m.s averaging alone. It has introduced two methods (referred to as 'additional methods') to evaluate rides containing shocks that give crest factors (peak vibration/r.m.s. vibration) above 9.

The Vibration Dose Value (VDV) method

As in the British Standard the vibration dose value is based on the fourth power instead of the second power used in the r.m.s averaging described above. Being a fourth power function, the VDV is more sensitive to peaks than the 'basic' evaluation method and therefore a better indicator of rides that contain shocks or jolts and jars. The caution zone is reached when the VDV is 8.5m/sec $^{1.75}$ and the likely health risk zone when the VDV is 17 m/sec $^{1.75}$.

The running r.m.s. method

The running r.m.s method takes into account occasional shocks and transient vibration by the use of a short integration time constant (one second). This gives a vibration acceleration defined as a maximum transient vibration value (MTVV) and will be higher when applied to shocks compared to continuous vibration. The MTVV value is then compared with the same criteria as the basic evaluation method.

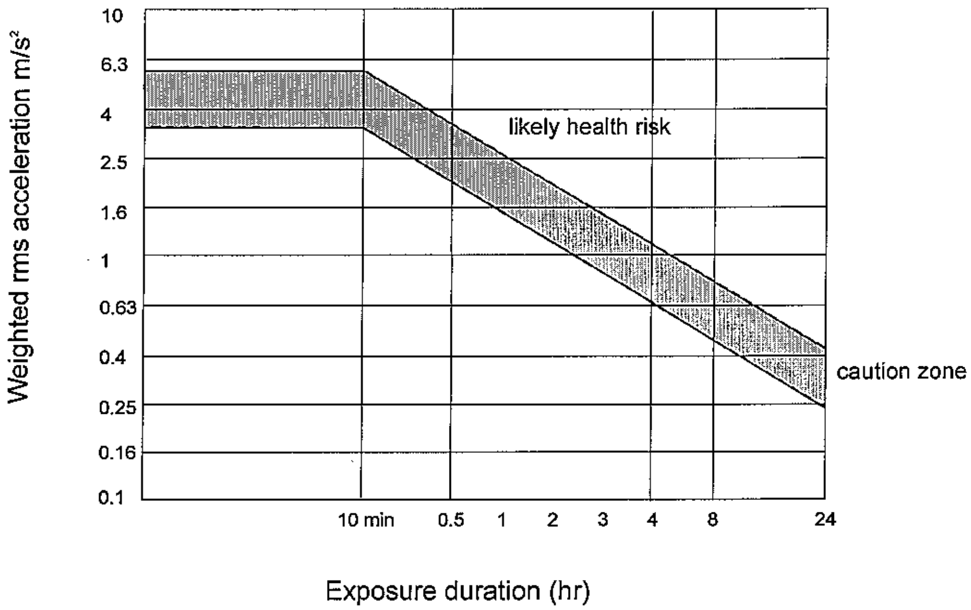


Figure 4. **New International Standard (ISO 2631-1, 1997): Health** guidance caution zones

4.7 Measured readings and operator's assessment of the ride

The vibration exposure levels were compared with operator's subjective opinion of the ride, complaints of back pain and other symptoms. Other factors such as road and vehicle condition, operator's opinions of the vehicle cab design, and work patterns were considered in the overall assessment.

Information gathered from operators on the 'quality of ride' has been directly compared with the objective recordings that were made.

Two types of ride assessment methods were used. The first was derived from the British Standards Institution (Figure 5) with a six-point scale ranging from 'not uncomfortable' to 'extremely uncomfortable'. Operators and passengers were asked to describe in these terms how they felt at the end of the recorded ride. The rating was linked with readings (r.m.s.) and any correlation noted.

The second was a simple (line) rating scale (Figure 6). It consisted of a 100mm line on the left end of which was 'best ever ride' and the right end was 'worst ever ride'. Operators and passengers were asked to point on the line where they regarded the recorded ride rated compared with all other rides they had ever experienced. For analysis the scale was divided into four equal parts that were labelled for analysis left to right as good, OK, fair and poor.

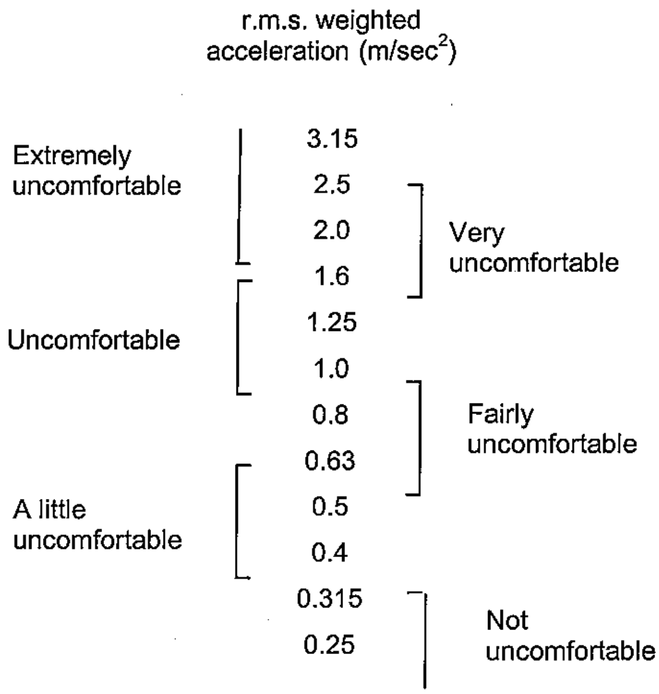


Figure 5. Scale of vibration discomfort (British Standards Institution, 1987)

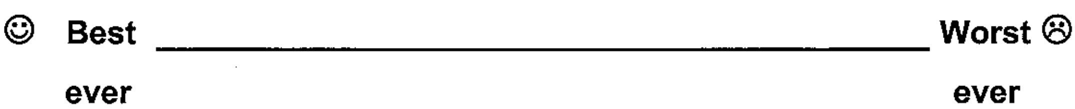


Figure 6. Simple Rating Scale

5. RESULTS

5.1 Introduction

In this part of the project a total of 42 participants took part on eight visits to four underground coal mines between August 1997 and June 2000. A total of 68 ride samples were recorded and analysed. There were some repeat readings. In addition 36 participants answered questions about themselves.

A summary of the results from each sample, as it was analysed using different methods, and information from participants can be found in Tables 1 to 9 and Figures 7-10.

Tables containing results for individual rides can be found in Appendix 1. Interpretation and discussion of these results are provided in the next section entitled Discussion.

Table 1 Vehicle Type Abbreviations used in Results Tables

Rail personnel carrier	Rail personnel carrier
Dollycar	Dollycar
Loco	Loco
FSV 4WD Make 1	Free Steered Vehicle (FSV) 4WD with suspension Make 1 (personnel 'troop' carrier)
FSV 4WD Make 2	Free Steered Vehicle (FSV) 4WD with suspension Make 2 (personnel 'troop' carrier)
FSV Make 3a	Free Steered Vehicle (FSV) without suspension Make 3a (materials and personnel carrier with trailer)
FSV Make 3b	Free Steered Vehicle (FSV) Make 3b (modified materials and personnel carrier Make 3a with suspension)
FSV Make 4	Free Steered Vehicle (FSV) without suspension Make 4 (materials and personnel carrier - convertible)
FSV Make 5	Free Steered Vehicle (FSV) with limited suspension Make 5 (materials and personnel carrier with forward facing seats)
LHD Make 1	Load haul dump (LHD) machine Make 1
LHD Make 2	Load haul dump (LHD) machine Make 2
Skid steer machine	Skid steer machine
Shuttle car (surface)	Shuttle car (surface)

Table 2.1 Australian Standard: Third-octave method, permissible time limits

Sample		RMS m/s2	Boundary exceeded fatigue (hr)	Boundary exceeded health (hr)	Implied exposure limit fatigue (hr)	Implied exposure limit health (hr)	Interpolated boundary fatigue (hr)	Interpolated boundary health (hr)
Rail personnel carrier								
passenger	GM	0.73	8	24	4	16	7.4	20.0
	min	0.65					6.8	18.2
	max	0.78					8.2	22.2
driver	GM	0.77	16	24	8	16	8.5	19.2
	min	0.46					5.8	15.4
	max	1.07					18.5	24.0
Dollycar								
driver		0.17	24	24	16	16	24.0	24.0
Loco								
driver	GM	0.57	16	24	8	16	10.0	22.8
	min	0.53					7.8	21.3
	max	0.59					13.2	24.0
FSV Make 5								
passenger		1.41	2.5	8	1	4	2.5	7.2
FSV 4WD Make 1								
driver	GM	0.54	16	24	8	16	14.3	23.5
	min	0.33					7.7	21.1
	max	0.76					24.0	24.0
passenger	GM	0.87	8	24	4	16	7.7	19.4
	min	0.69					5.5	14.9
	max	1.16					10.2	23.7

Table 2.2 Australian Standard: Third-octave method, permissible time limits (continued)

Sample		RMS m/s2	Boundary exceeded fatigue (hr)	Boundary exceeded health (hr)	Implied exposure limit fatigue (hr)	Implied exposure limit health (hr)	Interpolated boundary fatigue (hr)	Interpolated boundary health (hr)
FSV 4WD Make 2								
driver	GM	0.86	16	24	8	16	9.1	18.2
	min	0.58					4.5	12.8
	max	1.19					17.1	24.0
passenger	GM	1.03	8	16	4	8	4.9	13.4
	min	0.66					2.6	7.4
	max	1.36					7.5	20.6
FSV Make 3b								
driver	GM	1.05	8	16	4	8	4.2	11.5
	min	0.89					2.9	7.7
	max	1.18					7.8	21.5
trailer passenger	GM	1.24	4	8	2.5	4	2.8	7.6
	min	1.18					2.5	7.0
	max	1.31					3.2	8.3
FSV Make 3a								
Driver	GM	1.71	2.5	8	1	4	1.8	5.2
	min	1.33					1.3	3.9
	max	2.35					2.3	6.8
Trailer passenger	GM	2.20	1	4	25min	2.5	0.8	2.7
	min	2.17					0.7	2.4
	max	2.23					0.9	3.0
FSV Make 4								
passenger	GM	1.53	2.5	4	1	2.5	1.1	3.59
	min	1.18					0.6	2.3
	max	2.00					2.0	5.71
driver	GM	2.13	4	16	2.5	8	3.17	8.91
	min	1.20					2.76	7.58
	max	3.80					3.66	10.48

Table 2.3 Australian Standard: Third-octave method, permissible time limits (continued)

Sample		RMS m/s2	Boundary exceeded fatigue (hr)	Boundary exceeded health (hr)	Implied exposure limit fatigue (hr)	Implied exposure limit health (hr)	Interpolated boundary fatigue (hr)	Interpolated boundary health (hr)
LHD Make 1								
driver	GM	0.88	4	16	2.5	8	3.9	11.1
	min	0.68					2.3	6.6
	max	1.10					7.2	19.5
LHD Make 2								
driver	GM	1.44	2.5	8	1	4	1.7	5.6
	min	0.88					0.5	2.0
	max	2.33					5.8	15.4
Skid steer vehicle								
driver	GM	0.68	8	24	4	16	8.5	18.8
	min	0.41					4.5	12.6
	max	1.61					15.6	24.0
Shuttle car (on surface road)								
driver		0.77	8	24	4	16	6.5	17.3

Figure 7 Australian Standard implied exposure limits for fatigue and health criteria

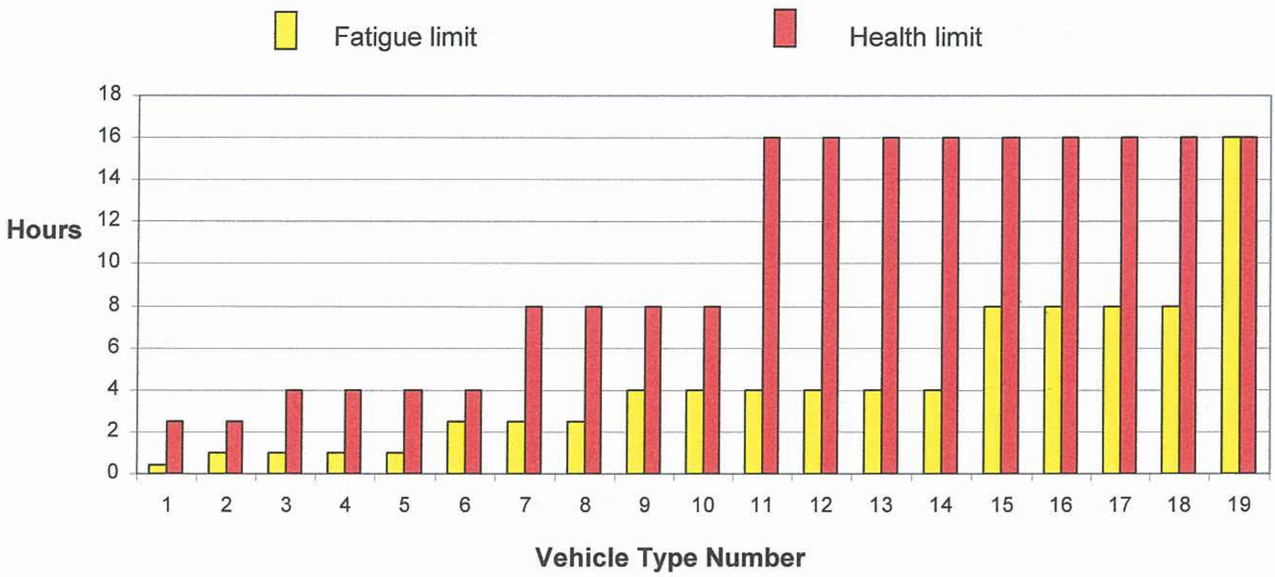


CHART KEY Vehicle Type Number

Vehicle Type	Number
FSV Make 3a-passenger	1
FSV Make 4-passenger	2
FSV Make 5-passenger	3
FSV Make 3a-driver	4
LHD Make 2	5
FSV Make 3b-passenger	6
FSV Make 4-driver	7
LHD Make 1	8
FSV 4WD Make 2 -passenger	9
FSV Make 3b-driver	10
Rail personnel carrier-passenger	11
FSV 4WD Make 1-passenger	12
Skid steer vehicle	13
Shuttle car on surface	14
Rail personnel carrier-driver	15
Loco-driver	16
FSV 4WD Make 1-driver	17
FSV 4WD Make 2 -driver	18
Dollycar-driver	19

Table 3.1 British Standard Assessment: Vibration Dose Values (VDV)

Sample	Activity	VDV 8hr (full shift) (m/sec1.75)	Time to reach action limit (hr)	Worst axis
Rail personnel carrier				
Driver	GM	18.02	3.84	z
	Min	12.31	1.37	
	Max	23.30	17.61	
Passenger	GM	16.98	4.87	z
	Min	13.44	2.95	
	Max	19.25	12.41	
Dollycar				
driver		7.26	145.50	z
Loco				
Driver	GM	5.59	13.30	z
	Min	5.54	13.00	
	Max	5.67	13.73	
FSV Make 5				
passenger		23.41	1.35	z
FSV 4WD Make 1				
driver	GM	11.67	21.86	z
	Min	8.07	7.13	
	Max	15.44	95.39	
passenger	GM	18.32	3.59	z
	Min	12.68	0.73	
	Max	27.29	15.65	

Table 3.2 British Standard Assessment: Vibration Dose Values (VDV) (Cont.)

Sample	Activity	VDV 8hr (full shift) (m/sec1.75)	Time to reach action limit (hr)	Worst axis
FSV 4WD Make 2				
driver	GM	15.85	6.42	z
	Min	11.57	2.73	
	Max	19.63	22.61	
passenger	GM	24.43	1.14	z
	Min	17.36	0.35	
	Max	32.89	4.46	
FSV Make 3b				
driver	GM	21.53	0.48	z
	Min	10.31	0.04	
	Max	56.66	4.76	
passenger	GM	11.18	0.30	z
	Min	10.50	0.21	
	Max	11.90	0.42	
FSV Make 3a				
driver	GM	29.07	0.09	z
	Min	19.15	0.04	
	Max	56.86	0.24	
passenger	GM	27.39	0.14	z
	Min	18.33	0.13	
	Max	40.93	0.14	
FSV Make 4				
passenger	GM	20.68	2.22	z
	Min	15.74	0.74	
	Max	27.16	6.60	
driver	GM	25.39	0.98	z
	Min	19.19	0.32	
	Max	33.58	2.98	

Table 3.3 British Standard Assessment: Vibration Dose Values (VDV) (Cont.)

Sample	Activity	VDV 8hr (full shift) (m/sec1.75)	Time to reach action limit (hr)	Worst axis
LHD Make 1				
driver	GM	22.59	1.55	z
	Min	14.34	0.37	
	Max	32.45	9.59	
LHD Make 2				
driver	GM	33.76	0.31	z
	Min	21.30	0.05	
	Max	53.52	1.97	
Skid steer vehicle				
driver	GM	16.88	4.99	z
	Min	11.54	0.35	
	Max	32.83	22.81	
Shuttle car on surface road				
driver		17.85	3.99	z

Figure 8 Time to reach British Standard VDV Action Level

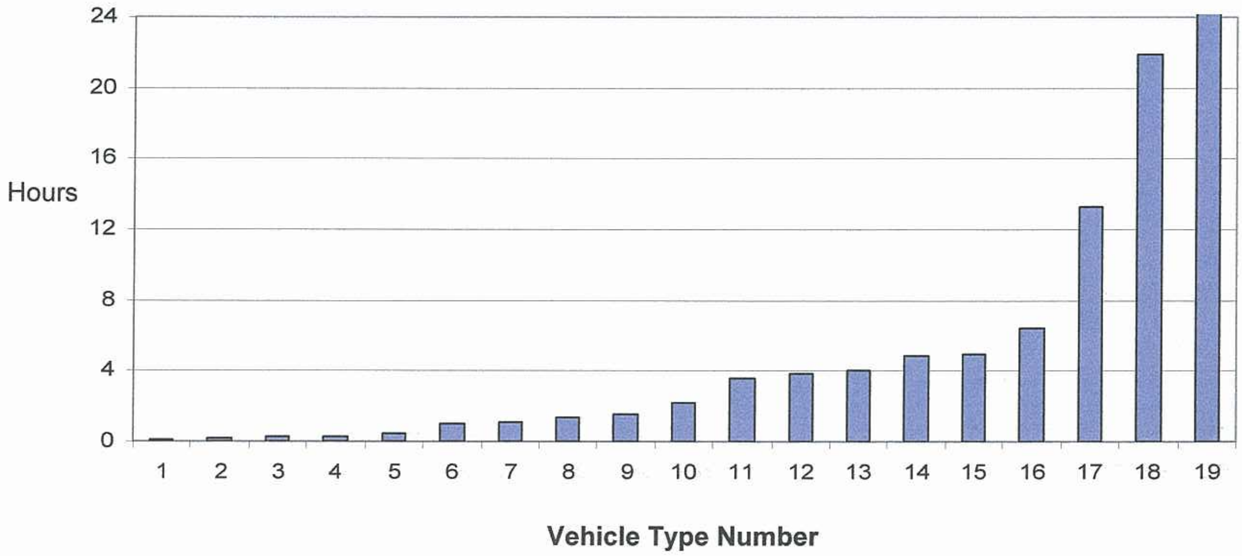


CHART KEY – Vehicle Type Number

Vehicle Type	Number
FSV Make 3a-driver	1
FSV Make 3a-passenger	2
FSV Make 3b-passenger	3
LHD Make 2	4
FSV Make 3b-driver	5
FSV Make 4-driver	6
FSV 4WD Make 2 -passenger	7
FSV Make 5-passenger	8
LHD Make 1	9
FSV Make 4-passenger	10
FSV 4WD Make 1-passenger	11
Rail personnel carrier-driver	12
Shuttle car on surface	13
Rail personnel carrier-passenger	14
Skid steer vehicle	15
FSV 4WD Make 2 -driver	16
Loco-driver	17
FSV 4WD Make 1-driver	18
Dollycar-driver	19

Table 4.1 International Standard: Caution Zone and Likely Health Risk Zone

Sample		VDV (8 hour) (m/sec $^{1.75}$)	RMS accel. (m/s2)	RMS Criteria: Approx time to reach caution zone (hr)	RMS Criteria: Approx time to reach likely health risk zone (hr)	VDV Criteria: Approx time to reach caution zone (hr)	VDV Criteria: Approx time to reach likely health risk zone (hr)
Rail personnel carrier							
driver	GM	18.65	0.78	2.14	8.57	0.35	5.52
	Min	12.12	0.51	1.19	4.77	0.11	1.80
	Max	24.68	1.05	5.03	20.10	1.94	30.97
passenger	GM	18.69	0.74	2.36	9.44	0.34	5.48
	Min	14.41	0.62	1.70	6.82	0.17	2.65
	Max	22.40	0.88	3.41	13.64	0.97	15.49
Dollycar							
driver		7.25	0.22	24.00	24.00	15.10	241.53
Loco							
Driver	GM	13.76	0.58	3.88	15.51	1.16	18.62
	Min	13.18	0.55	3.49	13.97	1.02	16.39
	Max	14.21	0.61	4.30	17.22	1.39	22.17
FSV Make 5							
driver		25.44	1.10	1.09	4.35	0.10	1.60
FSV 4WD Make 1							
driver	GM	12.29	0.54	4.44	17.75	1.83	29.32
	Min	8.08	0.37	2.84	11.37	0.66	10.57
	Max	15.86	0.68	9.64	38.56	9.81	156.99
passenger	GM	19.64	0.87	1.75	6.98	0.28	4.49
	Min	13.75	0.62	0.85	3.39	0.06	0.88
	Max	29.49	1.24	3.37	13.49	1.17	18.72

Table 4.2 International Standard: Caution Zone and Likely Health Risk Zone (continued)

Activity		VDV (8 hour) (m/sec $^{1.75}$)	RMS accel (m/s^2)	RMS Criteria: Approx time to reach caution zone (hr)	RMS Criteria: Approx time to reach likely health risk zone (hr)	VDV Criteria: Approx time to reach caution zone (hr)	VDV Criteria: Approx time to reach likely health risk zone (hr)
FSV 4WD Make 2							
driver	GM	17.02	0.87	1.72	6.90	0.50	7.96
	Min	12.45	0.59	1.15	4.59	0.17	2.77
	Max	22.15	1.07	3.77	15.09	1.74	27.85
passenger	GM	24.90	1.22	0.88	3.50	0.11	1.74
	Min	17.51	0.83	0.44	1.76	0.04	0.57
	Max	32.95	1.72	1.90	7.62	0.44	7.11
FSV Make 3b							
driver	GM	33.17	1.37	0.70	2.79	0.03	0.55
	Min	19.05	0.82	0.16	0.65	0.00	0.05
	Max	61.70	2.82	1.93	7.73	0.32	5.07
passenger	GM	35.05	1.33	0.74	2.94	0.03	0.44
	Min	32.61	1.24	0.64	2.54	0.02	0.33
	Max	37.67	1.43	0.85	3.41	0.04	0.59
FSV Make 3a							
driver	GM	42.40	1.81	0.40	1.59	0.01	0.13
	Min	19.05	0.82	0.11	0.43	0.00	0.05
	Max	61.70	3.51	1.93	7.73	0.32	5.07
passenger	GM	39.66	1.69	0.46	1.82	0.01	0.16
	Min	32.61	1.24	0.26	1.04	0.01	0.15
	Max	45.95	2.24	0.85	3.41	0.04	0.59

Table 4.3 International Standard: Caution Zone and Likely Health Risk Zone (continued)

Sample		VDV (8 hour) ($m/sec^{1.75}$)	RMS accel (m/s2)	RMS Criteria: Approx time to reach caution zone (hr)	RMS Criteria: Approx time to reach likely health risk zone (hr)	VDV Criteria: Approx time to reach caution zone (hr)	VDV Criteria: Approx time to reach likely health risk zone (hr)
FSV Make 4							
passenger	GM	24.40	1.26	0.82	3.28	0.12	1.88
	Min	18.83	0.09	0.43	1.72	0.04	0.67
	Max	31.63	1.74	1.56	6.24	0.33	5.32
driver	GM	27.62	1.74	0.43	1.74	0.07	1.15
	Min	21.60	1.00	0.15	0.58	0.03	0.43
	Max	35.31	3.00	1.30	5.19	0.19	3.07
LHD Make 1							
Load haul dump Type 1							
driver	GM	23.46	0.82	1.92	7.70	0.14	2.21
	Min	15.88	0.58	1.16	4.65	0.03	0.44
	Max	35.06	1.06	3.87	15.47	0.66	10.51
LHD Make 2							
driver	GM	35.49	1.31	0.76	3.04	0.03	0.42
	Min	22.38	0.79	0.28	1.11	0.0042	0.07
	Max	56.28	2.17	2.08	8.32	0.17	2.66
Skid steer vehicle							
driver	GM	17.52	1.09	1.10	4.42	0.44	7.09
	Min	12.02	0.78	0.46	1.85	0.04	0.57
	Max	32.98	1.68	2.12	8.49	2.00	32.03
Shuttle car on surface road							
driver		19.11	0.67	4.0	16.0	0.31	5.01

Figure 9 Time to reach ISO Caution Zone and Likely Health Risk Zone – RMS criteria

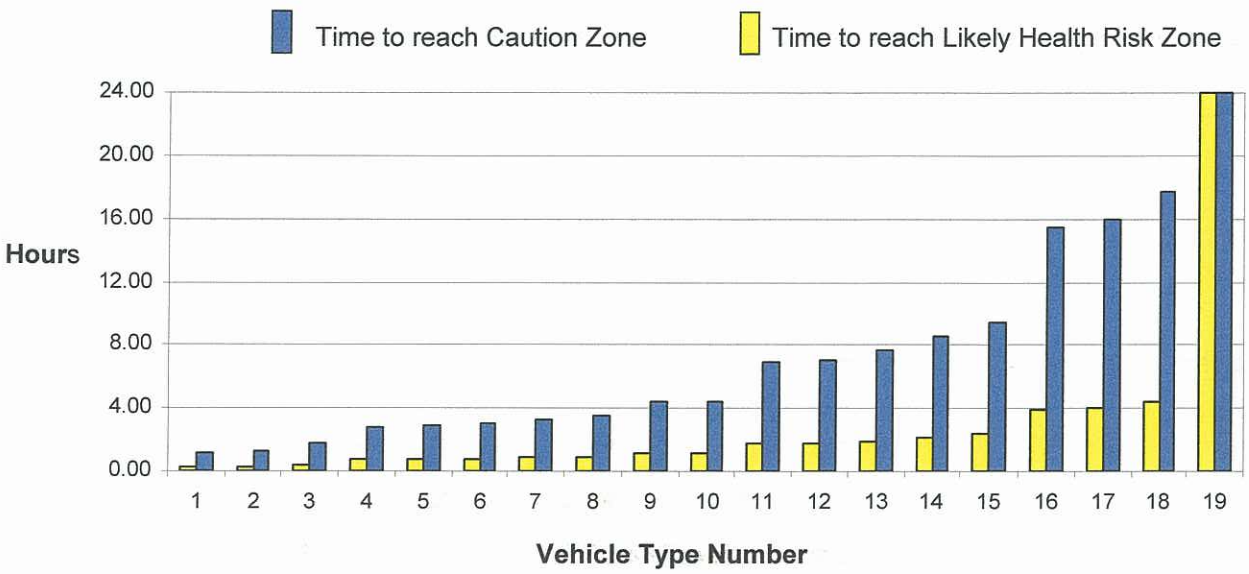


CHART KEY – Vehicle Type Number

Vehicle Type	Number
FSV Make 3a-passenger	1
FSV Make 3a-driver	2
FSV Make 4-driver	3
FSV Make 3b-driver	4
FSV Make 3b-passenger	5
LHD Make 2	6
FSV Make 4-passenger	7
FSV 4WD Make 2 -passenger	8
FSV Make 5-passenger	9
Skid steer vehicle	10
FSV 4WD Make 2 -driver	11
FSV 4WD Make 1-passenger	12
LHD Make 1	13
Rail personnel carrier-driver	14
Rail personnel carrier-passenger	15
Loco-driver	16
Shuttle car on surface	17
FSV 4WD Make 1-driver	18
Dollycar-driver	19

Figure 10 Time to reach ISO Caution Zone and Likely Health Risk Zone – VDV criteria

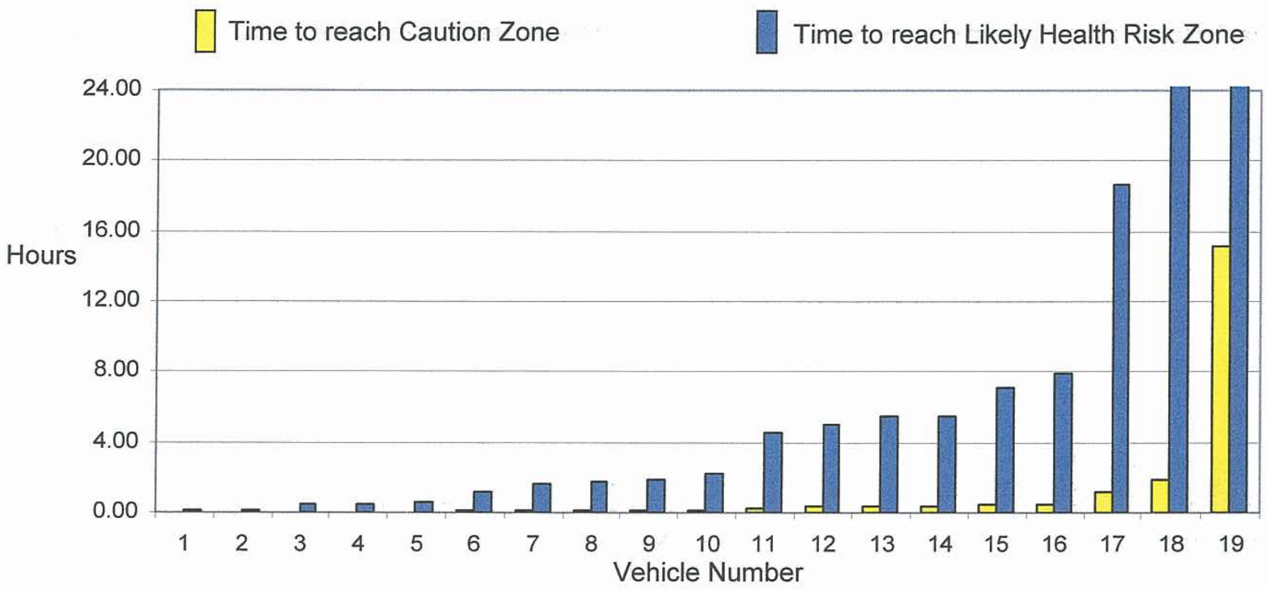


CHART KEY – Vehicle Type Number

Vehicle Type	Number
FSV Make 3a-driver	1
FSV Make 3a-passenger	2
LHD Make 2	3
FSV Make 3b-passenger	4
FSV Make 3b-driver	5
FSV Make 4-driver	6
FSV Make 5-passenger	7
FSV 4WD Make 2 -passenger	8
FSV Make 4-passenger	9
LHD Make 1	10
FSV 4WD Make 1-passenger	11
Shuttle car on surface	12
Rail personnel carrier-passenger	13
Rail personnel carrier-driver	14
Skid steer vehicle	15
FSV 4WD Make 2 -driver	16
Loco-driver	17
FSV 4WD Make 1-driver	18
Dollycar-driver	19

Table 5.1 Geometric mean SEAT values

Sample	SEAT value x	SEAT value y	SEAT value z
Rail personnel carrier			
passenger	1.40	0.88	0.83
driver	1.39	0.87	0.91
Dollycar			
driver	0.93	0.98	0.85
Loco			
driver	0.87	0.79	1.09
FSV Make 5			
passenger	1.52	1.07	1.15
FSV 4WD Make1			
passenger	0.86	1.21	0.98
driver	0.98	0.84	1.14
FSV 4WD Make 2			
passenger	1.03	1.12	1.01
driver	0.58	0.74	0.98
FSV 3b			
driver	1.19	1.32	1.35
trailer passenger	0.94	1.25	0.76
FSV Make 3a			
driver	1.44	1.16	1.23
passenger	0.92	1.13	1.02
FSV Make 4			
driver	0.74	1.17	1.06
passenger	0.74	1.04	1.92

Table 5.2 Geometric mean SEAT values (continued)

Sample	SEAT value x	SEAT value y	SEAT value z
LHD Make 1			
driver	0.91	0.89	1.36
LHD Make 2			
driver	0.83	1.27	1.71
Skid steer vehicle			
driver	0.90	0.75	1.31
Shuttle car on surface			
driver	1.00	0.87	2.13

Table 6. General statistics - responses from 36 participants on 8 visits

Average age and age range	Weight range and average weight	Years and months doing present work at this site	Hours worked per week - range & average	Smoke?	Disorders related to work
43 yrs (average) 26 - 59 yrs (range)	87.7kg (average) 62 -115kg (range)	11 yrs 5 mths (average) 9 mths - 21 yrs 10 mths (range)	42.5 hrs (average) 35 - 54 hrs (range)	12 - yes 23 - no	26 - yes 6 - no 4 - no symptoms

Table 7. Disorders in the last 12 months and 7 days and whether they are considered to be work-related – responses from 36 participants on 8 visits

Disorder	Yes – in the last 12 months	Yes – in the last 7 days	Believed to be work-related (numbers incomplete)
Neck	18 (50%)	7 (19.4%)	15 (41.6%)
Upper back	6 (16.6%)	4 (11.1%)	6 (16.6%)
Lower back	27 (75%)	16 (44.4%)	26 (72.2%)
Hip	12 (33.3%)	7 (19.4%)	10 (27.7%)
Knees	16 (44.4%)	6 (16.6%)	12 (33.3%)
Ankles and feet	10 (27.7%)	8 (22.2%)	8 (22.2%)
Shoulders	11 (30.5%)	7 (19.4%)	12 (33.3%)
Elbows	6 (16.6%)	1 (2.7%)	6 (16.6%)
Wrists and hands	3 (8.3%)	1 (2.7%)	3 (8.3%)

Table 8 **Ratings of the cab, seat and operation of other vehicles - 49 responses from 42 participants on 8 visits**

Displays	Controls	Visibility	Seat suitability	Adjust seat?
16 - good 16 - acceptable 17 - poor	27 - good 17 - acceptable 5 - poor	17 - good 18 - acceptable 3 - poor 4 - combined acceptable/poor rating 7 missing	12 - good 20 - average 15 - poor 2 - missing	1 - yes 44 - no (nearly all seats were not adjustable) 4 - missing

Table 9. **Ratings of ride - 77 responses from 42 participants on 8 visits**

Ratings of road conditions	Smoothness of ride	Ride rating using simple rating scale (line)	How did ride make you feel?
14 - good 39 - average 20 - poor 4 - combined average/poor rating	15 - good 37 - average 23 - poor 2 - combined average/poor rating	6 - good 27 - OK 26 - air 18 - poor	24 - not uncomfortable 31 - a little uncomfortable 7 - fairly uncomfortable 9 - uncomfortable 0 - very uncomfortable 6 - extremely uncomfortable

6. DISCUSSION

6.1 Introduction

This study has attempted to provide an overview of whole-body vibration exposures in coal mining in NSW. It is the most detailed study carried out in Australia to date and the results provide an insight into the range of exposures experienced in a range of commonly used vehicles and machines.

As a random sample the study provides a 'snapshot' in time of vibration exposures and it may not truly reflect the situation in 2001. However, it provides an excellent basis for the development of solutions to problems identified and for further research into more effective ways of reducing exposures.

The following vehicles were measured and the rides analysed:

- Rail personnel carrier
- Dollycar
- Loco
- Free Steered Vehicle (FSV) 4WD with suspension Make 1 (personnel 'troop' carrier)
- Free Steered Vehicle (FSV) 4WD with suspension Make 2 (personnel 'troop' carrier)
- Free Steered Vehicle (FSV) without suspension Make 3a (materials and personnel carrier with trailer)
- Free Steered Vehicle (FSV) Make 3b (modified materials and personnel carrier Make 3a with suspension)
- Free Steered Vehicle (FSV) without suspension Make 4 (materials and personnel carrier - convertible)
- Free Steered Vehicle (FSV) with limited suspension Make 5 (materials and personnel carrier with forward facing seats)
- Load haul dump (LHD) machine Make 1
- Load haul dump (LHD) machine Make 2
- Skid steer machine
- Shuttle car (surface)

6.2 Participants

Forty-two participants took part in the Study at the four underground coal mines and 36 answered questions about themselves and their history of musculoskeletal disorders (sprains and strains). The average age of participants was 43 years, which is higher than in many other industries but is similar to study participants from the open-cut mines. It probably reflects the general workforce age in the NSW coal industry (Table 6, Results). The range of time operators had been working at each site doing their current work (heavy vehicle operation) was 9 months to nearly 22 years on the job, with an average of 11.4 years. The majority of operators came from similar work in other industries and most were experienced in heavy vehicle operation before being employed in mining.

Thirty-two of the 36 participants (88.8 %) reported some musculoskeletal disorders (sprains and strains, aches and pains) in the previous 12 months. Low back pain (27 or 75%) and/or neck pain (18 or 50%) were the most commonly reported disorders. (Tables 6, 7, Results). In the last seven days 16 (44.4%) reported symptoms of back pain and 15 (41.6%) reported neck pain. Twenty-six (96.6% of those reporting back pain) believed that their back pain was related to what they do at work while 15 (83.3% of those reporting neck pain) believed that it was related to their work.

All operators were certified to drive more than one vehicle on site. As a result most operators are exposed regularly or intermittently to rides on vehicles that tend to be rough.

6.3 Opinions on cab design

A large percentage of participants rated cab design as good or acceptable. This included displays (32 or 65%), controls (44 or 90%), visibility from the cab (35 or 71%); and vehicle seat suitability (32 or 65%). However, some vehicles, most notably the Make 1 LHDs were rated as poor. In these vehicles cab space is extremely limited so preventing the installation of a suitable seat. The operator sits sideways facing inwards while operating and he must twist to see forward or backward. Controls and displays are located so that they limit any movement and are awkward to reach and see. All operators, particularly the older ones, made unfavourable comments about the Make 1 LHD machines and see it as one of the sources of discomfort particularly back and neck pain.

The basic design of other vehicles for operators and passengers in many cases was considered acceptable although from an ergonomics point of view there is much room for improvement. Cab design could more closely meet operator requirements as described in MDG 1 (Coal Mining Inspectorate and Engineering Branch, 1995: *Guideline for Free Steered Vehicles, MDG No 1*. Department of Mineral Resources NSW). Seating manufacturers need to design seats with particular attention to the shape of the seat, the backrest and the lumbar support, as these are believed to be important in reducing the detrimental effects of vibration on the operator.

Only one respondent said that he adjusted his seat before starting work in a vehicle, which is not surprising as seats in most vehicles were not adjustable (Table 8, Results).

6.4 Assessment by the Australian Standard

Results for assessment by the Australian Standard are summarised in Tables 2.1 to 2.3 Results Detailed test results for each sample are given in Table A2.1 to A2.4, Appendix 1. A comparison with other Standards is given in Table 10a and 10b (Discussion).

Results of analysis by the Australian Standard are expressed as the boundary exceeded, the next lowest boundary (implied exposure limit) and the interpolated (estimated) value between these two boundaries. Time limits for both 'fatigue' and 'health' criteria are given (see Methods section for explanation).

Health Criteria

Overall, the FSVs without suspension were rated worst by the Australian Standard with health criteria implied limits of between 1 to 4 hours for passenger trailer rides and about 4 hours for driver rides. The same vehicle type *with suspension* gave much smoother rides when new and allowed twice the exposure times under the health criteria even at much higher speeds. In general, all other vehicles were rated as having exposure limits of 8 to 16 hours except the Make 2 LHD, which averaged 5.6 hours to reach the exposure limit.

Fatigue Criteria

The FSVs without suspension reached, on average, 'fatigue criteria' implied exposure limits in 1 hour or less. LHD machines reached the fatigue limit in 25 minutes to 4 hours while other vehicles varied between 4 to 16 hours (see Table 1).

Comments on the Australian Standard

The Australian Standard is less stringent than the other Standards because exposure assessment is based on only one frequency for the worst axis (Figure 2, Methods). Another problem arises with this method of assessment because many of the rides only just fall under the eight-hour boundary but the implied exposure limits are taken at the next lowest boundary, which is only four hours.

This standard is not suitable for rides which contain jolts and jars or shocks producing crest factors (peak level/r.m.s. level) of greater than 6. Only the Dollycar, loco and most rail personnel carrier rides could be properly assessed using the Australian Standard because all other vehicles produced crest factors above this limit. In other words, the Australian Standard underestimates the risk of vibration exposures that contain shocks. See the Methods Section for further information.

The Australian Standard gives no guidance on whether the 'health' or the 'fatigue' criteria should be applied to satisfy statutory Occupational Health and Safety (OH&S) requirements. If tested in court, it is likely that OH&S regulations would be based on the health criteria. However, the fatigue criteria are probably much more useful as an indication of potential health and safety problems.

6.5 Assessment by the new International Standard

A summary of the assessment by the International Standard is given in the Results (Table 4.1 to 4.3) with individual ride values in Tables A4.1 to A4.4 in Appendix 1. A comparison between Standards is given in Table 10a and 10b (Discussion).

The International Standard recommends the use of r.m.s. vibration levels if the exposure does not include shocks or jolts and jars. It recommends the use of the VDV or the 'running r.m.s. method' for shock type vibration exposure. See the Methods Section for further information.

Assessment using the r.m.s vibration levels would, in general, apply to the Dollycar, loco and most rail personnel carrier rides. All other vehicles produce shocks and would require assessment using the VDV methods. Assessment using both r.m.s and VDV methods are discussed below.

The r.m.s and VDV vibration levels are then evaluated against two criteria ('caution zone' and 'likely health risk zone') in the International Standard. A detailed explanation of the International Standard is included in Section 4.6.2.3 in Methods.

(a) Dollycar, Loco and Rail Personnel Carrier rides-

Root mean square (r.m.s.) assessment - likely health risk criteria

These vehicles were not considered to be a likely health risk for an 8-hour exposure period. The Dollycar gave the smoothest ride with the Loco and Rail Personnel Carrier producing slightly rougher rides.

Root mean square (r.m.s.) assessment – caution zone criteria

On average, the Rail personnel carrier reached the caution zone in about 2.5 hours and the Loco in about 4 hours. The Dollycar was so smooth it did not reach the caution zone even for a 24-hour ride.

(b) Free Steered Vehicles (FSVs) for personnel and materials transport, Load Haul Dump (LHD) machines, Skid Steer vehicles-

VDV assessment – likely health risk criteria

The FSV Make 3a without suspension gave the roughest ride in terms of these criteria reaching the likely health limit in less than 12 minutes for some rides. This applied to both drivers and passengers. The same make of vehicle with suspension and when new performed much better, reaching the likely health risk limit in about 30 minutes for both passengers and drivers. One other FSV without suspension (Make 4) reached the health risk limit in 1.5 hours on average. The LHD machines reached the likely health risk zone in 2 to 3 hours.

Rides in the 4WD FSVs (Makes 1 and 2) greatly varied in roughness with times to reach the likely health risk zone assessed between 2 hours and 24 hours exposure. Passenger rides were much rougher than those experienced by the drivers of these vehicles.

VDV assessment – caution zone

The Make 1 4WD FSV gave the smoothest ride of this group of vehicles, reaching the VDV caution zone in an average time of about 2 hours. All other vehicles in this group reached the VDV caution zone in less than one hour and in only a few minutes in some rides in the unsprung FSVs (Makes 3, 4 and 5).

6.6 Assessment by the British Standard (BS) - VDV assessment

Results for assessment by the British Standard are provided in Table 3.1 to 3.3 (Results) and Tables A3.1 to A3.4 (Appendix 1).

The British Standard also uses the VDV to assess the cumulative vibration exposure (Section 4.6.2.2, Methods). The VDV is a sensitive measure of the roughness of a ride and can be used as an indicator of the severity of jolts and jars experienced by the operator. The Standard states that any ride which produces a VDV of $15 m/sec^{1.75}$ or greater is likely to cause an increased risk of injury and is recommended as an 'action level'. This level is between the VDV caution zone and likely health risk zone of the International Standard.

All FSVs, with and without suspension, reached the action level in less than one hour. The FSV Make 3a without suspension (drivers and passengers), on average, produced the roughest rides according to this Standard with only 10 minutes exposure to reach the action level. Several vehicles gave rides that reached the action level in about one to two hours.

Vibration axes used for assessment
The z-axis (up and down) vibration dominated the exposure for almost all rides. The Skid Steer vehicle produced relatively high vibration levels in all axes for one ride.

6.7 Comparison of assessment by different Standards

The guidelines for exposure to whole-body vibration vary depending on which Standard is used for assessment. A comparison between exposure guidelines for different Standards is shown in Tables 10a and 10b (Discussion)

- The Australian Standard rates the following vehicles as unacceptable for constant use over an 8-hour period under the health criteria:
  Make 3a FSV without suspension (driver and passenger)
  Make 3b FSV with suspension (passenger)
  Make 4 FSV without suspension (passenger)
  Make 5 FSV with limited suspension (passenger)
  Make 2 LHD machine

- The British Standard, assesses all vehicles as exceeding the action limit for an 8-hour exposure with the exception of the loco, Dollycar and FSV 4WD Make 1 (driver).

- The International Standard rated all vehicles rides, except rail personnel carriers, loco, Dollycar and FSV 4WD Type 1 driver, as reaching the likely health risk zone in less than an 8-hour exposure period.

Table 10a Comparison of WBV from vehicle types ranked from worst to best by the Australian Standard (Fatigue)

Vehicle Type	Australian Standard		British Standard	International Standard			
	Average time to reach fatigue limit (hr) (interpolated)	Average time to reach health limit (hr) (interpolated)	Average time to reach action limit (hr)	RMS Criteria average time to reach caution zone & likely health risk		VDV Criteria average time to reach caution zone & likely health risk	
FSV without suspension Make 3a - trailer passenger	0.8	2.7	0.14	0.46	1.82	0.01	0.16
FSV without suspension Make 4 - passenger	1.10	3.59	2.22	0.82	3.28	0.12	1.88
LHD Make 2 - driver	1.7	5.6	0.31	0.76	3.04	0.03	0.42
FSV without suspension Make 3a - driver	1.80	5.2	0.09	0.40	1.59	0.01	0.21
FSV with limited suspension Make 5 - passenger	2.48	7.21	1.35	1.09	4.35	0.10	1.60
FSV with suspension Make 3b – trailer passenger	2.8	7.6	0.30	0.74	2.94	0.03	0.44
FSV without suspension Make 4 - driver	3.17	8.91	0.98	0.43	1.74	0.07	1.15
LHD Make 1 - driver	3.93	11.09	1.55	1.92	7.70	0.14	2.21
FSV with suspension Make 3b - driver	4.2	11.5	0.48	0.70	2.79	0.03	0.55
FSV 4WD with suspension Make 2 - passenger	4.87	13.37	1.14	0.88	3.50	0.11	1.74
Shuttle car on surface road - driver	6.5	17.3	3.99	4.0	16.0	0.31	5.01
Rail personnel carrier Make 1 - passenger	7.39	19.99	4.87	2.36	9.44	0.34	5.48
FSV 4WD with suspension Make 1 - passenger	7.71	19.99	3.59	1.75	6.96	0.28	4.49
Rail personnel carrier Make 1 - driver	8.54	19.18	3.84	2.14	8.57	0.35	5.52
Skid steer vehicle - driver	8.54	18.81	4.99	1.10	4.42	0.44	7.09
FSV 4WD with suspension Make 2 - driver	9.13	18.19	6.42	1.72	6.90	0.50	7.96
Loco - driver	9.99	22.84	13.30	3.88	15.51	1.16	18.62
FSV 4WD with suspension Make 1 - driver	14.26	23.55	21.86	4.44	17.75	1.83	29.32
Dollycar - driver	24.00	24.00	145.50	24.00	24.00	15.10	241.00

Table 10b Comparison of WBV from vehicle types ranked from worst to best by the International Standard (VDV caution zone)

Vehicle Type	Australian Standard		British Standard	International Standard			
	Average time to reach fatigue limit (hr)	Average time to reach health limit (hr)	Average time to reach action limit (hr)	RMS Criteria average time to reach caution zone & likely health risk		VDV Criteria average time to reach caution zone & likely health risk	
FSV without suspension Make 3a - trailer passenger	0.8	2.7	0.14	0.46	1.82	0.01	0.16
FSV without suspension Make 3a - driver	1.80	5.2	0.09	0.40	1.59	0.01	0.21
LHD Make 2 - driver	1.7	5.6	0.31	0.76	3.04	0.03	0.42
FSV with suspension Make 3b – trailer passenger	2.8	7.6	0.30	0.74	2.94	0.03	0.44
FSV with suspension Make 3b - driver	4.2	11.5	0.48	0.70	2.79	0.03	0.55
FSV without suspension Make 4 - driver	3.17	8.91	0.98	0.43	1.74	0.07	1.15
FSV with limited suspension Make 5 - passenger	2.48	7.21	1.35	1.09	4.35	0.10	1.60
FSV 4WD with suspension Make 2 - passenger	4.87	13.37	1.14	0.88	3.50	0.11	1.74
FSV without suspension Make 4 - passenger	1.10	3.59	2.22	0.82	3.28	0.12	1.88
LHD Make 1 - driver	3.93	11.09	1.55	1.92	7.70	0.14	2.21
FSV 4WD with suspension Make 1 - passenger	7.71	19.99	3.59	1.75	6.96	0.28	4.49
Shuttle car on surface road - driver	6.5	17.3	3.99	4.0	16.0	0.31	5.01
Rail personnel carrier Make 1 - passenger	7.39	19.99	4.87	2.36	9.44	0.34	5.48
Rail personnel carrier Make 1 - driver	8.54	19.18	3.84	2.14	8.57	0.35	5.52
Skid steer vehicle - driver	8.54	18.81	4.99	1.10	4.42	0.44	7.09
FSV 4WD with suspension Make 2 - driver	9.13	18.19	6.42	1.72	6.90	0.50	7.96
Loco - driver	9.99	22.84	13.30	3.88	15.51	1.16	18.62
FSV 4WD with suspension Make 1 - driver	14.26	23.55	21.86	4.44	17.75	1.83	29.32
Dollycar - driver	24.00	24.00	145.50	24.00	24.00	15.10	241.00

6.8 Factors contributing to rough rides

Three major factors appear to be the sources of most vibration, and particularly jolts and jars in mining vehicles (Figure 11). These are:

- ♦ roads, work surfaces
- ♦ vehicle activity
- ♦ engine vibration to a much lesser extent

Other factors (Figure 12) appear to reduce vibration exposure for operators:

- ◊ well maintained roads/surfaces
- ◊ appropriate vehicle suspension including tyres
- ◊ well designed seating and seat suspension systems
- ◊ ergonomic cab layout and design
- ◊ well developed driver skills and awareness including driving at an appropriate speed
- ◊ good visibility
- ◊ intermittent exposures and varied work schedules including breaks

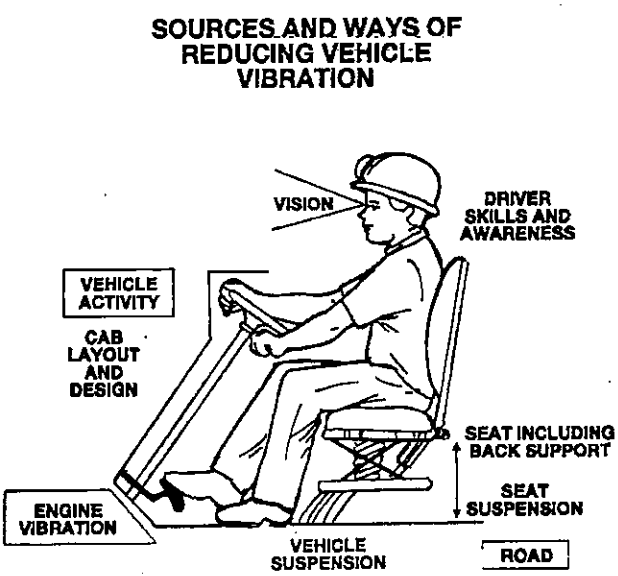


Figure 11.

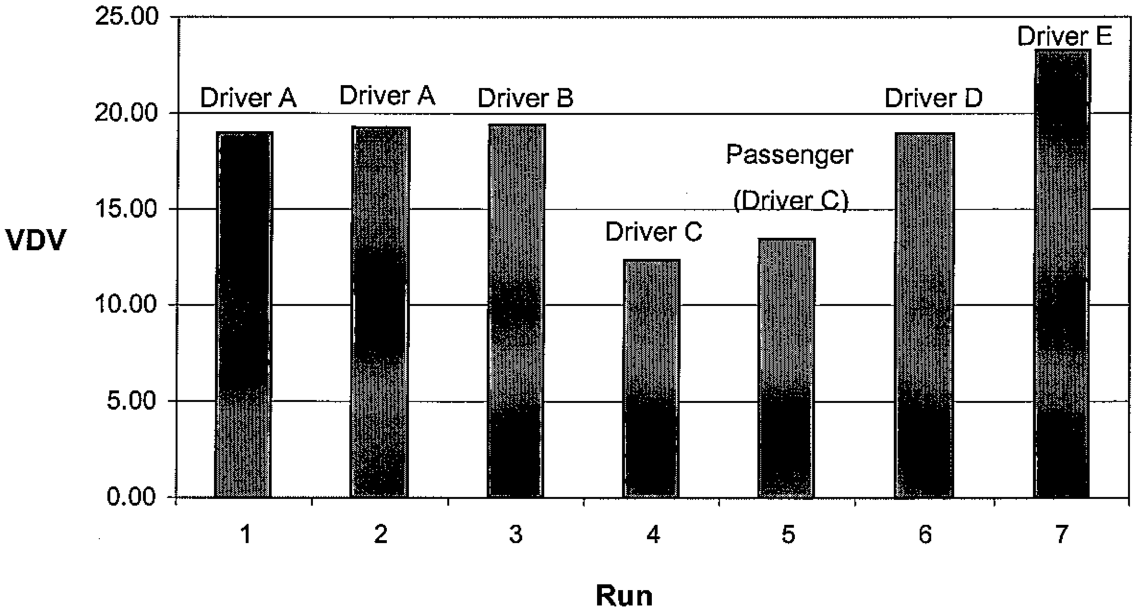
From: McPhee. Ergonomics for the Control of Sprains and Strains in Mining. Worksafe Australia and the Joint Coal Board, Sydney,1993.

In this Study there was a range of factors that mining personnel identified as contributing to rough rides in different vehicles. In general higher VDV values appear to confirm this. At all mines operators expressed preferences for different vehicles but the reasons for these differences did not show clearly in this analysis. For instance all operators of one particular make of LHD preferred it to the others because it was more 'comfortable'. The VDV, on the other hand, indicated that the preferred machine was rougher. In another example, tests of a new passenger vehicle with suspension compared with the older version without suspension showed that passengers found the ride much improved although the VDV did not indicate this. It is likely that other factors such as the drivers' experience and skills, cab space and the working conditions may play a part in these differences. However, it may also be that the VDV does not discriminate between the particular qualities of a ride. A 'bouncy' ride appeared to be much more tolerable than a 'jerky' ride although the VDV did not reflect the difference. The question to be answered is: does ride 'comfort' indicate that there is reduced potential for long term risks to health?

The numbers of readings were insufficient to confirm if operators' techniques contributed to smoother rides. The amount of the increase in vibration with speed will vary depending on the effectiveness on the vehicle and seat suspension. Some good comparative recordings of operators of rail personnel carriers were made at one mine (Figure 12). The only difference in these rides was time, which varied between 13 minutes (Driver E), 15 minutes (Driver A, B and D) and 18 minutes (Driver C) on the same route. The fastest run was significantly rougher than the slowest run.

Unfortunately, the range of factors that could have been measured far exceeded the time available to do so.

Figure 12 VDV values for rail personnel carrier runs with different drivers



This study has identified the following factors as contributing to rougher rides. These were observed by the researchers or brought out in discussions with mining personnel and confirmed to a large extent by the rides analyses:

1. *Type of work/activity*
   - Length of driving or travelling period e.g. long travelling times to the face in man transport
   - Type of load e.g. full or empty
   - Type of activity e.g. ramp making, carrying ballast
   - Activity of vehicle leading to predominant movement forward (x axis) or sideways (y axis) (LHDs mucking out or scaling the roof)
   - Numbers of trips and work routine
   - Slewing sideways when travelling or working

2. *Roads/ work areas*
   - Rough work areas such as those that are being cleaned up
   - Secondary roads that are not maintained to the standard of the main travelling roads but which are used by vehicles such as LHDs
   - Excessive water leading to rapid deterioration of road surfaces e.g. potholes
   - Poor road building and/or maintenance programs

3. *Vehicle suspension*
   - Generally vehicles without some suspension gave a rougher ride than those with full suspension. Rubber, air-filled tyres was the only suspension in many vehicles and these vehicles gave rougher rides
   - Riding in front of or behind the wheel-base was rougher than rides between the wheels
   - A 'bouncy' ride appeared to be more comfortable for the driver or the passenger than a 'jerky' ride although the rides gave the similar VDV values

4. *The design/type of vehicle*
   - Particular classes of vehicles such as LHDs with little or no suspension also had inadequate cab space, poor seating and with the driver facing inwards. It was difficult to separate these factors from the roughness of the ride as the cause of discomfort

- Certain unsprung transport vehicles (equipment and personnel) are regarded universally as 'rough' by operators and passengers and this was confirmed by the measurements
- Seat design varied and some appeared to be more accepted than others
- Passengers sit sideways in 'troop carriers' and have no lateral stability

5. *Age and condition of the vehicle*
   - Rides in some older vehicles with suspension systems were reported to be rougher than rides in new vehicles of the same make and model and the measurements confirmed this
   - Some vehicles were old and in need of maintenance from the operators point of view. Measurements showed rides in these vehicles were rougher
   - Seat maintenance was highly variable and in some cases was poor. This is likely to have contributed in some cases to rougher rides.

6. *Visibility*
   - Hitting potholes and other causes of roughness which cannot be seen due to poor lighting and water
   - Passengers cannot anticipate jolts and jars because they cannot see ahead

7. *Driver skills and awareness*
   - Increasing speed of travel tended to increase the roughness of the ride (Figure 13)
   - Some operators appear to have inherent skills which enable them to drive in a way that gives a better ride
   - Drivers appear to have little indication of the roughness of the ride for the passengers, particularly when the passengers are sitting sideways at the back of the vehicle and unable to brace themselves.
   - 'Driving to conditions' is interpreted differently by each person and is insufficient guidance to reduce risks of injury.

8. *Other factors*
   - Back and neck pain adversely influenced reports of 'discomfort' and ride quality.
   - In one or two cases operators or passengers appeared to be lodging a 'protest vote' against the mine or their specific conditions. These responses fell outside the expected range of responses.

While there were not enough data to determine statistically the contribution of different factors, these appear to be the most important factors contributing to ride quality.

6.9 Seat Damping Performance

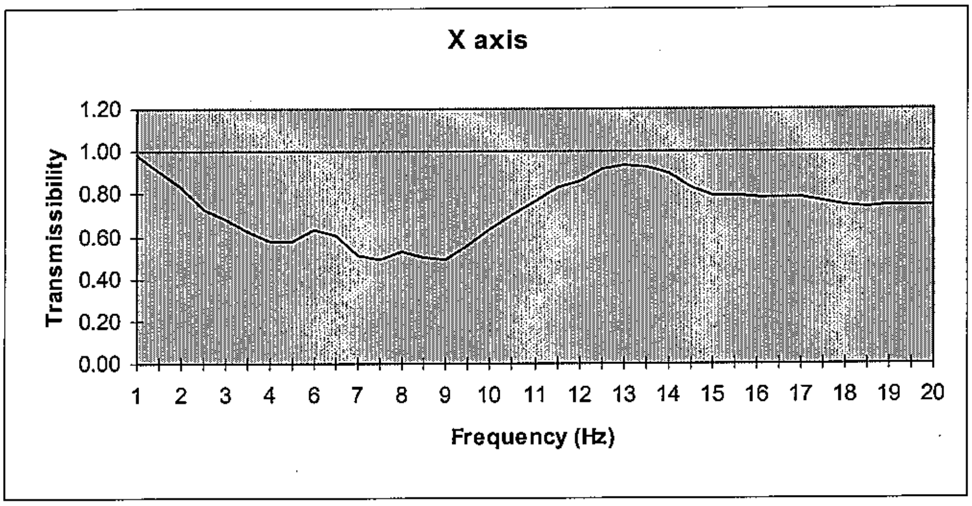
6.9.1 Transmissibility

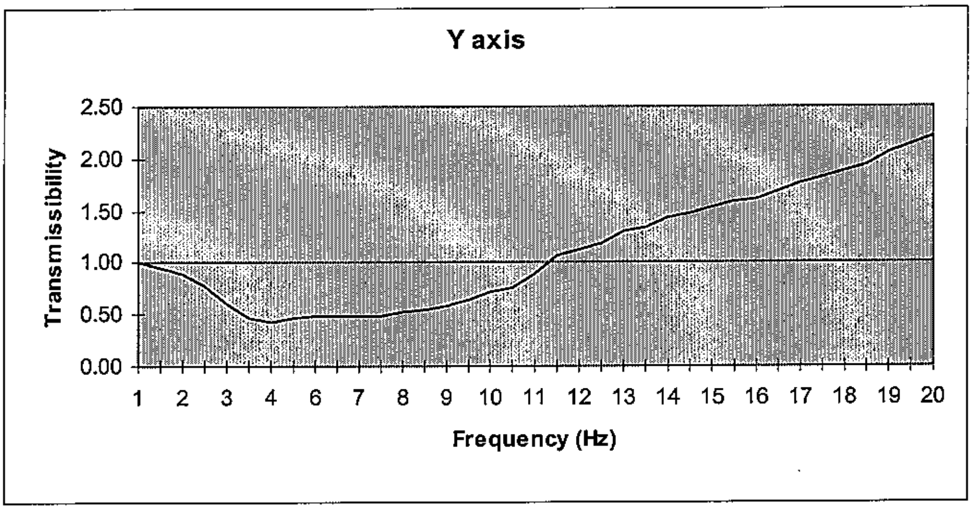
A comparison of the vibration measured on the vehicle floor with that transmitted through the seat gave an indication of seat damping performance. The vibration transmissibility of a FSV Make 1 (without suspension) vehicle driver's seat is shown in Figure 13.

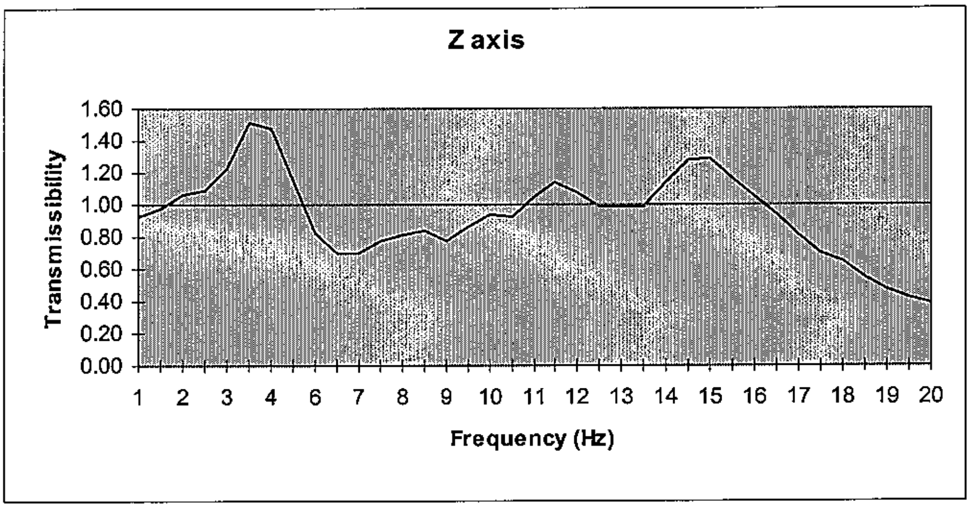
Transmissibility levels above a value of 1.0 indicate amplification of vibration, while below 1.0 means that the vibration has been attenuated. Due to seat resonance, vibration transmitted through the seat may be amplified at certain frequencies. This commonly occurs around 2 - 4 Hz in the z-axis. An unfortunate consequence is that the human body is most sensitive to vibration around these low frequencies.

Seat resonance and vibration amplification can be seen in Figure 13. The chart for the FSV Make 3a seat shows amplification of the vibration in the z-axis between 1.5 Hz and 5 Hz. Between 5 Hz and 11Hz the seat is reducing vibration levels transmitted to the driver in the z-axis with some amplification around 11.5Hz and 15Hz. The x-axis (forward to back) chart indicates that the seat is damping vibration transmitted to the driver over all frequencies from 1 Hz to 20 Hz. Performance in the y-axis shows damping up to about 11 Hz.

Figure 13 Transmissibility chart for FSV without suspension Make 3a (driver)







6.9.2 SEAT Values

Vibration transmissibility of the seat may also be expressed as a single number or SEAT (Seat Effective Amplitude Transmissibility) value and is calculated as:

$$SEAT = \frac{VDV\ on\ seat}{VDV\ on\ floor}$$

The SEAT is an indication of overall seat performance over a range of frequencies. The SEAT value is applied when the vibration contains shocks (high crest factors). A value below 1.0 indicates that the seat is effectively damping vibration over the range of frequencies, while a value above 1.0 indicates that the seat is amplifying the overall vibration transmitted to the operator. The lower the SEAT value the more attenuation achieved by the seat.

The geometric mean SEAT values for the vehicle seats tested are given in Table 5.1 and 5.2 (Results). The following Table 11 summaries the SEAT results.

Table 11 Summary of SEAT results for vehicle seats

Vehicle Type	Comments on seat performance
Rail personnel carrier	*Driver and passenger*: Some vibration reduction in z and y-axes. Increased vibration in x axis.
Dolly car	*Driver:* Slight vibration reduction in z- axis but neutral effect in other axes.
Loco	*Driver:* Seat performed best in y-axis with moderate vibration reduction. No effect of seat in other axes (neutral)
FSV without suspension Make 5	*Passenger:* Amplification of vibration in the x-axis and to a lesser extent in the other axes.
FSV 4WD with suspension Make 1	*Passenger:* Slight increase in y-axis. Little effect on other axes. *Driver:* Fairly neutral effect on most rides. Some rides gave high amplification in z-axis.
FSV 4WD with suspension Make 2	*Passenger:* Neutral effect of seat in all axes. *Driver:* Neutral effect in z-axis. Good attenuation in x-axis and moderate attenuation in y-axis.
FSV with suspension Make 3b	*Driver:* Amplification of vibration in all axes, highest in z-axis. *Passenger:* Good performance in z-axis, increased vibration in y-axis and neutral performance in the x-axis.
FSV without suspension Make 3a	*Driver:* Variable performance – slight amplification on average in all axes. *Passenger:* Generally neutral
FSV without suspension Make 4	*Driver & Passenger:* Variable performance – some attenuation in x-axis on average.
LHD Make 1	*Driver:* On average-amplification In z-axis, some attenuation in y-axis and neutral in x-axis.
LHD Make 2	*Driver:* Some attenuation in x-axis, amplification in z-axis and neutral effect in y-axis on average.
Skid steer vehicle	*Driver:* Attenuation in y-axis, neutral in x-axis and amplification in the z-axis.
Shuttle car on surface road	*Driver:* High amplification in z-axis, some attenuation in y-axis and neutral in x-axis.

The SEAT results provide some useful findings although the information on seating is not complete as many seats were unidentifiable (Table A5.1 to A5.4, Appendix 1).

1. There was a wide performance range for various seats. Some seats made specifically for particular vehicles by the manufacturer did not appear to reduce transmitted vibration as well as seats in other vehicles of a similar design.

2. Some seats made specifically for underground vehicles performed reasonably well in some vehicles and not in others.
3. The same seats in the same vehicles performed less well as the roughness of the ride increased.
4. No seats performed consistently well in all three axes.

As with the open-cut mines seats are not solving the problems of rough rides. In some cases they appear to be accentuating the roughness. More might be gained from improving cab design and suspension or isolating the cab from damaging levels of vibration generated by the machine and its activity. Nevertheless, a supportive and well-shaped lumbar support and seat are still considered essential in helping to reduce the detrimental effects of vibration.

6.10 Operators' ratings of roads and rides

There was a spread of opinions on road/work area conditions, smoothness or roughness of ride, and on ride comfort.

- ❑ Overall 68.8 % of operators and passengers rated the road conditions as good or average
- ❑ There appeared to be little difference between the ratings of road conditions from mine to mine even at the mine which had a dedicated road maintenance program.
- ❑ On the main travelling roads driving speeds tended to be faster where roads were rated as good. The measured roughness for the ride in the 4WD FSV Type 1 tended to be similar on all roads despite different road roughness and different speeds. It may be that drivers increase their speed to a tolerable level of roughness. This appears to be at a VDV value of between 8 and 15 (caution zone).
- ❑ LHDs often work in returns and areas where floor conditions are poor and operators generally rated conditions as poor even when roads generally were rated as good.
- ❑ 67.5% of operators considered their ride to be good or average. Our data indicate that these rides were generally rougher than the operators reported.
- ❑ Ratings of rides appear to have been adversely influenced by discomfort from musculoskeletal disorders such as back and neck pain.

6.10.1 Ride rating using the BSI scale and measured vibration using the r.m.s.

There was a poor correlation (r=0.38) between operators' ratings of the ride using the British Standards Institution (BSI) rating scale (Figure 5, Methods) and the measured vibration on all vehicles. 49 rides out of 69 (72%) described their ride as not uncomfortable or a little uncomfortable (Table A6.1 to A6.6, Appendix 1) indicating a weighted r.m.s. value of $0.63 m/s^2$ or less on the BSI Scale. When compared with the measured results only 17 rides (25%) were at or below $0.63 m/s^2$ and would be classified as not or a little uncomfortable. No rides in unsprung FSVs or LHDs came under this cut-off point. Therefore most of these operators and some passengers underrated the roughness of the ride.

The reasons for the lack of any apparent relationship between the BSI comfort ratings and the measured vibration levels are unclear because it was impossible to separate factors that may influence the perception of ride comfort. It may be related to previous exposures and habits; back pain and other symptoms in some operators; or the use of the word 'comfortable', which is poorly defined and may not be precise enough for research. It may be also that those who reported more severe discomfort worked differently to those without pain. Certainly there was evidence that current back or neck pain appeared to influence the operators' responses to the comfort ratings.

If the word 'rough' is substituted for 'uncomfortable' there may be a slightly better correlation with the measured vibration readings.

6.10.2 Ride rating using the simple scale (line) and measured vibration using the VDV

The simple rating scale (Figure 6, Methods) yielded similar results. The VDV correlated poorly (r=0.39) with the subjective rating by operators and passengers. Figure 14 is a scattergram showing the tendency towards linear correlation between these variables. Ratings for individual rides are given in Table A6.1 to 6.6 (Appendix 1).

This scale asked operators and passengers to point on the line where they regarded the recorded ride rated compared with all other rides they had ever experienced. There were no words to classify the ride quality.

Figure 14 Ride roughness vs VDV for 8-hour exposure

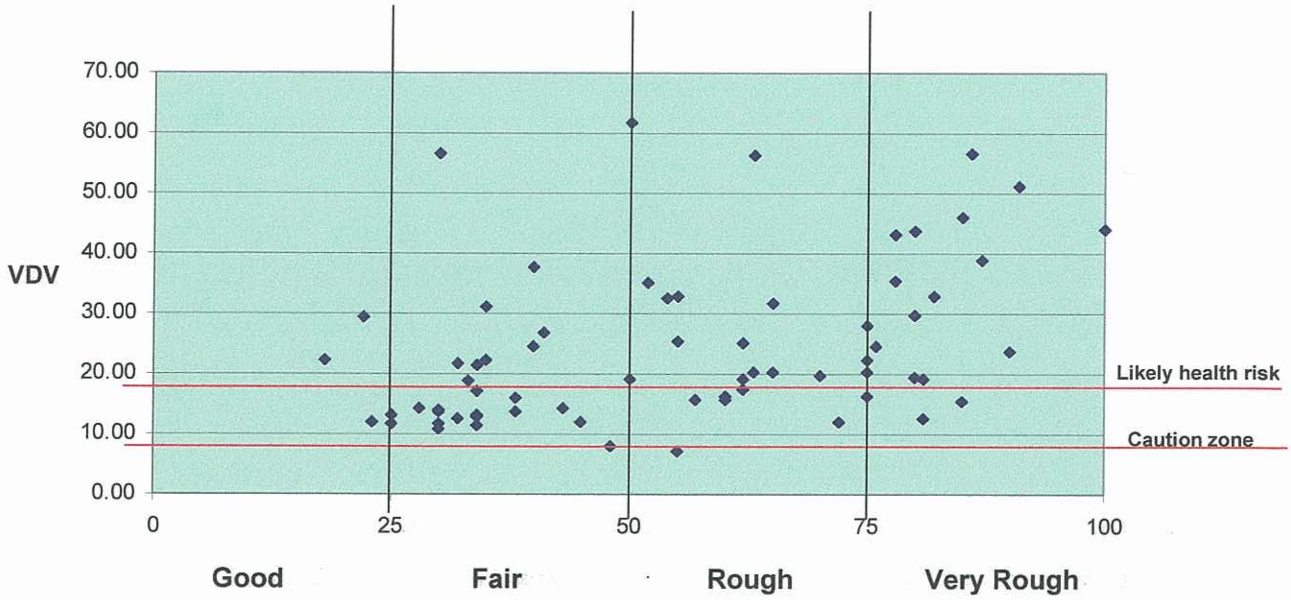


Figure 14 shows the pattern of ride roughness over-estimation and under-estimation. Where the ride roughness was under-estimated there is evidence that a 'bouncy' ride is rated as much more comfortable than a 'jerky' ride even though the VDV values were similar. On the other side, over-estimation may be related to discomfort from other factors such as poor cramped operating postures or back or neck pain.

6.11 Summary of results

1. The Australian Standard rates the following vehicles as unacceptable for constant use over an 8-hour period under the health criteria:

   Make 3a FSVs without suspension (driver and passenger)

   Make 3b FSV with suspension (passenger)

   Make 4 FSV without suspension (passenger)

   Make 5 FSV with limited suspension (passenger)

   Make 2 LHD machine

2. The British Standard, is much more stringent and assesses most vehicles as exceeding the action limit for an 8-hour exposure with the exception of the loco, Dollycar and FSV 4WD Make 1 (driver).

3. The International Standard rated all vehicles rides, except rail personnel carriers, loco, Dollycar and FSV 4WD Make 1 driver, as reaching the likely health risk zone in less than an 8-hour exposure period.

4. The current Australian Standard states that the r.m.s. methods described in the Standard could underestimate the health effects of vibration which includes shocks or jolts and jars commonly experienced in mining vehicles. It is recommended that the Australian Standard be used only for rides that have crest factors less than 6. Most vehicle rides with the exception of Dollycars, locos and most rail personnel carriers exceeded this crest factor limit. Therefore this Standard may not be valid when used to analyse these rides.

5. Both the British and International Standards have developed assessment methods to account for shock-type vibration. A better indication of shocks is possible with the use of the vibration dose value (VDV), which is very sensitive to high peak values caused by jolts and jars. In addition the International Standard offers the 'running r.m.s' method (not used in this study) as an alternative to the VDV for assessment of shock-type vibration. The r.m.s. methods are also retained in these Standards for the assessment of steady state vibration.

6. The current Australian and British and the new International Standards give widely varying exposure time limits depending on the type of exposure and how the analysis is carried out. There is evidence from our results that the current Australian Standard does not provide sufficient guidance to equipment manufacturers, employers and employees on what are 'safe' limits, particularly in relation to musculoskeletal disorders (sprains and strains).

7. Future standards in Australia may require the use of an overall r.m.s.and VDV or running r.m.s to assess exposure, as adopted by the new International Standard (ISO 2631-1.2 - 1997). This will result in significantly reduced exposure times compared to the current one-third octave band method of assessment recommended in the Australian Standard. In some cases exposure times will need to be reduced by more than one-third of those currently considered to be acceptable.

8. Forty-three rides out of 68 (63%) were in the 'likely health risk zone' using the VDV (Figure 10, Results and Tables 4.1 to 4.4, Appendix 1).

9. There was a poor correlation between measured vibration on all vehicles and operators' ratings of the ride using either the British Standards Institution rating scale or the simple rating scale. Most operators and some passengers underrated the roughness of rides. The roughest rides were reported in LHDs and unsprung FSV driver and passenger rides (Tables A6.1 to A6.6, Appendix 1).

10. Thirty-two of the 36 participants interviewed (88.8 %) reported some musculoskeletal disorders (sprains and strains, aches and pains) in the previous 12 months. This is similar to those reported by open-cut mineworkers (84% - see Report Part 1). Sixteen (44.4%) and 7 (19.4%) participants reported low back pain and neck pain respectively in the previous week. Low back pain (27 or 75%), neck pain (18 or 50%), knees (16 or 44.%) and hips (12 or 33.3%) were the most commonly reported disorders in the previous 12 months (Tables 6 & 7 Results).

11. There was a wide performance range for various seats. The ability of the seat to cushion vibration generally tended to decrease as the roughness of the ride increased. No seats performed consistently well in all three axes (Table A5.1 to A5.4, Appendix).

12. The results from the study overall indicate that seating does not solve all the vibration problems. The shape of the seat and backrest (particularly the lumbar support) are believed to be important in reducing the detrimental effects of vibration on the operator. However, while there have been efforts to improve seating in underground vehicles there still appears to be a fundamental lack of understanding by manufacturers about what constitutes an adequate seat.

13. There was evidence that poor cab design increased operators' complaints of discomfort quite independently of the vibration. In some vehicles (LHDs in particular) the orientation of seat (sideways looking inwards) and the need to twist constantly to see in front or behind meant that many operators were in considerable discomfort from these awkward and potentially damaging postures.

14. Unrelieved sitting posture (like other postures) leads to increased reports of musculoskeletal discomfort and disorders. Fortunately work in underground mines, (unlike that in open-cut mines) is generally very varied and dynamic and therefore operators can avoid this major source of discomfort.

15. These results confirm that a range of factors is likely to contribute to high VDV values and therefore rougher rides. Our information indicates that the type, age, design and make of vehicle as well as vehicle suspension, seat suspension, road and work surfaces, activity, speed of operation and driver skills contribute to what participants considered to be rougher rides with higher VDV values.

6.12 Factors for consideration

6.12.1 Cab design, operators' postures, work routines and back pain

It became obvious while observing and interviewing operators that good posture is extremely important for comfortable operating. Well-designed seating and work breaks may alleviate some of the discomfort reported by operators. However, cramped cabs and the requirement for operators to twist to see in front or behind them clearly accentuated discomfort due to low back or neck disorders. Serious consideration should be given to improving cab design so that the operator can sit in a reasonably comfortable posture to operate controls and can see without having to adopt awkward and potentially damaging postures.

As mentioned in the Introduction (Part 1 of the Report) there is an increasing amount of scientific evidence to suggest that unrelieved sitting (like many other unrelieved postures) leads to increased reports of musculoskeletal discomfort and disorders, especially back and neck pain. Therefore, when operating a vehicle for more than an hour at a time it is advisable that drivers take a break. Fortunately in underground this usually happens as part of the work routine.

While it was evident that breaks also reduced the vibration exposure the contribution of breaks to the reduction of back and other disorders arising from prolonged sitting and exposure to vibration is unclear. There is published evidence as well as indications from this study that work breaks are far more important than we appreciated in the past. Therefore, the more varied the work routine and the working postures and movements the less likely operators are to experience symptoms of strain.

There are several different scenarios where injuries appear to occur in mining. The first arises in open-cut mines with drivers of dump trucks and similar vehicles who complain about low-grade symptoms at the end of the working day. It is presumed that these arise from prolonged sitting, which has been identified in other research as an independent factor associated with the development of back pain. It also may be that constant exposure to low grade vibration, without the breaks that are possible on other vehicles, is contributing to a significant extent. The underlying causes of the back pain are not obvious to the operator but could be addressed through such strategies as encouraging breaks out of the seat and job rotation.

The second scenario is where injuries manifest themselves after a one-off severe jolt in an otherwise reasonable ride such as that caused by a deep and unexpected pothole in a well-maintained road where the vehicle is travelling relatively fast. This is a straightforward situation where cause and effect are seen to be linked. However, the solution requires considerable attention to improving road conditions (including reducing the impact of unwanted water); improving visibility from the vehicle; driving at speeds appropriate to the conditions especially with passengers on board; and designing vehicles that are better able to isolate the occupants from harmful vibration (including cab and seat design).

The third situation is where pain arises after an extended period of moderate jolts and jars such as LHD operation. These incidents are known to lead to low back and neck injury and are recognised by operators as damaging. However, the question: 'how much is too much?' cannot be answered with current knowledge.

Scientifically speaking no real cause-effect relationship has been established between overall WBV exposure or one-off large shocks, and injury, nor have the mechanisms for injury been described. The phenomenon of the one-off jolt may need to be dealt with by applying a time-limiting exposure. The contribution of prolonged moderate levels of vibration to the development of symptoms is only estimated at this point.

Despite the fact that symptoms are reported after operating or riding in different vehicles most operators reported satisfaction with the vehicle they were driving at the time of the interview. The exceptions were the LHDs and the unsprung FSV Make 3a. It would seem that most drivers can operate the machines they prefer and this is important for job satisfaction.

6.12.2 Adoption of the new International Standard

In broad terms we know that a significant number of low back and neck injuries have been precipitated by "rough rides". The Australian Standard permits these exposures and therefore is not helpful in injury prevention. However the new International Standard attempts to assess the important components of rough rides, that is jolts and jars, and as a result reduces the allowable exposures to these.

Past experience with Standards indicates that the new International Standard eventually will be adopted as the Australian Standard. In this case vibration exposure limits will be reduced significantly. In the medium to long term this will require improved roads; better-designed vehicle suspension; improved vehicle maintenance systems; and equipment to reduce the transmission of vibration and to encourage better work postures.

Nevertheless, it is likely that controls will be needed in the interim in vehicles undertaking activities that result in jolts and jolts. Administrative controls such as reducing operating times on certain machines and certain activities; improving roads and work surfaces; and reducing speeds can be useful in the short term to reduce the impact of vibration.

The question arises: are the methods used in the new International Standard valid for the assessment of jolts and jars? It appears from this study that they go some way in assessing the type of vibration that may lead to the onset of injury. The British and International Standards have introduced the Vibration Dose Value (VDV) in an attempt to assess the contribution of shocks or 'jolts and jars' to the vibration exposure. The VDV is very sensitive to high peaks produced by typical 'rough rides'. Consequently, when the VDV is used for assessment the acceptable exposure times are greatly reduced when compared with the Australian Standard.

6.12.3 Important issues arising from this study

In the researchers' opinion some important issues arise from the results of the vibration measurements and analysis, and from information provided by mining personnel during the study. These are:

- There appears to be a fairly high prevalence of musculoskeletal disorders in both open-cut and underground mineworkers particularly in the low back, neck, knees and hips. This has been acknowledged for some time but may need further investigation with respect to the possible causes.

- The Australian Standard permits apparently harmful WBV exposures and therefore is not helpful in injury prevention. The VDV (Vibration Dose Value) used in the new International Standard appears to be a good indicator of what operators and passengers call a 'rough ride' i.e. the VDV goes up with increasing complaints of roughness. However, it is not possible to say at this point what is the absolute threshold for damaging vibration, especially jolts and jars, although the various Standards attempt to put in guides for this. The VDV appears to be a better indicator of potential problems than other methods used in the Standards but a good deal more research is needed to give us a 'dose-response relationship'.

- Time limits given using different analysis techniques are only convenient ways of expressing an exposure level in the absence of anything better. The fact that a damaging jolt can occur in the first few minutes of a 30-minute exposure indicates that the time limit may not be 'protective'. It is therefore imperative that exposures to potentially damaging jolts and jars are eliminated.

- Asking operators and passengers how 'comfortable' they are (as in the BSI rating) gives poor results. It may be more reliable to ask a person about the roughness of a ride or to compare the ride in terms of his/her life experience of rides using a line such as the simple rating scale. In this study this method showed a good correlation to the measured roughness of the ride using the VDV for open-cut mine workers but not for underground workers. It may be that the perceived quality of the ride by the person riding may change with a 'bounce' rather than a 'jerk' although these rides may give the same VDV value.

- Cab design in most underground vehicles needs improvement especially with respect to space for and orientation of the operator. The operator needs to see clearly and operate controls without having to adopt awkward and potentially damaging postures. Seat adjustment is an important way of avoiding these. Improved vehicle suspension and/or isolation of the cab from vibration generated by the machine and its activity must be a next step.

- Most manufacturers of seating for underground vehicles appear not to understand the basic ergonomics principles of seating. Seat shapes are copied from manufacturer to manufacturer without attention to the important aspects of seat profile especially seat angle, backrest angle and the location and shape of the lumbar support. This is despite readily available information on how seats should be designed. As well the problems of vibration transmission have not been addressed adequately. Well-designed seats are very important in reducing exposures to damaging vibration. This includes suspension systems that do not magnify exposures and do not bottom out; and seat profiles that support the back and legs but do not restrict movement.

- When comparing rides in a new machine with suspension and a similar three-year old machine with suspension there appeared to have been a serious deterioration in the suspension system. Maintenance of suspension systems in good condition needs to be given the same priority as other mechanical maintenance.

- Roads, work areas and work activities contribute significantly to rough rides but they are not the whole story. The administrative problems of maintaining roads in a satisfactory, rather than in perfect condition, needs to be addressed in a systematic way in the mining industry. Methods of alerting drivers to potential road problems especially when they might be driving at higher speeds need to be explored.

- Speed can accentuate the ride roughness under most conditions. It may be that for all types of conditions there is an optimum speed – neither too slow nor too fast. Drivers' skills and awareness of the conditions appear to be important in determining this optimum speed, especially when it is coupled with speed limits and safety requirements. It would appear that drivers choose a speed that gives them a tolerable level of ride roughness. This compares to measured a VDV value of somewhere between 8 and 15 ('caution zone').

- Training of operators and drivers in ways of avoiding potentially harmful vibration could prove useful and cost-effective. The expression 'drive to conditions' has not been properly defined or described and means different things to different people. In practical terms it does not provide enough guidance to operators and drivers in difficult or abnormal conditions. Feedback to operators, drivers and passengers on what constitutes potentially harmful vibration should be part of training. Drivers need to be aware of passengers' comfort and that speeds suitable for the driver may not be appropriate for the passengers.

- Appropriate maintenance of vehicles, especially of seating and vehicle suspension systems, is likely to be important in reducing the generation and transmission of vibration from the vehicles to the operator. These elements should be regarded as major components and maintained as such by specialists.

6.13 Reducing operators' and passengers' exposures to WBV

There are a range of ways in which mines might attempt to reduce potentially harmful vibration for operators, drivers and passengers. These include engineering/design as well as administrative/organisational controls. It is unlikely that one approach or solution will be fully effective. The application of a range of smaller controls which, when taken together, reduce exposures to an acceptable level are likely to be most effective in the majority of cases. The following are approaches that are being used or could be used by coal mines in Australia:

1. *Training*
   - Raising awareness of the possible harmful effects of vibration amongst all workers
   - Training operators in what constitutes harmful vibration
   - Driver competency training

2. *Restricting speed*
   - Speed limits which are enforced
   - Speed limited vehicles in specific situations
   - Appointing drivers and operators who are deemed competent and safe (appropriate training) especially if they are carrying passengers

3. *Road maintenance programs*
   - Dedicated vehicles and drivers for road maintenance
   - Road maintenance programs that are planned and systematic and not regarded as secondary to production demands
   - Effective communication of information on road conditions and potential problems e.g. caution markers for pot holes or poor conditions
   - Effective use of water pumps and drainage techniques
   - Professional road construction especially for main headings
   - Fast communication of problems that may lead to rough rides
   - Immediate rectification of problems e.g. filling of pot holes, removal of materials on the road

4. *Design of vehicles and seats*
   - Cab and vehicle suspension. Suspension systems must appropriate for loads typically carried by the vehicle. Vehicle suspension systems must never bottom out
   - Good seat design and improved seat suspension. Seats must never bottom out

- Improved visibility especially in personnel transport where passengers are unable to anticipate jolts and jars e.g. improved vehicle headlights and 'line of sight'
- Transport vehicles with forward facing seats and appropriately designed seating for passengers
- Cab design and layout should allow sufficient head and leg space (a minimum of one metre clearance seat to roof, preferably more)
- Adjustable seating for drivers where possible

4. *Maintenance of vehicles*

- Planned maintenance programs for vehicle suspension systems
- Specialist maintenance for seating and suspension systems

The relative contribution of each of these factors needs to be explored further to determine the most cost-effective approach of solutions. In the short term some design solutions will not be possible but administrative and maintenance controls will be.

6.14 Summary

This study cannot and does not attempt to provide answers on the effect or outcomes (e.g. back pain) of such exposures; nor can it identify which are the most important contributing factors. However, it does provide new information on the range and type of WBV exposures and a basis for action and further study in areas where exposures might be higher than appears to be desirable.

7. CONCLUSIONS

This study was aimed at measuring and analysing whole-body vibration (WBV) exposures in coal miners and has been carried out over the last five years in NSW. This report details the findings from this study at four underground mines undertaken from 1997 to 2000. A previous Report (Part 1) documents the findings from four open-cut mines and a coal loader undertaken in 1996 and 1997

The three vibration Standards applied in the analysis use different assessment methods and exposure criteria and yield quite different outcomes. The one-third octave method preferred in the Australian Standard is the least stringent but still rates the rides in six different vehicles as unacceptable for constant use over an 8-hour period under the health criteria. As well the Standard is not suitable for rides containing jolts and jars (shocks) and underestimates the risk of vibration exposures in such rides.

The new International Standard attempts to assess the important components of rough rides, that is jolts and jars, and as a result reduces the allowable exposures to these. Nearly two-thirds of the rides measured in the underground mines were in the 'likely health risk zone' using the VDV. If the new International Standard is adopted in Australia, some recommended exposures would drop significantly. This has wide implications for employees, employers and machinery manufacturers. In particular some equipment will need to be redesigned and different approaches to reducing vibration exposure and improving operator comfort, such as cab redesign and isolation, may need to be considered.

There appeared to be a poor agreement with the operators' rating of rides and the VDV using the two rating scales. Results also highlighted the fact that while complaints of back and neck pain arising from vehicle rides in mining are common, operators and passengers generally tend to underestimate the roughness of rides that could be leading to long-term damage.

There was a wide performance range for various seats. The ability of the seat to cushion vibration generally tended to decrease as the roughness of the ride increased. No seats performed consistently well in all three axes. It appears that seating cannot solve all the vibration problems while the basic design of the vehicle remains unchanged. However, the shape of the seat and backrest (particularly the lumbar support) are important in reducing the detrimental effects of vibration on the operator.

Our results indicate that a range of factors is likely to contribute to rough rides. Factors such as the type, age, design and make of vehicle, vehicle suspension, seat suspension, road and work surfaces, activity, speed of operation and driver skills are considered important rougher rides with higher VDV values.

There is a range of possible strategies for reducing exposures to WBV, many of which could be implemented within current systems. It is likely that acceptable levels of exposure could be achieved through a combination of:

1. training of operators to recognise damaging levels of vibration and in driving skills
2. limiting speed
3. prompt communication and correction of specific road problems
4. timely and effective road maintenance programs
5. appropriate design of vehicles including cab and seat design, lighting and visibility
6. effective maintenance of vehicles particularly suspension systems and seats

While the results of this study need further investigation, especially in respect the factors that might contribute to rough rides, they should provide guidance to the mining industry on the nature and extent of rough rides within it and what might be done to prevent exposures to them.

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Airdrie Long

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** Copies can found in Appendix 2, Part 1 of this Report*

*** A copy can be found in Appendix 2, Part 2 of this Report*

APPENDIX 1

Tables

APPENDIX 1 TABLES

Table 1 Vehicle Type Abbreviations used in Results Tables

Rail personnel carrier	Rail personnel carrier
Dollycar	Dollycar
Loco	Loco
FSV 4WD Make 1	Free Steered Vehicle (FSV) 4WD with suspension Make 1 (personnel 'troop' carrier)
FSV 4WD Make 2	Free Steered Vehicle (FSV) 4WD with suspension Make 2 (personnel 'troop' carrier)
FSV Make 3a	Free Steered Vehicle (FSV) without suspension Make 3a (materials and personnel carrier with trailer)
FSV Make 3b	Free Steered Vehicle (FSV) Make 3b (modified materials and personnel carrier Make 3a with suspension)
FSV Make 4	Free Steered Vehicle (FSV) without suspension Make 4 (materials and personnel carrier - convertible)
FSV Make 5	Free Steered Vehicle (FSV) with limited suspension Make 5 (materials and personnel carrier with forward facing seats)
LHD Make 1	Load haul dump (LHD) machine Make 1
LHD Make 2	Load haul dump (LHD) machine Make 2
Skid steer machine	Skid steer machine
Shuttle car (surface)	Shuttle car (surface)

Table A2.1 Australian Standard: Third-octave method, permissible exposure limits

Sample	Activity	RMS acceleration	Boundary exceeded		Implied exposure limit		Interpolated boundary		Worst axis
			fatigue (hr)	health (hr)	fatigue (hr)	health (hr)	fatigue (hr)	health (hr)	
Rail personnel carrier									
6,01	passenger	0.78	8	24	4	16	6.8	18.2	z
6,02	passenger	0.77	8	24	4	16	7.2	19.7	z
6,19	passenger	0.65	16	24	8	16	8.2	22.2	z
	GM	**0.73**					**7.4**	**20.0**	
	min	**0.65**					**6.8**	**18.2**	
	max	**0.78**					**8.2**	**22.2**	
6,05	driver	1.07	8	16	4	8	5.8	15.4	z
6,03	driver	0.86	8	24	4	16	7.2	19.6	z
6,23	driver	0.85	8	24	4	16	6.9	18.7	z
6,14	driver	0.46	24	24	16	16	18.5	24.0	z
	GM	**0.77**					**8.5**	**19.2**	
	min	**0.46**					**5.8**	**15.4**	
	max	**1.07**					**18.5**	**24.0**	
Dollycar									
9,02	driver	0.17	24	24	16	16	24.0	24.0	z
Loco									
6,06	driver	0.59	8	24	4	16	7.8	21.3	z
6,09	driver	0.58	16	24	8	16	9.7	23.3	z
6,11	driver	0.53	16	24	8	16	13.2	24.0	z
	GM	**0.57**					**10.0**	**22.8**	
	min	**0.53**					**7.8**	**21.3**	
	max	**0.59**					**13.2**	**24.0**	
FSV Make 5									
8,03	passenger	1.41	2.5	8	1	4	2.5	7.2	z

Table A2.2 Australian Standard: Third-octave method, permissible exposure limits (cont.)

Sample	Activity	RMS acceleration	Boundary exceeded fatigue (hr)	Boundary exceeded health (hr)	Implied exposure limit fatigue (hr)	Implied exposure limit health (hr)	Interpolated boundary fatigue (hr)	Interpolated boundary health (hr)	Worst axis
FSV 4WD Make 1									
6,18	driver	0.76	8	24	4	16	7.7	21.1	z
7,01	driver	0.67	16	24	8	16	8.0	22.1	z
6,08	driver	0.58	16	24	8	16	12.2	24.0	z
7,02	driver	0.56	16	24	8	16	12.2	24.0	z
7,03	driver	0.55	16	24	8	16	14.7	24.0	z
8,04	driver	0.55	24	24	16	16	18.4	24.0	z
7,15	driver	0.54	24	24	16	16	18.1	24.0	z
9,09	driver	0.53	16	24	8	16	14.9	24.0	z
7,13	driver	0.52	24	24	16	16	18.9	24.0	z
9,01	driver	0.48	24	24	16	16	16.3	24.0	z
9,10	driver	0.33	24	24	16	16	24.0	24.0	z
	GM	**0.54**					**14.3**	**23.5**	
	min	**0.33**					**7.7**	**21.1**	
	max	**0.76**					**24.0**	**24.0**	
6,20	passenger	1.16	8	16	4	8	5.5	14.9	z
7,12	passenger	0.98	8	24	4	16	6.4	17.0	z
7,11	passenger	0.72	16	24	8	16	9.8	23.6	z
6,21	passenger	0.69	16	24	8	16	10.2	23.7	z
	GM	**0.87**					**7.7**	**19.4**	
	min	**0.69**					**5.5**	**14.9**	
	max	**1.16**					**10.2**	**23.7**	
FSV 4WD Make 2									
7,22	driver	1.19	8	16	4	8	4.5	12.8	z
7,21	driver	0.92	24	24	16	16	16.5	24.0	z
7,08	driver	0.86	8	16	4	8	5.4	14.9	z
9,12	driver	0.58	24	24	16	16	17.1	24.0	z
	GM	**0.86**					**9.1**	**18.2**	
	min	**0.58**					**4.5**	**12.8**	
	max	**1.19**					**17.1**	**24.0**	
7,25	passenger	1.36	4	8	2.5	4	2.6	7.4	z
7,23	passenger	1.23	8	16	4	8	5.8	15.6	z
7,24	passenger	0.66	8	24	4	16	7.5	20.6	z
	GM	**1.03**					**4.9**	**13.4**	
	min	**0.66**					**2.6**	**7.4**	
	max	**1.36**					**7.5**	**20.6**	

Table A2.3 Australian Standard: Third-octave method, permissible exposure limits (cont.)

Sample	Activity	RMS acceleration	Boundary exceeded		Implied exposure limit		Interpolated boundary		Worst axis
			fatigue (hr)	health (hr)	fatigue (hr)	health (hr)	fatigue (hr)	health (hr)	
FSV Make 3b									
6,28	driver	1.18	4	8	2.5	4	2.9	7.7	z
6,27	driver	1.11	4	16	2.5	8	3.4	9.1	z
6,24	driver	0.89	8	24	4	16	7.8	21.5	z
	GM	**1.05**					**4.2**	**11.5**	
	min	**0.89**					**2.9**	**7.7**	
	max	**1.18**					**7.8**	**21.5**	
6,25	trailer passenger	1.31	2.5	8	1	4	2.5	7.0	z
6,26	trailer passenger	1.18	4	16	2.5	8	3.2	8.3	z
	GM	**1.24**					**2.8**	**7.6**	
	min	**1.18**					**2.5**	**7.0**	
	max	**1.31**					**3.2**	**8.3**	
FSV Make 3a									
6,07	driver	2.35	2.5	4	1	2.5	1.3	3.9	z
6,22	driver	2.03	2.5	8	1	4	1.6	4.6	z
6,04	driver	1.75	2.5	8	1	4	2.0	5.7	z
6,31	driver	1.67	2.5	8	1	4	1.7	4.8	z
6,12	driver	1.34	2.5	8	1	4	2.3	6.8	z
6,30	driver	1.33	2.5	8	1	4	2.1	5.8	y
	GM	**1.71**					**1.8**	**5.2**	
	min	**1.33**					**1.3**	**3.9**	
	max	**2.35**					**2.3**	**6.8**	
6,29	trailer passenger	2.17	1	4	25min	2.5	0.9	3.0	z
6,13	trailer passenger	2.23	1	2.5	25min	1	0.7	2.4	z
	GM	**2.20**					**0.8**	**2.7**	
	min	**2.17**					**0.7**	**2.4**	
	max	**2.23**					**0.9**	**3.0**	
FSV Make 4									
7,07	passenger	2.00	1	2.5	25min	1	0.6	2.3	z
7,05	passenger	1.18	2.5	8	1	4	2.0	5.7	z
	GM	**1.53**					**1.10**	**3.59**	
	min	**1.18**					**0.62**	**2.26**	
	max	**2.00**					**1.98**	**5.71**	
7,20	driver	1.20	4	8	2.5	4	2.8	7.6	z
7,17	driver	3.80	4	16	2.5	8	3.7	10.5	z
	GM	**2.13**					**3.17**	**8.91**	
	min	**1.20**					**2.76**	**7.58**	
	max	**3.80**					**3.66**	**10.48**	

Table A2.4 Australian Standard: Third-octave method, permissible exposure limits (cont.)

Sample	Activity	RMS acceleration	Boundary exceeded		Implied exposure limit		Interpolated boundary		Worst axis
			fatigue (hr)	health (hr)	fatigue (hr)	health (hr)	fatigue (hr)	health (hr)	
LHD Make 1									
9,05	driver	1.10	4	8	2.5	4	2.3	6.6	z
7,19	driver	1.03	4	16	2.5	8	3.6	10.0	z
8,06	driver	1.03	4	8	2.5	4	2.9	7.8	z
8,05	driver	0.99	4	16	2.5	8	3.8	10.9	z
7,10	driver	0.89	8	16	4	8	4.2	12.3	z
6,10	driver	0.79	4	16	2.5	8	3.8	11.2	z
9,04	driver	0.79	8	16	4	8	4.1	12.0	z
7,09	driver	0.74	8	16	4	8	5.1	14.0	z
7,14	driver	0.68	8	24	4	16	7.2	19.5	z
	GM	***0.88***					***3.9***	***11.1***	
	min	***0.68***					***2.3***	***6.6***	
	max	***1.10***					***7.2***	***19.5***	
LHD Make 2									
9,03	driver	2.33	1	2.5	25min	1.0	0.5	2.0	z
6,15	driver	0.88	8	16	4	8	5.8	15.4	z
	GM	**1.44**					**1.7**	**5.6**	
	min	**0.88**					**0.5**	**2.0**	
	max	**2.33**					**5.8**	**15.40**	
Skid steer vehicle									
6,34	driver	0.41	16	24	8	16	14.8	24.0	x
6,35	driver	0.41	16	24	8	16	15.6	24.0	z
9,08	driver	1.61	8	24	4	16	6.0	16.0	comb
6,32	driver	0.64	8	24	4	16	7.4	20.2	z
6,33	driver	0.86	8	16	4	8	4.5	12.6	z
	GM	**0.68**					**8.5**	**18.8**	
	min	**0.41**					**4.5**	**12.6**	
	max	**1.61**					**15.6**	**24.0**	
Shuttle car on surface road									
7,16	driver	0.77	8	24	4	16	6.5	17.3	z

Table A3.1 British Standard: Vibration Dose Values (VDV)

Sample	Activity	VDV 8hr (full shift) ($m/sec^{1.75}$)	Time to reach action limit (hr)	Worst axis
Rail personnel carrier				
6,05	driver	23.30	1.37	z
6,03	driver	19.38	2.87	z
6,23	driver	18.95	3.14	z
6,14	driver	12.31	17.61	z
	GM	**18.02**	**3.84**	
	Min	**12.31**	**1.37**	
	Max	**23.30**	**17.61**	
6,02	passenger	19.25	2.95	z
6,01	passenger	18.93	3.15	z
6,19	passenger	13.44	12.41	z
	GM	**16.98**	**4.87**	
	Min	**13.44**	**2.95**	
	Max	**19.25**	**12.41**	
Dollycar				
9,02	driver	7.26	145.50	z
Loco				
6,06	passenger	5.56	13.00	z
6,09	driver	5.67	13.73	z
6,11	driver	5.54	13.18	z
	GM	**5.59**	**13.30**	
	Min	**5.54**	**13.00**	
	Max	**5.67**	**13.73**	
FSV Make 5				
8,03	passenger	23.41	1.35	z

Table A3.2 British Standard: Vibration Dose Values (VDV) (continued)

Sample	Activity	VDV 8hr (full shift) (m/sec$^{1.75}$)	Time to reach action limit (hr)	Worst axis
FSV 4WD Make 1				
9,01	driver	15.44	7.13	z
6,18	driver	14.13	10.15	z
7,03	driver	12.72	15.47	z
8,04	driver	12.72	15.45	z
7,01	driver	12.58	16.19	z
9,09	driver	11.34	24.49	z
7,02	driver	11.02	27.48	z
7,15	driver	10.97	28.01	z
6,08	driver	10.66	31.33	z
7,13	driver	10.41	34.54	z
9,10	driver	8.07	95.39	z
	GM	**11.67**	**21.86**	
	Min	**8.07**	**7.13**	
	Max	**15.44**	**95.39**	
6,20	passenger	27.29	0.73	z
7,12	passenger	20.06	2.50	z
7,11	passenger	16.24	5.82	z
6,21	passenger	12.68	15.65	z
	GM	**18.32**	**3.59**	
	Min	**12.68**	**0.73**	
	Max	**27.29**	**15.65**	
FSV 4WD Make 2				
7,22	driver	19.63	2.73	z
7,08	driver	18.16	3.73	z
7,21	driver	15.31	7.38	z
9,12	driver	11.57	22.61	z
	GM	**15.85**	**6.42**	
	Min	**11.57**	**2.73**	
	Max	**19.63**	**22.61**	
7,25	passenger	32.89	0.35	z
7,23	passenger	25.55	0.95	z
7,24	passenger	17.36	4.46	z
	GM	**24.43**	**1.14**	
	Min	**17.36**	**0.35**	
	Max	**32.89**	**4.46**	

Table A3.3 British Standard: Vibration Dose Values (VDV) (continued)

Sample	Activity	VDV 8hr (full shift) (m/sec$^{1.75}$)	Time to reach action limit** (hr)	Worst axis
FSV Make 3b				
6,28	driver	56.66	0.04	z
6,27	driver	17.08	4.76	z
6,24	driver	10.31	0.60	z
	GM	**21.53**	**0.48**	
	Min	**10.31**	**0.04**	
	Max	**56.66**	**4.76**	
6,26	passenger	11.90	0.21	z
6,25	passenger	10.50	0.42	z
	GM	**11.18**	**0.30**	
	Min	**10.50**	**0.21**	
	Max	**11.90**	**0.42**	
FSV Make 3a				
6,30	driver	56.86	0.04	z
6,31	driver	50.79	0.06	z
6,07	driver	25.81	0.05	z
6,12	driver	21.88	0.11	z
6,04	driver	19.32	0.24	z
6,22	driver	19.15	0.14	z
	GM	**29.07**	**0.09**	
	Min	**19.15**	**0.04**	
	Max	**56.86**	**0.24**	
6,29	passenger	40.93	0.14	z
6,13	passenger	18.33	0.13	z
	GM	**27.39**	**0.14**	
	Min	**18.33**	**0.13**	
	Max	**40.93**	**0.14**	
FSV Make 4				
7,07	driver	27.16	0.74	z
7,05	driver	15.74	6.60	z
	GM	**20.74**	**2.22**	
	Min	**15.74**	**0.74**	
	Max	**27.16**	**6.60**	
7,17	driver	33.58	0.32	z
7,20	driver	19.19	2.98	z
	GM	**25.39**	**0.98**	
	Min	**19.19**	**0.32**	
	Max	**33.58**	**2.98**	

Table A3.4 British Standard: Vibration Dose Values (VDV) (continued)

Sample	Activity	VDV 8hr (full shift) (m/sec$^{1.75}$)	Time to reach action limit** (hr)	Worst axis
LHD Make 1				
9,05	driver	32.45	0.37	z
8,05	driver	30.73	0.45	z
8,06	driver	26.93	0.77	z
7,19	driver	25.74	0.92	z
9,04	driver	24.34	1.15	z
6,10	driver	23.34	1.36	z
7,10	driver	18.49	3.46	z
7,14	driver	14.74	8.57	z
7,09	driver	14.34	9.59	z
	GM	**22.59**	**1.55**	
	Min	**14.34**	**0.37**	
	Max	**32.45**	**9.59**	
LHD Make 2				
9,03	driver	53.52	0.05	z
6,15	driver	21.30	1.97	z
	GM	**33.76**	**0.31**	
	Min	**21.30**	**0.05**	
	Max	**53.52**	**1.97**	
Skid steer vehicle				
9,08	driver	32.83	0.35	z
6,33	driver	18.52	3.44	z
6,32	driver	15.69	6.68	x
6,34	driver	12.44	16.92	z
6,35	driver	11.54	22.81	z
	GM	**16.88**	**4.99**	
	Min	**11.54**	**0.35**	
	Max	**32.83**	**22.81**	
Shuttle car on surface road				
7,16	driver	**17.85**	**3.99**	z

Table A4.1 International Standard: Caution Zone and Likely Health Risk Zone (cont.)

Sample	Activity	VDV (8 hour)	Wt. RMS acceleration (m/s^2)	RMS Criteria: Approx time to reach Caution zone (hr)	RMS Criteria: Approx time to reach Likely health risk zone (hr)	VDV Criteria: Approx time to reach caution zone (hr)	VDV Criteria: Approx time to reach Likely health risk zone (hr)
Rail personnel carrier							
6,05	driver	24.68	1.05	1.2	4.8	0.11	1.80
6,03	driver	20.42	0.83	1.9	7.5	0.24	3.85
6,23	driver	19.81	0.84	1.9	7.5	0.27	4.34
6,14	driver	12.12	0.51	5.0	20.1	1.94	30.97
	GM	**18.65**	**0.78**	**2.14**	**8.57**	**0.35**	**5.52**
	Min	**12.12**	**0.51**	**1.19**	**4.77**	**0.11**	**1.80**
	Max	**24.68**	**1.05**	**5.03**	**20.10**	**1.94**	**30.97**
6,19	passenger	14.41	0.62	3.4	13.6	0.97	15.49
6,02	passenger	22.40	0.88	1.7	6.8	0.17	2.65
6,01	passenger	20.22	0.76	2.3	9.0	0.25	4.00
	GM	**18.69**	**0.74**	**2.36**	**9.44**	**0.34**	**5.48**
	Min	**14.41**	**0.62**	**1.70**	**6.82**	**0.17**	**2.65**
	Max	**22.40**	**0.88**	**3.41**	**13.64**	**0.97**	**15.49**
Dollycar							
9,02	driver	**7.25**	**0.22**	**24.0**	**24.0**	**15.10**	**241.53**
Loco							
6,06	driver	13.93	0.58	3.9	15.5	1.11	17.76
6,09	driver	14.21	0.61	3.5	14.0	1.02	16.39
6,11	driver	13.18	0.55	4.3	17.2	1.39	22.17
	GM	**13.76**	**0.58**	**3.88**	**15.51**	**1.16**	**18.62**
	Min	**13.18**	**0.55**	**3.49**	**13.97**	**1.02**	**16.39**
	Max	**14.21**	**0.61**	**4.30**	**17.22**	**1.39**	**22.17**
FSV Make 5							
8,03	passenger	**25.44**	**1.10**	**1.1**	**4.3**	**0.10**	**1.60**

Table A4.2 International Standard: Caution Zone and Likely Health Risk Zone (cont.)

Sample	Activity	VDV (8 hour)	Wt. RMS acceleration (m/s^2)	RMS Criteria: Approx time to reach Caution zone (hr)	RMS Criteria: Approx time to reach Likely health risk zone (hr)	VDV Criteria: Approx time to reach caution zone (hr)	VDV Criteria: Approx time to reach Likely health risk zone (hr)
FSV 4WD Make 1							
6,18	driver	15.86	0.68	2.8	11.4	0.66	10.57
9,01	driver	15.47	0.48	5.6	22.3	0.73	11.66
8,04	driver	13.58	0.55	4.2	17.0	1.23	19.65
7,01	driver	13.27	0.68	2.8	11.4	1.35	21.58
7,03	driver	12.96	0.59	3.8	15.1	1.48	23.72
8,09	driver	11.92	0.52	4.8	19.3	2.07	33.13
6,08	driver	11.85	0.51	5.1	20.3	2.12	33.91
7,15	driver	11.79	0.55	4.3	17.2	2.16	34.55
7,02	driver	11.53	0.57	4.1	16.2	2.36	37.77
7,13	driver	10.85	0.54	4.4	17.7	3.02	48.29
9,10	driver	8.08	0.37	9.6	38.6	9.81	156.99
	GM	**12.29**	**0.54**	**4.44**	**17.75**	**1.83**	**29.32**
	Min	**8.08**	**0.37**	**2.84**	**11.37**	**0.66**	**10.57**
	Max	**15.86**	**0.68**	**9.64**	**38.56**	**9.81**	**156.99**
6,20	passenger	29.49	1.24	0.8	3.4	0.06	0.88
7,12	passenger	21.56	0.95	1.5	5.8	0.19	3.09
7,11	passenger	17.02	0.76	2.2	8.9	0.50	7.97
6,21	passenger	13.75	0.62	3.4	13.5	1.17	18.72
	GM	**19.64**	**0.87**	**1.75**	**6.98**	**0.28**	**4.49**
	Min	**13.75**	**0.62**	**0.85**	**3.39**	**0.06**	**0.88**
	Max	**29.49**	**1.24**	**3.37**	**13.49**	**1.17**	**18.72**
FSV 4WD Make 2							
7,22	driver	22.15	1.07	1.1	4.6	0.17	2.77
7,08	driver	19.24	0.90	1.6	6.4	0.30	4.87
7,21	driver	15.81	1.01	1.3	5.1	0.67	10.68
9,12	driver	12.45	0.59	3.8	15.1	1.74	27.85
	GM	**17.02**	**0.87**	**1.72**	**6.90**	**0.50**	**7.96**
	Min	**12.45**	**0.59**	**1.15**	**4.59**	**0.17**	**2.77**
	Max	**22.15**	**1.07**	**3.77**	**15.09**	**1.74**	**27.85**
7,25	passenger	32.95	1.72	0.4	1.8	0.04	0.57
7,23	passenger	26.76	1.28	0.8	3.2	0.08	1.30
7,24	passenger	17.51	0.83	1.9	7.6	0.44	7.11
	GM	**24.90**	**1.22**	**0.88**	**3.50**	**0.11**	**1.74**
	Min	**17.51**	**0.83**	**0.44**	**1.76**	**0.04**	**0.57**
	Max	**32.95**	**1.72**	**1.90**	**7.62**	**0.44**	**7.11**

Table A4.3 International Standard: Caution Zone and Likely Health Risk Zone (cont.)

Sample	Activity	VDV (8 hour)	Wt. RMS acceleration (m/s^2)	RMS Criteria: Approx time to reach Caution zone (hr)	RMS Criteria: Approx time to reach Likely health risk zone (hr)	VDV Criteria: Approx time to reach caution zone (hr)	VDV Criteria: Approx time to reach Likely health risk zone (hr)
FSV Make 3b							
6,28	driver	61.70	2.82	0.2	0.7	0.00	0.05
6,24	driver	31.04	0.82	1.9	7.7	0.04	0.72
6,27	driver	19.05	1.11	1.1	4.3	0.32	5.07
	GM	**33.17**	**1.37**	**0.70**	**2.79**	**0.03**	**0.55**
	Min	**19.05**	**0.82**	**0.16**	**0.65**	**0.00**	**0.05**
	Max	**61.70**	**2.82**	**1.93**	**7.73**	**0.32**	**5.07**
6,26	passenger	37.67	1.24	0.9	3.4	0.02	0.33
6,25	passenger	32.61	1.43	0.6	2.5	0.04	0.59
	GM	**35.05**	**1.33**	**0.74**	**2.94**	**0.03**	**0.44**
	Min	**32.61**	**1.24**	**0.64**	**2.54**	**0.02**	**0.33**
	Max	**37.67**	**1.43**	**0.85**	**3.41**	**0.04**	**0.59**
FSV Make 3a							
6,07	driver	56.53	2.13	0.3	1.2	0.00	0.07
6,30	driver	56.67	3.51	0.1	0.4	0.00	0.06
6,22	driver	43.95	1.96	0.3	1.4	0.01	0.18
6,12	driver	43.20	1.23	0.9	3.4	0.01	0.19
6,31	driver	51.25	3.02	0.1	0.6	0.01	0.10
6,04	driver	38.90	1.52	0.6	2.3	0.02	0.29
	GM	**47.93**	**2.09**	**0.30**	**1.20**	**0.01**	**0.13**
	Min	**38.90**	**1.23**	**0.11**	**0.43**	**0.00**	**0.06**
	Max	**56.67**	**3.51**	**0.86**	**3.45**	**0.02**	**0.29**
6,29	passenger	43.82	2.24	0.3	1.0	0.01	0.18
6,13	passenger	45.95	2.07	0.3	1.2	0.01	0.15
	GM	**44.87**	**2.16**	**0.28**	**1.13**	**0.01**	**0.16**
	Min	**43.82**	**2.07**	**0.26**	**1.04**	**0.01**	**0.15**
	Max	**45.95**	**2.24**	**0.30**	**1.21**	**0.01**	**0.18**
FSV Make 4							
7,07	passenger	31.63	1.74	0.4	1.7	0.04	0.67
7,05	passenger	18.83	0.92	1.6	6.2	0.33	5.32
	GM	**24.40**	**1.26**	**0.82**	**3.28**	**0.12**	**1.88**
	Min	**18.83**	**0.92**	**0.43**	**1.72**	**0.04**	**0.67**
	Max	**31.63**	**1.74**	**1.56**	**6.24**	**0.33**	**5.32**
7,17	driver	35.31	3.00	0.1	0.6	0.03	0.43
7,20	driver	21.60	1.00	1.3	5.2	0.19	3.07
	GM	**27.62**	**1.74**	**0.43**	**1.74**	**0.07**	**1.15**
	Min	**21.60**	**1.00**	**0.15**	**0.58**	**0.03**	**0.43**
	Max	**35.31**	**3.00**	**1.30**	**5.19**	**0.19**	**3.07**

Table A4.4 International Standard: Caution Zone and Likely Health Risk Zone (cont.)

Sample	Activity	VDV (8 hour)	Wt. RMS acceleration (m/s^2)	RMS Criteria: Approx time to reach Caution zone (hr)	RMS Criteria: Approx time to reach Likely health risk zone (hr)	VDV Criteria: Approx time to reach caution zone (hr)	VDV Criteria: Approx time to reach Likely health risk zone (hr)
LHD Make 1							
9,05	driver	35.06	1.06	1.2	4.6	0.03	0.44
8,05	driver	29.66	0.87	1.7	6.9	0.05	0.86
8,06	driver	27.97	0.90	1.6	6.5	0.07	1.09
9,04	driver	25.28	0.71	2.6	10.3	0.10	1.63
6,10	driver	24.58	1.05	1.2	4.7	0.11	1.83
7,19	driver	23.66	1.04	1.2	4.9	0.13	2.13
7,10	driver	19.54	0.77	2.2	8.7	0.29	4.58
7,14	driver	16.19	0.58	3.9	15.5	0.61	9.71
7,09	driver	15.88	0.61	3.5	14.1	0.66	10.51
	GM	**23.46**	**0.82**	**1.92**	**7.70**	**0.14**	**2.21**
	Min	**15.88**	**0.58**	**1.16**	**4.65**	**0.03**	**0.44**
	Max	**35.06**	**1.06**	**3.87**	**15.47**	**0.66**	**10.51**
LHD Make 2							
9,03	driver	56.28	2.17	0.3	1.1	0.0042	0.0666
6,15	driver	22.38	0.79	2.1	8.3	0.17	2.66
	GM	**35.49**	**1.31**	**0.76**	**3.04**	**0.03**	**0.42**
	Min	**22.38**	**0.79**	**0.28**	**1.11**	**0.0042**	**0.07**
	Max	**56.28**	**2.17**	**2.08**	**8.32**	**0.17**	**2.66**
Skid steer vehicle							
9,08	driver	32.98	1.68	0.5	1.9	0.04	0.57
6,33	driver	20.27	1.28	0.8	3.2	0.25	3.96
6,32	driver	16.32	1.12	1.0	4.2	0.59	9.41
6,34	driver	12.60	0.81	2.0	8.1	1.66	26.55
6,35	driver	12.02	0.78	2.1	8.5	2.00	32.03
	GM	**17.52**	**1.09**	**1.10**	**4.42**	**0.44**	**7.09**
	Min	**12.02**	**0.78**	**0.46**	**1.85**	**0.04**	**0.57**
	Max	**32.98**	**1.68**	**2.12**	**8.49**	**2.00**	**32.03**
Shuttle car on surface road							
7,16	driver	**19.11**	**0.67**	**4.0**	**16.0**	**0.31**	**5.01**

Table A5.1 Vehicle SEAT values

Sample			SEAT value x	SEAT value y	SEAT value z
Rail personnel carrier					
6,01	passenger		1.89	0.92	1.02
6,02	passenger		1.39	0.97	0.86
6,19	passenger		1.05	0.78	0.66
		GM	**1.40**	**0.88**	**0.83**
6,03	driver		1.38	0.84	0.99
6,05	driver		1.61	0.96	0.89
6,23	driver		1.22	0.83	0.89
6,14	driver		1.37	0.83	0.87
		GM	**1.39**	**0.87**	**0.91**
Dollycar					
9,02	driver		0.93	0.98	0.85
Loco					
6,06	driver		0.48	0.75	1.11
6,09	driver		1.04	0.82	1.11
6,11	driver		1.31	0.80	1.07
		GM	**0.87**	**0.79**	**1.09**
FSV Make 5					
8,03	passenger		1.52	1.07	1.15

Table A5.2 Vehicle SEAT values (Continued)

Sample			SEAT value x	SEAT value y	SEAT value z
FSV 4WD Make 1					
6,20	passenger		0.40	1.90	1.83
6,21	passenger		1.16	1.01	0.87
7,12	passenger		1.17	1.11	0.79
7,11	passenger		1.00	1.00	0.72
		GM	**0.86**	**1.21**	**0.98**
9,01	driver		0.82	0.41	2.95
7,15	driver		1.06	0.35	2.11
7.01	driver		0.85	0.24	1.65
6,08	driver		1.02	1.34	1.13
8,04	driver		1.11	1.20	1.12
6,18	driver		1.28	1.25	1.10
9,09	driver		0.98	1.15	0.92
7,03	driver		0.88	1.16	0.86
7,13	driver		1.00	1.21	0.79
7,02	driver		0.88	1.13	0.76
9,10	driver		0.93	1.13	0.65
		GM	**0.98**	**0.84**	**1.14**
FSV 4WD Make 2					
7,25	passenger		1.00	1.22	1.09
7,24	passenger		1.10	1.09	1.05
7,23	passenger		1.00	1.05	0.91
		GM	**1.03**	**1.12**	**1.01**
7,22	driver		0.27	0.72	1.58
7,08	driver		0.87	1.11	0.95
9,12	driver		0.61	0.44	0.81
7,21	driver		0.78	0.85	0.75
		GM	**0.58**	**0.74**	**0.98**

Table A5.3 Vehicle SEAT values (Continued)

Sample		SEAT value x	SEAT value y	SEAT value z
FSV Make 3b				
6,24	driver	1.17	0.79	1.78
6,27	driver	1.05	1.21	1.21
6,28	driver	1.39	2.36	1.15
	GM	**1.19**	**1.32**	**1.35**
6,26	trailer passenger	1.01	1.31	0.79
6,25	trailer passenger	0.88	1.19	0.73
	GM	**0.94**	**1.25**	**0.76**
FSV Make 3a				
6,31	driver	2.74	1.63	2.95
6,12	driver	0.99	0.84	1.45
6,07	driver	1.20	0.78	1.06
6,22	driver	1.00	0.95	0.94
6,30	driver	2.53	2.16	0.93
6,04	driver	1.10	1.11	0.89
	GM	**1.44**	**1.16**	**1.23**
6,29	passenger	1.01	1.27	1.10
6,13	passenger	0.85	1.01	0.94
	GM	**0.92**	**1.13**	**1.02**
FSV Make 4				
7,05	passenger	0.30	1.38	4.62
7,07	passenger	1.84	0.78	0.80
	GM			
7,20	driver	1.00	0.91	0.90
7,17	driver	0.55	1.49	1.25
	GM	**0.74**	**1.10**	**1.43**

Table A5.4 Vehicle SEAT values (continued)

Sample			SEAT value x	SEAT value y	SEAT value z
LHD Make 1					
6,10	driver		1.09	1.00	1.91
9,05	driver		0.77	0.78	1.70
8,05	driver		1.07	0.76	1.53
7,19	driver		1.00	0.80	1.49
8,06	driver		1.12	0.94	1.39
7,10	driver		0.76	1.00	1.23
7,09	driver		0.46	0.76	1.18
9,04	driver		1.17	1.02	1.06
7,14	driver		1.03	0.96	1.02
		GM	**0.91**	**0.89**	**1.36**
LHD Make 2					
9,03	driver		0.79	1.65	1.83
6,15	driver		0.88	0.98	1.60
		GM	**0.83**	**1.27**	**1.71**
Skid steer vehicle					
9,08	driver		1.00	0.71	2.49
6,33	driver		1.00	0.74	2.36
6,34	driver		0.82	0.70	0.99
6,35	driver		0.78	0.67	0.82
6,32	driver		0.95	0.98	0.80
		GM	**0.90**	**0.75**	**1.31**
Shuttle car on surface	driver				
7,16			1.00	0.87	2.13

Table A6.1 Measured versus individuals' ratings of ride

Sample	Activity	AS Wt RMS acceleration. (m/s2)	8-hour VDV (ISO)	Ride Sample VDV (ISO)	ISO (VDV) guidance for 8 hr exposure	Individuals' simple rating	Rating of ride British Std. Inst. comfort rating	Operator's comments on ride
Rail personnel carrier								
6,05	driver	1.07	24.68	8.58	likely health risk	v. rough (76)	little uncomfortable	poor ride, average rail conditions, one or two undulations and kinks
6,03	driver	0.86	20.42	9.65	likely health risk	rough (63)	little uncomfortable	average ride, average rail conditions, one or two undulations and kinks
6,23	driver	0.85	19.81	8.19	likely health risk	rough (70)	very uncomfortable	poor ride, average rail conditions, one or two undulations and kinks
6,14	driver	0.46	12.12	4.48	caution zone	good (23)	not uncomfortable	good ride, average rail conditions, one or two undulations and kinks
	GM	**0.77**	**18.65**					
6,02	passenger	0.77	22.40	9.57	caution zone	rough (75)	uncomfortable	average ride, average rail conditions, one or two undulations and kinks
6,01	passenger	0.78	20.22	8.64	likely health risk	rough (75)	uncomfortable	average ride, average rail conditions, one or two undulations and kinks
6,19	passenger	0.65	14.41	5.96	caution zone	fair (43)	little uncomfortable	good ride, average rail conditions, one or two undulations and kinks
	GM	**0.73**	**18.69**					
Dolly car								
9,02	driver	0.17	7.25	2.89	below caution	rough (55)	not uncomfortable	good ride, average rail conditions, moderate speed
Loco								
6,09	driver	0.58	14.21	5.87	caution zone	fair (28)	not uncomfortable	average ride, average rail conditions, one or two undulations and kinks
6,06	driver	0.59	13.93	5.95	caution zone	fair (30)	not uncomfortable	average ride, average rail conditions, one or two undulations and kinks
6,11	driver	0.53	13.18	5.54	caution zone	good (25)	not uncomfortable	average ride, average rail conditions, one or two undulations and kinks
	GM	**0.57**	**13.76**					
FSV Make 5								
8,03	passenger	1.41	25.44	11.77	likely health risk	rough (55)	little uncomfortable	average ride, reasonably good road, rough patches

Table A6.2 Measured versus Individuals' rating of ride (continued)

Sample	Activity	AS Wt RMS acceleration. (m/s2)	8-hour VDV (ISO)	Ride Sample VDV (ISO)	ISO (VDV) guidance for 8 hr exposure	Individuals' simple rating	Rating of ride British Std. Inst. comfort rating	Operator's comments on ride
FSV 4WD Make 1								
6,18	driver	0.76	15.86	7.50	caution zone	rough (57)	uncomfortable	poor ride, poor roads, water, potholes, rocks
9,09	driver	0.53	15.47	7.74	caution zone	v. rough (85)	little uncomfortable	average to rough ride, main travelling road, rough in parts
8,04	driver	0.55	13.58	6.35	caution zone	fair (30)	not uncomfortable	good ride, good travelling roads, speed 15 to 30kph
7,01	driver	0.67	13.27	5.67	caution zone	fair (34)	little uncomfortable	average ride, variable road conditions - good to poor.
7,03	driver	0.55	12.96	6.37	caution zone	fair (34)	little uncomfortable	average ride, good travelling road, poor in-bye, 15 to 20kph
9,01	driver	0.48	11.92	4.74	caution zone	fair (45)	not uncomfortable	average ride, good travelling road - 20 to 25kph, rougher in-bye
6,08	driver	0.58	11.85	5.48	caution zone	good (25)	not uncomfortable	good ride, average to good roads, some rough patches
7,15	driver	0.54	11.79	4.96	caution zone	fair (30)	not uncomfortable	average ride, good travelling roads
7,02	driver	0.56	11.53	5.14	caution zone	fair (34)	little uncomfortable	average ride, good travelling road, poor in-bye, 15 to 20kph
7,13	driver	0.52	10.85	4.48	caution zone	fair (30)	not uncomfortable	average ride, good travelling road, some water
9,10	driver	0.33	8.08	2.44	caution zone	fair (48)	not uncomfortable	average ride, slippery road, some slewing
	GM	**0.54**	**12.29**					
6,20	passenger	1.16	29.49	8.91	likely health risk	good (22)	not uncomfortable	average ride, rear of vehicle, average road with a few problems
7,12	passenger	0.98	21.56	6.06	likely health risk	fair (34)	not uncomfortable	good ride, good road, out-bye to surface
7,11	passenger	0.72	17.02	5.44	caution zone	fair (34)	not uncomfortable	good ride, good road, out-bye to surface
6,21	passenger	0.69	13.75	5.68	caution zone	fair (38)	not uncomfortable	average ride, rear of vehicle, average to poor road, water, slow speed
	GM	**0.87**	**19.64**					

Table A6.3 Measured versus Individuals' rating of ride (continued)

Sample	Activity	AS Wt RMS acceleration. (m/s2)	8-hour VDV (ISO)	Ride Sample VDV (ISO)	ISO (VDV) guidance for 8 hr exposure	Individuals' simple rating	Rating of ride British Std. Inst. comfort rating	Operator's comments on ride
FSV 4WD Make 2								
7,22	driver	1.19	22.15	7.08	likely health risk	good (18)	not uncomfortable	good ride, good travelling road, rough at end
7,08	driver	0.86	19.24	8.47	likely health risk	rough (62)	not uncomfortable	good ride, good travelling road, one rough patch, 30 to 35kph
7,21	driver	0.92	15.81	4.45	caution zone	rough (60)	fairly uncomfortable	poor ride, good travelling road, rough at end
9,12	driver	0.58	12.45	4.47	caution zone	fair (32)	not uncomfortable	average ride, travelling road, a little rough in spots
	GM	**0.86**	**17.02**					
7,25	passenger	1.36	32.95	10.53	likely health risk	rough (55)	little uncomfortable	average ride, good travelling roads then corrugations
7,23	passenger	1.23	26.76	9.90	likely health risk	fair (41)	not uncomfortable	good ride, good travelling road, rough at end
7,24	passenger	0.66	17.51	4.92	likely health risk	rough (62)	little uncomfortable	average ride, good travelling road, a little rough at end
	GM	**1.03**	**24.90**					
FSV Make 3b								
6,28	driver	1.18	61.70	27.88	likely health risk	fair (50)	not uncomfortable	poor ride, vehicle nearly 3 years old, av. road with rough patches, av speed > 20kph
6,24	driver	0.89	31.04	11.15	likely health risk	fair (35)	not uncomfortable	good ride, new vehicle, average road with potholes, speed > 20kph
6,27	driver	1.11	19.05	8.61	likely health risk	fair (50)	not uncomfortable	poor ride, vehicle nearly 3 years old, av. road with rough patches, av speed > 20kph
	GM	**1.05**	**33.17**					
6,26	trailer passenger	1.18	37.67	12.03	likely health risk	fair (40)	not uncomfortable	good ride, average ride, average road, soft spots, speed at least 25kph
6,25	trailer passenger	1.31	32.61	10.90	likely health risk	rough (54)	little uncomfortable	average ride, average road, soft spots, speed at least 25kph
	GM	**1.24**	**35.05**					

Table A6.4 Measured versus Individuals' rating of ride (continued)

Sample	Activity	AS Wt RMS acceleration. (m/s2)	8-hour VDV (ISO)	Ride Sample VDV (ISO)	ISO (VDV) guidance for 8 hr exposure	Individuals' simple rating	Rating of ride British Std. Inst. comfort rating	Operator's comments on ride
FSV Make 3a								
6,30	driver	1.33	56.67	26.22	likely health risk	v. rough (86)	fairly uncomfortable	poor, fairly rough ride, 12 yr old machine no load for half the ride, average speed 10kph
6,07	driver	2.35	56.53	26.73	likely health risk	fair (30)	little uncomfortable	poor ride, poor road with potholes, some water, soft spots
6,31	driver	1.67	51.25	22.86	likely health risk	v. rough (91)	uncomfortable	poor, fairly rough ride, 12 yr old machine towing timber pod, average speed 10kph
6,22	driver	2.03	43.95	20.33	likely health risk	v. rough (100)	very uncomfortable	poor ride, average road with potholes, soft spots
6,12	driver	1.34	43.20	21.60	likely health risk	v. rough (78)	little uncomfortable	poor ride,
6,04	driver	1.75	38.90	20.90	likely health risk	v. rough (87)	uncomfortable	poor ride, average road with water, potholes, soft spots, several stops
	GM	**1.49**	**53.89**					
6,29	trailer passenger	2.17	43.82	18.42	likely health risk	v. rough (80)	very uncomfortable	average ride, moderately rough road with some very rough patches, passenger in middle of pod, average speed about 10kph
6,13	trailer passenger	2.23	45.95	19.93	likely health risk	v. rough (85)	very uncomfortable	poor ride, poor road conditions, potholes, rocks, uneven gravel, slow speed, rear of pod, speed about 5kph
	GM	**2.20**	**44.87**					
FSV Make 4								
7,07	passenger	2.00	31.63	14.63	likely health risk	rough (65)	fairly uncomfortable	poor ride, moderately rough road
7,05	passenger	1.18	18.83	8.90	likely health risk	fair (33)	little uncomfortable	good ride, good travelling road, rough in-bye, 5 to 20kph
	GM	**1.53**	**24.40**					
7,17	driver	3.80	35.31	7.54	likely health risk	v. rough (78)	little uncomfortable	average ride, driving around on the surface, sealed and sealed parts
7,20	driver	1.20	21.60	10.32	likely health risk	fair (32)	not uncomfortable	good ride, good travelling roads
	GM	**2.13**	**27.62**					

Table A6.5 Measured versus Individuals' rating of ride (continued)

Sample	Activity	AS Wt RMS acceleration. (m/s2)	8-hour VDV (ISO)	Ride Sample VDV (ISO)	ISO (VDV) guidance for 8 hr exposure	Individuals' simple rating	Rating of ride British Std. Inst. comfort rating	Operator's comments on ride
LHD Make 1								
7,10	driver	0.89	19.54	7.60	likely health risk	v. rough (80)	little uncomfortable	average ride, consolidating ramp, some rocks and slewing
7,14	driver	0.68	16.19	8.70	caution zone	rough (75)	fairly uncomfortable	poor ride, mucking out, stowage transported in back headings
9,05	driver	1.10	35.06	20.94	caution zone	rough (52)	uncomfortable	average ride, main travelling road, light load and empty, several big pot holes and rough patches
7,09	driver	0.74	15.88	8.13	caution zone	fair (38)	little uncomfortable	average ride, good travelling road, mucking out sump, taking stowage out
7,19	driver	1.03	23.66	14.18	likely health risk	v. rough (90)	uncomfortable	average ride, good travelling roads, carting ballast from surface to U/G
6,10	driver	0.79	24.58	14.74	likely health risk	fair (40)	not uncomfortable	average ride, average road, potholes, loaded, some breaks from the cab
9,04	driver	0.79	25.28	13.67	caution zone	fair (62)	uncomfortable	poor ride, typical run, loading and dumping, full and empty
8,06	driver	1.03	27.97	14.74	likely health risk	rough (75)	little uncomfortable	poor ride, fairly good roads, taking ballast on, emptying out
8,05	driver	0.99	29.66	15.19	likely health risk	v. rough (80)	uncomfortable	poor ride, main travelling road, transporting light materials and towing trailer
	GM	**0.88**	**23.46**					
LHD Make 2								
9,03	driver	2.33	56.28	29.25	likely health risk	rough (63)	little uncomfortable	good ride, poor road, load of fine road base
6,15	driver	0.88	22.38	9.98	likely health risk	fair (35)	not uncomfortable	average ride, main travelling road, rough in patches
	GM	**1.44**	**35.49**					

Table A6.6 Measured versus Individuals' rating of ride (continued)

Sample	Activity	AS Wt RMS acceleration. (m/s2)	8-hour VDV (ISO)	Ride Sample VDV (ISO)	ISO (VDV) guidance for 8 hr exposure	Individuals' simple rating	Rating of ride British Std. Inst. comfort rating	Operator's comments on ride
Skid steer vehicle								
9,08	driver	1.61	32.98	12.83	likely health risk	v. rough (82)	fairly uncomfortable	poor ride, muddy work area, mucking out under conveyor
6,33	driver	0.86	20.27	8.38	likely health risk	rough (65)	little uncomfortable	average ride backing & filling, cleaning up around conveyor belt, some stops
6,32	driver	0.64	16.32	7.38	caution zone	rough (60)	little uncomfortable	average ride, backing & filling, cleaning up around conveyor belt, some stops
6,34	driver	0.41	12.60	5.62	caution zone	v. rough (81)	little uncomfortable	average ride, rough work area, breaking up coal and stone around conveyor
6,35	driver	0.41	12.02	4.45	caution zone	rough (72)	little uncomfortable	average ride, rough work area, breaking up coal & stone around conveyor
	GM	**0.68**	**17.52**					
Shuttle car on surface road								
7,16	driver	0.77	19.11	6.39	likely health risk	v. rough (81)	little uncomfortable	good ride, little rough, good road conditions, a little rougher at the end

APPENDIX 2

Paper presented at the NSW Mining and Quarrying Industry OHS Conference Terrigal, August 2000

Using New Vibration Standards to Assess Typical Rides in Mining Vehicles

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Introduction

Whole-Body Vibration (WBV) is now considered to contribute to the development of a range of health disorders in those exposed. The most common of these are in the musculoskeletal system, most notably in the lower back. Exposure that includes jolts and jars is thought to be particularly damaging.

It is acknowledged that the current Australian Standard (AS 2670 -1990)[1] does not properly assess the risks of WBV to drivers of vehicles especially if exposures include shocks or jolts and jars. The damaging effect of these jolts and jars was recognised in the new International Standard on whole-body vibration (ISO 2631-1.)[2] which was published in 1997.

The Australian Standard assesses vibration exposures against a set of criteria curves for comfort, fatigue and health. The new International Standard uses different methods to assess vibration exposure against criteria which indicate when caution should be taken and where there is a likely health risk. The International Standard has introduced the use of the Vibration Dose Value (VDV) for rough rides that include jolts and jars.

Results from a recent study[3] of whole-body vibration exposures in NSW coal mines has shown vastly different outcomes are possible depending on which Standard is used for assessment. The disparity between assessments is greatest when the exposure includes a high proportion of jolts and jars.

This paper shows how three different exposure scenarios are assessed by the different Standards and how these exposures can be controlled.

Table 1. Three typical exposure scenarios and their assessment by the Australian and International Standards.

Scenario		Australian Standard limits		International Standard	
		Fatigue	Health	Caution zone	Likely health risk
1	Dump truck	16 hours	24 hours	7 hours (rms criteria)	24 hours (rms criteria)
2	Track Dozer	4 hours	16 hours	1 hour (rms criteria)	4 hours (rms criteria)
3	Manhaul Passenger	4 hours	16 hours	6 minutes (VDV criteria)	2 hours (VDV criteria)

Three common whole-body vibration exposure scenarios.

SCENARIO 1- Operating a Dump truck driver-prolonged sitting with low level vibration exposure

The first scenario arises with drivers of dump trucks and similar vehicles who complain about low-grade symptoms at the end of the working day. These presumably arise from prolonged sitting, which has been identified in other research (see reference 3), as an independent factor associated with the development of back pain. It also may be that constant exposure to low grade vibration, without the breaks that are possible on other vehicles, is a significant contributor.

Standards assessment

The Australian Standard fatigue limit for a typical dump truck ride is 16 hours with a health exposure limit of 24 hours. The International Standard exposure guidelines indicate that the caution zone is reached in 7 hours and the likely health risk zone after 24 hours exposure.

Possible solutions

Exposure to vibration is not likely to be the real problem here. The main issue is likely to be the prolonged sitting which is, in itself, a risk factor for back pain. Tension and fatigue can accentuate the effects of discomfort.

The underlying causes of the back pain are not obvious to the operator but could be addressed through such strategies as encouraging breaks out of the seat and job rotation.

Engineering design

- Adequate cab space especially leg and headroom.
- Appropriate layout of controls and displays.
- Good visibility from the cab.
- Appropriate seat design and maintenance.

Administrative

- Job rotation – operation of perhaps two or three different vehicles each shift.
- Regular, frequent breaks out of the seat (a minimum of 5 minutes within each hour preferably 10 minutes within each hour especially where 12-hour shifts are worked).

SCENARIO 2.

Generally rough ride in a bulldozer or other type of LHD (load-haul-dump vehicle)

The roughness of the conditions and the activity of the vehicle contribute substantially to the ride roughness. The vehicle is usually unsprung, is of extremely robust construction and is very heavy. Every movement is transmitted to the cab and, if the seat does not damp the vibration effectively, it is also transmitted to the operator.

Standards assessment

The Australian Standard fatigue limit is typically 4 hours for this ride, while the health exposure limit is16 hours. The International Standard assesses the ride as reaching the caution zone after one hour and the likely health risk zone in 4 hours using the rms criteria.

Possible solutions

Engineering design

- Effective vehicle suspension.
- Effective seat suspension (seat must not bottom out).
- Isolation of the cab from the frame of the machine.
- Appropriate vehicle maintenance including appropriate seat maintenance and timely seat replacement.

Administrative

- Define harmful vibration for operators and give them feedback on what 'operating to conditions' means in practice.
- Specific vehicle operator training.
- Job rotation – operation of perhaps two or three different vehicles each shift.
- Regular, frequent breaks out of the seat (a minimum of 5 minutes within each hour preferably 10 minutes within each hour especially where 12-hour shifts are worked).

SCENARIO 3.

One-off severe jolt e.g. hitting a pothole in a manhaul, bashing the body of a truck with a shovel or loader, dumping of large rocks in the body of a truck

The one-off jolt usually occurs without warning and so the operators, drivers or passengers are unprepared. Speed of movement, either when travelling or when swinging the shovel, accentuates the impact. Less skilled or experienced drivers or operators are more likely to be exposed.

Standards assessment

There was not an opportunity to measure a one-off jolt during the survey but a rough ride in a manhaul vehicle gives an indication of the effect. The Australian Standard assesses the fatigue and health limits for a rough manhaul ride as 4 hours and 16 hours, similar to those of the track dozer. However, the International Standard is much more stringent assessing the ride as reaching the caution zone in only 6 minutes and the likely health risk zone in 2 hours (under the Vibration Dose Value criteria). Although the 6-minute caution zone is very limiting it does not protect against a one-off jolt which could occur in the first few seconds or minutes of the ride.

Possible solutions

Engineering design

- Effective vehicle suspension.
- Effective seat suspension (seat must not bottom out).
- Isolation of the cab from the frame of the machine.
- Appropriate vehicle maintenance including appropriate seat maintenance and timely seat replacement.
- Truck locating device when parking next to the shovel.
- Adequate lighting at night (must not dazzle).

Administrative

- Appropriate and effective road maintenance systems.
- Define harmful vibration for operators and give them feedback on what 'driving to conditions' means in practice.
- Enforce speed limits (manhaul).
- Specific operator/driver training – manhaul driver, shovel or loader operator, truck driver.
- Communication of information on road conditions and potential problems from and to drivers.

General Recommendations for reducing operators' and passengers' exposures to WBV

There are a range of ways in which mines might attempt to reduce potentially harmful vibration for operators, drivers and passengers. These include engineering/design as well as administrative/organisational controls. It is unlikely that one approach or solution will be fully effective. The application of a range of smaller controls which, when taken together, reduce exposures to an acceptable level are likely to be most effective in the majority of cases. The following are approaches that are being used or could be used by coal mines in Australia:

1. *Restricting speed*

- Speed limits which are enforced.
- Speed limited vehicles in specific situations.
- Drivers and operators who are deemed competent and safe (appropriate training).

2. *Road maintenance programs*

- Dedicated vehicles and drivers for road maintenance.
- Road maintenance programs that are planned and systematic and not regarded as secondary to production demands.
- Effective communication of information on road conditions and potential problems.
- Effective use of water pumps and drainage techniques.
- Professional road construction especially for main roads.
- Immediate removal of materials on the road likely to cause jolts and jars e.g. rocks.

3. *Design of vehicles*

- Appropriate cab and vehicle suspension. Suspension systems must appropriate. for loads typically carried by the vehicle. Vehicle suspension systems must never bottom out.
- Good seat design and improved vehicle suspension. Seat suspension must never bottom out.
- Improved visibility especially in bulldozers, graders etc.
- Transport vehicles with forward facing seats and appropriately designed seating.
- Appropriate tyres and tyre pressures.
- Cab design and layout including sufficient head and leg space.
- Fully adjustable controls and seating.

4. *Maintenance of vehicles*

- Planned maintenance programs which include seating and vehicle suspension systems.
- Specialist maintenance for seating and suspension systems.

5. *Miscellaneous*

- Ensuring adequate shot firing standards.
- Communication and correction of problems that may lead to rough rides particularly at night.

- Regular rotation of operators on vehicles. ss
- Regular breaks out of the seat/cab.

The relative contribution of each of these factors needs to be explored further to determine the most cost-effective approach of solutions. In the short term some design solutions will not be possible but administrative and maintenance controls will be.

Conclusion

In terms of exposure time limits and guidance, the new International Standard is generally much more stringent than the current Australian Standard and is probably a better indicator of vibration exposures that could lead to injury. However, neither Standard protects against the one-off jolt that could occur after only a few seconds or minutes of a ride. It may be necessary to apply a peak limit to protect against severe jolts and jars.

Control of whole-body vibration using only time limits will not be feasible under the new Standard because these limits would be too restrictive for some vehicles in practice. Other control strategies will need to be adopted.

Ideally, vibration exposure including one-off jolts should be controlled by road maintenance, vehicle suspension, driving technique and the other methods suggested above

References

1. Australian Standard, AS 2670.1 - 1990, *Evaluation of human exposure to whole-body vibration, Part 1: General requirements*. Standards Australia, Sydney.

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3. McPhee, B., Foster, G., Long, A., Exposure to Whole-body Vibration for Drivers and Passengers in Mining Vehicles, Part 1, Report of findings at four open-cut mines and a coal loader, Joint Coal Board and the National Occupational Health and Safety Commission (previously Worksafe Australia) May 2000.