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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

1996 and 1997

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May 2000

A Project funded by the Joint Coal Board Health and Safety Trust and National Occupational Health and Safety Commission (Worksafe Australia)

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EXPOSURE TO WHOLE BODY VIBRATION FOR DRIVERS AND PASSENGERS IN MINING VEHICLES – PART 1

REPORT TO THE JOINT COAL BOARD HEALTH AND SAFETY TRUST

1. EXECUTIVE SUMMARY

1.1 Introduction

In the coal industry 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.

Unfortunately, it appears that the current Australian Standard (AS 2670-1990) does not adequately assess jolts and jars commonly experienced in mining vehicles. However, the new International Standard (ISO 2631-1, 1997), which is based on more recent research, has been designed to assess these jolts and jars and appears better for evaluating such vibration exposures.

This is the report of a study of WBV exposure in coal miners in NSW commenced in 1995 at four open-cut mines and a coal loader. Measurements were made on a range of vehicles undertaking a range of activities under normal operational conditions. A range of factors that might influence the ride of a vehicle also was recorded.

As a random sample this study provides a 'snapshot' in time of vibration exposures in open-cut mines in 1996 and 1997. 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.

1.2 Methods

Participants in the study were operating 13 dump trucks (electric and mechanical), 10 track bulldozers, two rubber tyred dozers, three graders, six loaders, two water trucks, seven manhaul vehicles (two drivers and five passengers) and five fitter's vehicles undertaking a variety of activities.

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 'quality of ride' 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

According to the Australian Standard the exposure to whole-body vibration (WBV) experienced by operators of most vehicles was found to be within permissible times for 'health criteria' for an eight-hour shift. The 'fatigue limits' ranged on average from 2.5 hours (rubber tyred dozers), 4 hours (fitter's vehicles, track dozers, graders and manhaul passengers) and 8 hours or more (loaders, water carts, manhaul drivers, dump trucks and the excavator).

However, the method of analysis used by the Australian Standard may not be valid when rides are rough. Also it 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).

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.

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'. The VDVs varied widely but correlated moderately well (r=0.61) with operators' ratings using the simple rating scale. Most operators and some passengers appear to underrate the roughness of their rides.

Fifty-eight of the 69 participants (84%) reported some musculoskeletal disorders (sprains and strains, aches and pains) in the previous 12 months which they believed were related to what they did at work. Twenty-four (34.8%) and 18 (26%) participants reported low back pain and neck pain respectively in the last week. Low back pain (59 or 85.5%) and/or neck pain (39 or 56.5%) were the most commonly reported disorders in the previous 12 months. (Tables 5, 6 Results). However, most operators had not taken time off work for these complaints because they did not consider their symptoms severe enough to warrant it.

Most seats performed well in the z-axis (up/down), especially the seats in the dozers. However, only the seats in the dump trucks performed consistently well in the x-axis (fore/aft). No seats performed well in all three axes and most performed poorly in the y-axis (side to side).

The results indicate that seating does not solve all the vibration problems. Too much may be expected from the seat while the basic design of the vehicle remains unchanged. However, the manufacturers must carefully consider the shape of the seat and backrest (particularly the lumbar support) as these are believed to be 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 all appeared to contribute to what participants considered to be rougher rides with higher VDV values.

There was evidence that poor cab design increased operators' complaints of discomfort and reduced the benefits of good seating. In some vehicles (track dozers and graders in particular) the location of controls and the need to see behind or down to the front in order to see clearly meant that operators adopted awkward and potentially damaging postures and could not make the best use of the seat.

Unrelieved sitting posture (like other postures) leads to increased reports of musculoskeletal discomfort and disorders. This is particularly the case with truck drivers. Operators should be encouraged to take short breaks out of their seats and move around during a working day. Five minutes every half hour or so is probably sufficient to reduce discomfort to a tolerable level during an eight-hour shift.

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 design and administrative controls and each mine will need to consider what works for them. Controls come under the following categories:

- Limiting speed
- Effective road maintenance programs
- Appropriate design of vehicles
- Effective maintenance of vehicles
- Miscellaneous e.g. shot firing standards, regular rotation of operators on vehicles and 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 some administrative and maintenance controls could be applied.

1.4 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 is the least stringent and would classify most rides in this study as acceptable. As well the Standard 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.

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. If the new International Standard is adopted in Australia, some recommended exposures would drop by more than two thirds. 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.

We expect that, as a result of this study, we shall be able to make more specific recommendations on exposure limits to WBV and analysis methods in the mining industry in preparation for the adoption of a new Standard within the next few years.

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.

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. BACKGROUND TO THE STUDY

3.1 Exposure to whole-body vibration at work

In Australia there are a number of industries and occupations which require workers to drive 'off road' vehicles and machinery. These include mining, farming and agriculture, forestry, construction, minerals exploration and utilities. The intensity and duration of exposures to whole-body vibration (WBV) appear to vary but there is no information to confirm this or whether these exposures lead to ill health or injuries. The need to reduce the risks for back pain and other sprains and strains is being recognised by employers, unions and others; the reduction of WBV exposure is now viewed as one way to prevent or, at least reduce, the severity of these disorders.

The scientific literature increasingly points to links between WBV exposure and health disorders such as low back pain (LBP). Mining in Australia requires 'off road' driving, such as unsealed and other temporary roads or tracks, thereby subjecting employees to unknown levels of WBV. Unfortunately we know little of the actual WBV exposures and their causative factors such as the condition of roads; the engine and vehicle activity; vehicles, cab and seat design; and driver skills. As well, the link between exposures and health problems needs to be clarified with respect to mine workers.

The supposed effects on humans of exposure to WBV at best may be discomfort and interference with activities; at worst may be injury or disease *(Griffin 1993)*. However, comparatively little is known about the specific effects of exposure to vibration, particularly WBV, on the musculoskeletal system.

3.2 Risk factors for back pain

In the developed world, work-related back disorders are the commonest causes of workers' compensation claims, sick leave and early retirement *(Kelsey and Hardy 1975; Frymoyer et al 1983; Kumar and Davis 1983; Westgaard and Åaras 1984)*. Back disorders are usually accompanied by back pain and no truly effective medical or surgical treatment exists for a large number of cases.

Back disorders are believed to arise from damage to the spine and surrounding structures brought about by an accumulation of strains placed on the back over time and some occupations have been associated with earlier, more frequent or more severe symptoms (*Wickström 1978; Riihimäki et al 1989*). These disorders are most commonly seen in middle aged and older people (> 35 years) *(Andersson 1981)* although it is not unusual for symptoms to be reported by teenagers and young adults. In some cases acute injuries, resulting from severe trauma, such as car accidents, precipitate symptoms in young people with little evidence of prior damage. However, in most people the precipitating event is unlikely to be the 'cause' of the disorder - it is simply 'the last straw'.

A number of different work-related and individual factors are considered to be risk factors for back disorders but there is no clear understanding of the relative contribution of these factors. As well there is no general explanation of *how* back disorders occur, that is, what actually goes wrong in the back which gives rise to symptoms. However, epidemiological studies have indicated that the following factors in physical work increase the risk of back disorders and pain:

- heavy dynamic physical work (e.g. manual handling)
- static work postures (including sedentary work)
- frequent bending and twisting of the trunk
- lifting and forceful movements
- repetitive work
- vibration *(Andersson 1981).*

While there has been a range of research carried out in the areas of physical loads and postures and their relationship to back pain, much less is known about the effects on the musculoskeletal system of exposure to WBV.

3.3 Disorders arising from exposure to whole-body vibration

Research to date reveals a lack of dose-response relationship between WBV exposure and symptoms of musculoskeletal disorders such as LBP. This reflects more on the complexity of the research rather than a lack of interest by investigators. It has proved very difficult to obtain real exposure and follow-up data. Many of the investigations deal with *either* the effects of short or long-term exposure on health, *or* the measurement of exposure at work or in the laboratory. Both are difficult areas: the former because of either the variability of measures for clinical outcomes, or the lack of information on the link between biomechanical, physiological or psychological changes and exposures. The latter is difficult because of the problems associated with gathering representative WBV exposure data.

The most frequently reported adverse effect from all sources of WBV is LBP and sciatica thought to arise from premature degeneration of the joints and end plates of the spinal vertebrae and herniated lumbar disc *(Wickström 1978; Wilder et 1982; Frymoyer et al 1983; Kjellberg and Wikström 1985; Kjellberg, Wikström and Dumberg 1985; Seidel, Bluethner and Hinz 1986; Dupuis and Zerlett 1987; Hulshof and Van Zanten 1987; Kjellberg and Wikström 1987; Boshuizen, Hulshof and Bongers 1990; Dupuis, Hartung and Haverkamp 1991; Pelmear, Roos and Maehle 1992, Seidel 1993; Wikström, Kjellberg and Landström 1994).* Paraesthesia of the limbs also has been reported *(Dupuis and Zerlett 1987).* Laboratory studies have noted degeneration of the lumbar vertebrae after intense long-term exposure to WBV *(Seidel and Heide 1986).*

Dupuis and Zerlett (1987) noted that reports of back pain were age-related, i.e. reports of LBP increased with age, as might be expected in the general population *(Wickström 1978; Andersson 1981).* However, there is evidence that back pain is occurring earlier than expected for workers exposed to WBV (*Boshuizen, Bongers and Hulshof 1992*). In the Netherlands, Germany and the USA studies of people exposed to vibration at work indicate that, *when compared with controls,* premature spinal degeneration and/or low back pain was more prevalent in crane operators *(Bongers et al 1988a,b; Boshuizen et al 1990a,b; Burdorf and Zondervan 1990);* helicopter pilots *(Bongers et al 1990; Boshuizen, Bongers and Hulshof 1990b);* subway train operators *(Johanning 1991);* tractor drivers *(Boshuizen et al 1990 a,b; Boshuizen, Bongers and Hulshof 1992);* and forklift drivers *(Brendstrup and Biering-Sørensen 1987).*

Prolonged sitting, poor working postures and inadequate ergonomic conditions (including poor seat and cab design) also are believed to contribute to back pain and are usually found in association with WBV exposure *(Kelsey and Hardy 1975; Troup 1978; Wickström 1978; Bongers et al 1988a, 1990; Riihimäki et al 1989; Burdorf and Zondervan 1990; Johanning 1991; Boshuizen, Bongers and Hulshof 1992).* As well, many driving jobs involve manual handling *(Wickström 1978; Riihimäki et al 1989).*

Therefore it is not possible at this stage to indicate the specific contribution WBV exposures make to low back pain (LBP), and other musculoskeletal symptoms, separate from these important factors.

Injuries believed to arise, at least partially, from exposure to WBV have led to lost work days through increased absenteeism, early retirement, work inefficiencies and increased compensation costs *(Seidal and Heide 1986; Bongers et al 1988b; Boshuizen, Bongers and Hulshof 1990b;). Deacon (1990)* reported that the NSW Joint Coal Board figures indicated that vibration and shock is responsible for 30% of all back injuries in open-cut coal mines. *Cross and Walters (1994)* examined NSW mine workers' compensation data relating to reported 'causes' of back pain. They found that no conclusion could be drawn from these data with regard to the relationship between overall vibration exposure and claims for back injury. However, approximately 11% of neck and back injuries were reported to be due to vehicle jarring. The contributory effects of vibration, as one of several risk factors, to the onset of back and neck pain could not be determined from the Workers' Compensation statistics.

There is virtually no information on ways by which workers' exposure to WBV might be reduced such as the impact of improved road maintenance; correct cab and seat design; carefully selected seat cushioning; vehicle suspension and tyres; and well designed seat suspension. These aspects are now considered to be important but to date no intervention studies appear to have addressed them.

3.4 Exposure to whole-body vibration in mining

Mine workers are exposed to WBV while using transport and other mining equipment. While some work has been done on WBV exposure in coal mine workers in Australia *(Oh and Middlin 1991a,b; Cross 1993, Cross and Walters 1994)*, Canada (*Village 1989; Village Morrison and Leong 1989)* and the USA *(Hutton and Brubaker 1982; Love et al 1992; Gagliardi and Utt 1993)* the full extent of WBV exposure in mining in Australia is not known. However, there is evidence that some exposure levels are above that recommended in the current Australian Standard (AS 2670-1990) for many operators and perhaps passengers *(Oh and Middlin 1991a,b; Cross 1993, 1994)*.

A previous study of open-cut mines found that many vehicles in use including scrapers, haulage trucks, dozers and graders were unacceptable when assessed against current Australian Standards *(Oh and Middlin 1991a)*. Anecdotal evidence suggests that drivers of bulldozers and dump trucks in open-cut mines are exposed to excessive WBV according to the Australian Standard. For workers in underground mines the duration of exposure to WBV may be less but the magnitude is likely to be higher than in open-cut mines due to the poor conditions and nature of the vehicles used. A study *(Village 1989)* of underground load-haul-dump vehicles (LHDs), found that 20 of 22 tested vehicles exceeded the ISO 2631 six-hour limit in the z direction (vertical axis through the body).

In mining, WBV is considered as having two different components i.e. a continuous level (or steady state); and jolts and jars. The main sources of vibration for operators of mining equipment are machine activity (dumping, loading etc), road conditions and low frequency engine vibration to a lesser extent (see Fig 12 Discussion section). The jolts and jars that occur while a vehicle is in motion are usually referred to as 'rough rides'. The immediate effects of 'rough rides' for many mine workers may not be more than discomfort or fatigue. However, increasingly, they are being reported as the source or aggravation of injuries *(McPhee and Knowles 1992; Cross and Walters 1994)*. In underground and open cut coal mines both passengers and drivers experience mines 'rough rides'. They are believed to be the major source of vibration responsible for the development of back and neck disorders in mine workers.

A number of other factors including vehicle suspension, cab and seat design, visibility and driver skills are all believed to either amplify or reduce the exposures *(McPhee and Knowles 1992; McPhee 1993, p13)*.

While passengers in mine transport vehicles often are seated for shorter periods than drivers, rough rides for them may still be harmful: passengers cannot see or anticipate rough patches; they often face sideways and have no way of bracing or reducing the impact of jolts and jars; much of the seating is poorly designed; and some transport vehicles do not have suspension.

3.5 Reducing vibration exposures

To reduce vibration exposure while driving the following factors need to be addressed:

- poor road conditions
- lack of adequate suspension in vehicles

- inappropriate tyres or tyre pressures
- lack of appropriate seat suspension
- poor cab design, layout and position
- poor seat design
- poor visibility and
- inadequate driver skills and awareness *(McPhee and Knowles 1992).*

These problems exist in a range of industries but especially in underground and open cut mining. They are gaining recognition as the probable source of at least some of the back and other musculoskeletal disorders experienced by mine workers. While there appears to have been very little research into, or systematic review of these factors, the NSW Coal Mining Inspectorate, mine managers and most manufacturers of equipment now recognise the need for better seating and vehicle suspension (*Department of Mineral Resources NSW 1995*).

3.5.1 Seat suspensions

Oh and Middlin (1991a,b) undertook WBV measurement in both open-cut and underground coalmines in NSW and Queensland. These data were used to develop a seat prototype suspension mechanism to reduce the detrimental effects of vibration on open-cut mine machinery operators. While the underground version is some way off, the open-cut version is currently being trialed in NSW mines.

From experimental data *Cross (1993)* found that the acceleration of the seat is a strong function of the roadway surface, the speed of the vehicle and the seat design. Cross also indicated that the vibration measurements should evaluate the vibration over the period that the vehicle is in motion, otherwise the vibration is easily dominated by the work cycle rather than the intrinsic vehicle vibration.

The U.S. Bureau of Mines *(Gagliardi and Utt 1993)* compared mechanical and air suspension seats in laboratory tests. At the vibration levels tested, the air suspension seat, pressurised above 503.3kPa provided better vibration attenuation than the mechanical suspension.

3.5.2 Road construction and maintenance

The Australian Road Research Board (1993) has produced a handbook on the construction and maintenance of unsealed roads. This contains useful information for all industries. In order to assist underground mining personnel with the correct development and maintenance of roads a report has been written which outlines ways in which problems such as water and vehicle damage to roads can be reduced (*Coffey and Partners 1994).* However, while it provides technical information it does not address the administrative barriers to achieving ongoing road maintenance, which appear to be the greatest challenge to mine managers.

3.6 Vibration Standards

The current Australian Standard AS2670.1-1990 *Evaluation of Human Exposure to Whole-Body Vibration* is essentially the same as the old International Standard ISO2631-1985 and is based on research and international consensus before 1970.

This Standard assesses the WBV exposure against three criteria:

1. the preservation of health or safety ('exposure limit')
2. the preservation of working efficiency ('fatigue decreased deficiency boundary')
3. the preservation of comfort ('reduced comfort boundary').

The limits consider the permissible duration of the exposure at different frequencies.

A major limitation of the Australian Standard is the inability to properly assess vibration exposures that are subjectively felt as jolts and jars because assessment is based on root mean square (r.m.s.) acceleration values that interpret average exposure rather than give weight to the shocks felt as jolts and jars. It is now considered important to assess this component of WBV as it is thought to be a major cause of injury. The r.m.s. acceleration (m/s^2) is calculated from Equation 1 below.

Equation 1

$$rms = \left[\frac{1}{T}\int_0^T a_w^2(t)\,dt\right]^{\frac{1}{2}}$$

where:

$a_w(t)$ = frequency - weighted acceleration in ms^{-2}

T = period, in seconds, during which vibration occurs

The r.m.s. processing of the vibration signal does not give sufficient weighting to the high peaks. In an attempt to address this limitation, *Griffin and Whitham* (1980a,b) investigated the use of the root-mean-quad (r.m.q) as a method for assessing vibration exposures that contain shocks. The r.m.q. is exactly the same as the r.m.s. except that the function, (Equation 1), is raised to the 4th power and the 4th root of the result is taken. This mathematical function gives more weighting to the high peaks contained within the vibration signals. Griffin and Whitham found that r.m.q. averaging gave a better correlation with subjective responses than did the r.m.s. vibration value.

The 'vibration dose value' (VDV), which is based on fourth power methods, has been incorporated into the British Standard BS 6840:1987, *Guide to measurement and evaluation of human exposure to whole body mechanical vibration and repeated shock.* The VDV provides a value that is sensitive to high peak vibration and therefore gives a better assessment of rides containing jolts and jars. It is also more applicable to mining because it is a measure of *total* exposure rather than the *average* exposure. The vibration dose procedure yields a better correlation with subjective responses of the ride than does the Australian Standard. However, there is still much research needed before a proper dose - response relationship can be established for WBV.

Equation 2

$$VDV = \left[\int_0^T a_w^4(t)\,dt\right]^{\frac{1}{4}}$$

where:

$a_w(t)$ = frequency – weighted acceleration in ms^{-2}

T = total period, in s, during which vibration may occur

In the British Standard, steady state vibration with a low level of shocks may be assessed using an 'estimated vibration dose value' (eVDV), which is based on the root mean square (r.m.s.) acceleration value.

Published literature to date indicates that the British Standard has not been used to assess vibration in the mining industry.

The new International Standard ISO 2631-1:1997, *Mechanical vibration and shock-Evaluation of human exposure to whole-body vibration*, has incorporated methods to assess both steady state and shock type vibration using r.m.s and VDV values. It also gives an alternative to the VDV called the 'running r.m.s. method' which uses a short integration time for analysis of the acceleration signals.

The new standard has replaced the exposure limits and boundaries with guidance on exposures that could lead to adverse health effects. The concept of 'fatigue-decreased proficiency' has been deleted. Guidance on the effects of vibration on comfort, perception and motion sickness are also included in the new standard.

4. 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?

5. METHODS AND INSTRUMENTATION

5.1 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 open-cut mines and the coal loader 69 participants (including one woman) had taken part in the Study, and 87 useable recordings had been made ranging from 10 to 60 minutes in length. Only two operators had refused the invitation. The research team spent up to ten days at each facility over a 10-month period. Data were collected over three to four days at each visit. This report describes these data and discusses them. A subsequent report will describe and discuss data from the underground mines.

5.2 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 xxx.

5.3 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. A custom designed data logger was built by AR Technologies in Sydney. 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.

5.3.1 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.

5.3.2 '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.

5.3.3 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 three or four self-tapping screws. 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.

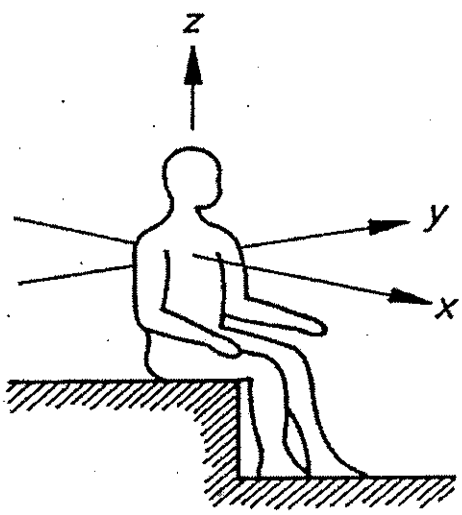


Figure 1. Vibration Axes

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

5.4 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.

5.5 Types of vehicles selected for measurement

Measurements of whole-body vibration levels were conducted on a range of vehicles. The vehicles measured were 13 dump trucks (electric and mechanical), 10 track bulldozers, two rubber tyred dozers, three graders, six loaders, two water trucks, seven manhaul vehicle (two drivers and five passengers) and five fitter's vehicles. These 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.

5.6 Data analysis

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

5.6.1 Seat vibration isolation efficiency

Two methods were used to indicate seat vibration isolation efficiency

5.6.1.1 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 track dozer 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.

5.6.1.2 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 4 in the Results Section and Tables A4 in Appendix 1.

5.6.2 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). 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.

5.6.2.1 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 Result section (Table 1) and Appendix 1 (Table A1).

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.

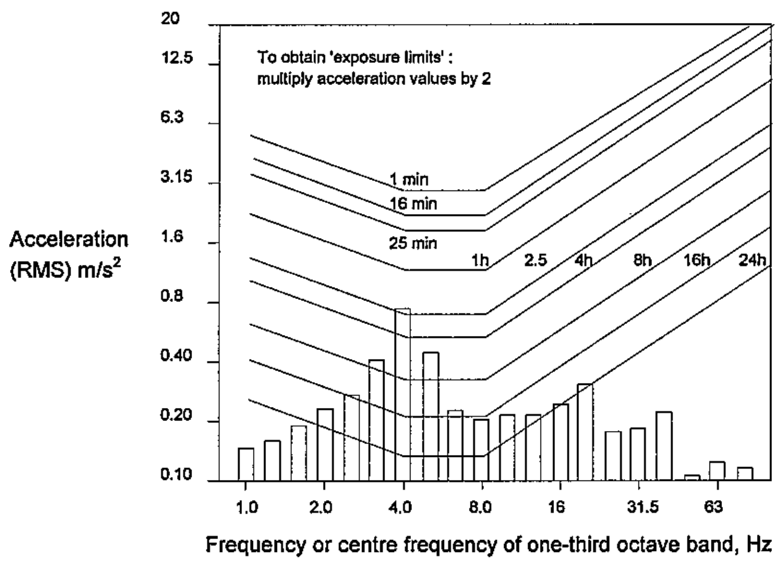


Figure 2. Australian Standard Vibration Time Limits for Z Axis: Fatigue-decreased deficiency boundary ('fatigue')

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.

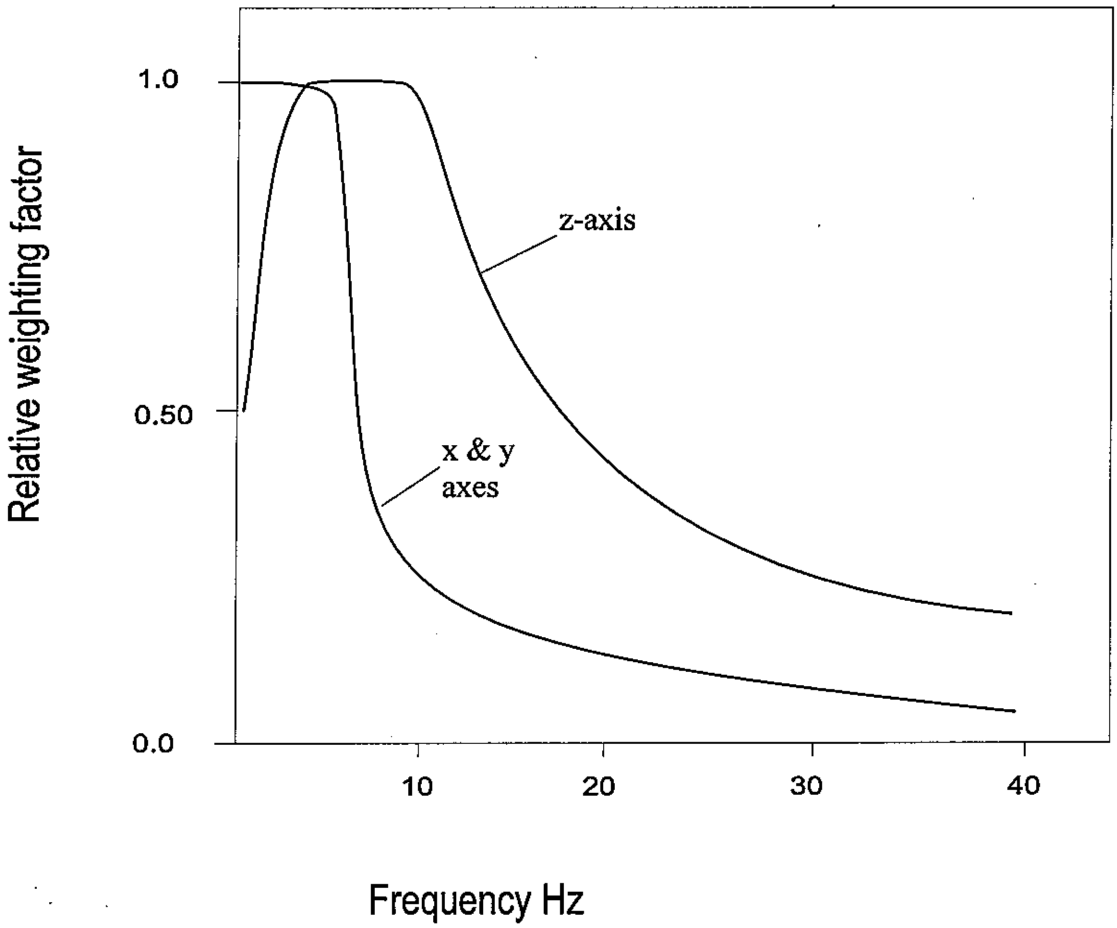


Figure 3. Australian Standard (AS2670.1, 1990): Frequency Weighting Factors for x, y, and z-axes.

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.

5.6.2.2 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:

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

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.

5.6.2.3 *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.

<u>Combined Axes</u>

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. It is caused by the vehicles' activity, particularly the pushing and ripping (x-axis) and turning (y-axis) phases.

<u>Assessment of shocks</u>

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.

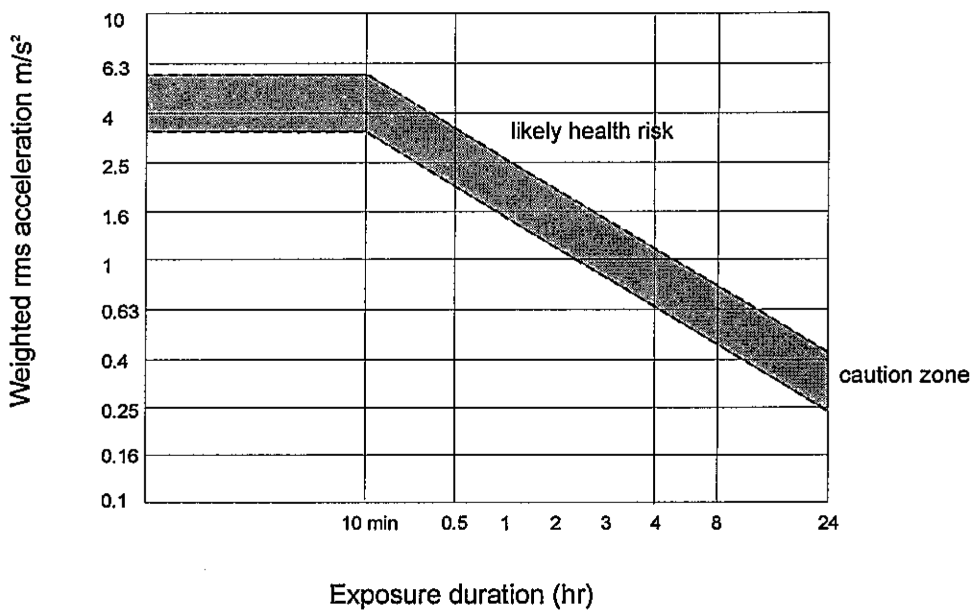


Figure 4. New International Standard (ISO 2631-1, 1997): Health guidance caution zones

5.7 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 which were labelled for analysis left to right as good, OK, fair and poor

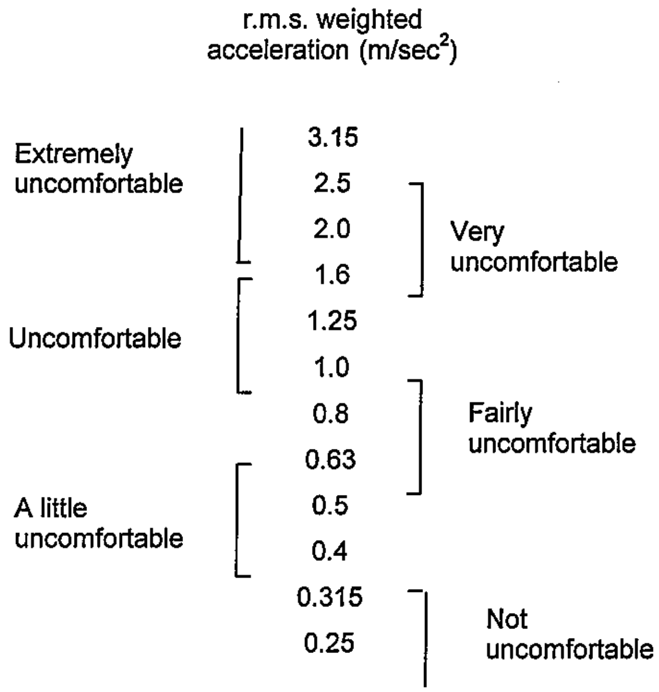


Figure 5. Scale of vibration discomfort (British Standards Institution, 1987)

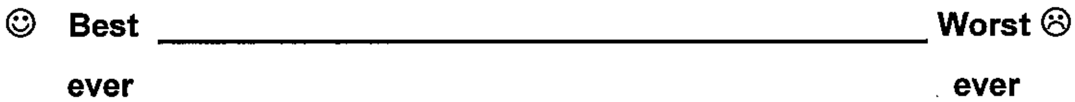


Figure 6. Simple Rating Scale

6. RESULTS

A total of 69 operators took part in this part of the project on ten visits to four open-cut coal mines and a coal loading facility between August 1996 and May 1997. A total of 78 samples were recorded and analysed. There were some repeat readings.

A summary of the results from each sample, as it was analysed using different methods, and information from participants can be found in the following tables (Tables 1 to 8, Figs 7-10). Tables containing individual rides results can be found in Appendix 1, Tables A1 to A5. Interpretation and discussion of these results can be found in the next section entitled Discussion.

Table 1. Australian Standard Assessment: Third-octave method, permissible time limits
(***worst to best*** - ranked according to increasing interpolated limit - fatigue criteria)

Vehicle type		RMS m/s²	Boundary exceeded fatigue (hr)	Boundary exceeded health (hr)	Implied exposure limits fatigue (hr)	Implied exposure limits health (hr)	Interpolated limits fatigue (hr)	Interpolated limits health (hr)
Rubber tyred dozers	*GM*	*1.36*	4	16	2.5	8	**3.3**	**10.1**
	Min	*1.23*					3.0	8.0
	Max	*1.50*					4.0	13.0
Fitters vehicle	*GM*	*0.94*	8	24	4	16	**6.7**	**17.8**
	Min	*0.81*					4.6	13.1
	Max	*1.35*					10.6	24.0
Track dozers	*GM*	*1.13*	8	24	4	16	**7.2**	**17.8**
	Min	*0.53*					2.0	7.0
	Max	*1.98*					22.0	24.0
Graders	*GM*	*0.76*	8	16	4	8	**7.2**	**15.7**
	Min	*0.38*					3.7	10.0
	Max	*1.14*					18.3	24.0
Manhaul passenger	*GM*	*0.95*	8	24	4	16	**7.8**	**17.8**
	Min	*0.44*					5.7	15.4
	Max	*1.22*					20.5	24.0
Loaders	*GM*	*0.83*	16	24	8	16	**9.0**	**21.8**
	Min	*0.68*					5.2	15.1
	Max	*1.16*					13.7	24.0
Watercart	*GM*	*0.74*	16	24	8	16	**9.5**	**20.3**
	Min	*0.22*					3.7	10.0
	Max	*1.16*					24.0	24.0
Manhaul driver	*GM*	*0.71*	16	24	8	16	**12.0**	**23.9**
	Min	*0.69*					10.0	23.8
	Max	*0.74*					14.4	24.0
Dump trucks	*GM*	*0.41*	24	24	16	16	**17.5**	**23.8**
	Min	*0.27*					7.9	21.9
	Max	*0.67*					24.0	24.0
Excavator		*0.22*	24	24	24	24	**24.0**	**24.0**

GM = Geometric mean

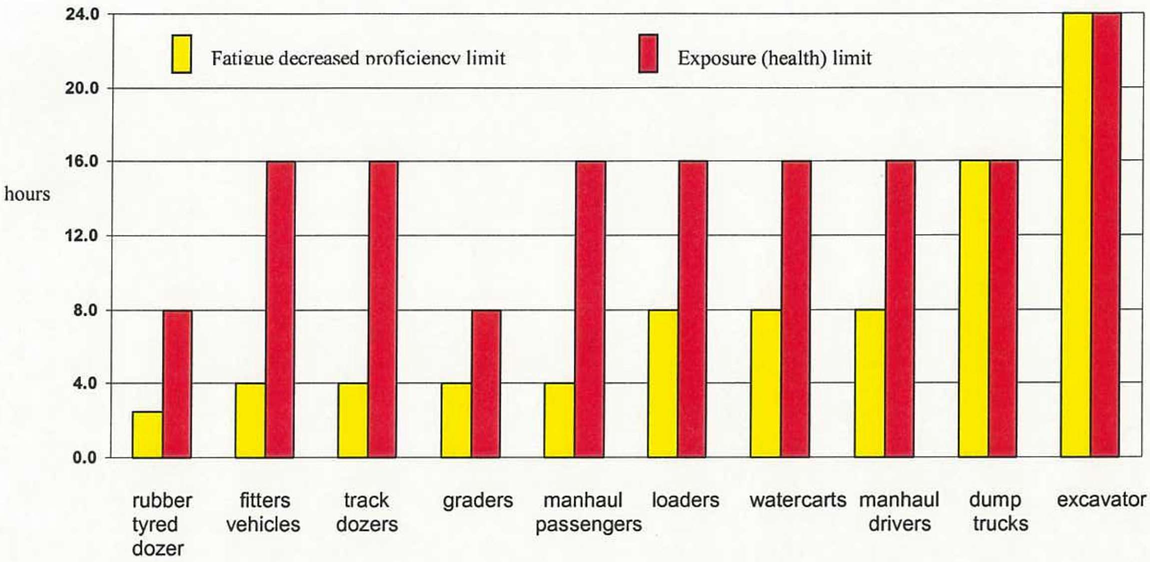


Figure 7 **Australian Standard Implied exposure limits for fatigue and health criteria**

Table 2 **British Standard Assessment: Vibration Dose Values (VDV)**
(***worst to best*** - ranked in order of increasing mean time to reach VDV action level)

Vehicle type		VDV 8hr (full shift) ($m/sec^{1.75}$)	Time to reach action limit** (hr)
Manhaul passenger	*Geometric mean*	**26.95**	**1.41**
	Min	23.16	0.77
	Max	26.95	1.41
Rubber tyred dozers	*Geometric mean*	**21.67**	**1.84**
	Min	19.76	1.12
	Max	24.50	2.66
Track dozers	*Geometric mean*	**17.05**	**4.68**
	Min	11.18	0.62
	Max	28.44	25.95
Fitters vehicle	*Geometric mean*	**17.98**	**5.37**
	Min	16.32	0.51
	Max	29.90	5.71
Manhaul driver	*Geometric mean*	**15.93**	**10.14**
	Min	14.14	6.28
	Max	15.93	10.14
Loaders	*Geometric mean*	**13.49**	**12.21**
	Min	11.15	0.95
	Max	25.58	26.23
Graders	*Geometric mean*	**12.17**	**18.46**
	Min	9.48	10.19
	Max	14.12	50.22
Watercart	*Geometric mean*	**9.86**	**24+**
	Min	9.10	31.11
	Max	10.68	59.10
Dump trucks	*Geometric mean*	**9.28**	**24+**
	Min	6.85	14.25
	Max	12.98	184.32
Excavator	*One sample*	**4.04**	**24+**

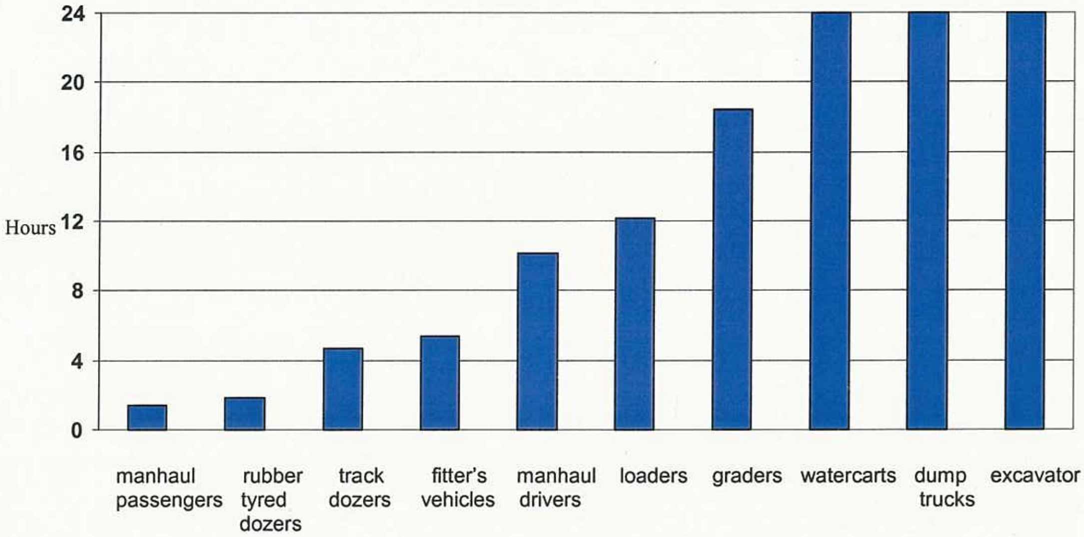


Figure 8 Time to reach British Standard VDV Action Level

Table 3 **International Standard (ISO 2631-1.2): Caution Zone and Likely Health Risk Zone.** (***worst to best*** - ranked according to increasing time to reach RMS caution zone)

Vehicle		VDV comb-axis ($m/sec^{1.75}$)	RMS (comb) acceleration (m/s^2)	RMS Approx time to reach caution zone (hr)	RMS Approx time to reach likely health risk zone (hr)	VDV Approx time to reach caution zone (hr)	VDV Approx time to reach likely health risk zone (hr)
Rubber tyred dozers	*GM*	**21.78**	**1.62**	**0.5**	**2.0**	**0.2**	**3.0**
	Min	19.80	1.51	0.4	1.7	0.1	1.8
	Max	24.59	1.73	0.6	2.3	0.3	4.4
Track dozers	*GM*	**17.70**	**1.32**	**0.9**	**3.5**	**0.5**	**8.2**
	Min	11.15	0.63	0.3	1.1	0.1	1.1
	Max	28.13	2.22	3.3	13.4	2.7	43.2
Manhaul passenger	*GM*	**25.74**	**1.01**	**1.3**	**5.1**	**0.1**	**1.5**
	Min	23.91	0.50	0.8	3.1	0.1	1.0
	Max	28.57	1.30	5.3	21.3	0.1	2.0
Loaders	*GM*	**12.88**	**0.96**	**1.4**	**5.7**	**1.5**	**24.3**
	Min	11.20	0.77	0.8	3.1	0.4	6.7
	Max	17.78	1.29	2.2	8.8	2.7	42.5
Fitters vehicle	*GM*	**20.52**	**0.94**	**1.5**	**5.9**	**0.2**	**3.8**
	Min	17.50	0.82	0.6	2.6	0.0	0.7
	Max	31.62	1.43	1.9	7.8	0.4	7.1
Manhaul driver	*GM*	**15.89**	**0.73**	**2.4**	**9.8**	**0.7**	**10.5**
	Min	14.77	0.73	2.4	9.7	0.5	7.8
	Max	17.09	0.73	2.5	9.8	0.9	14.1
Graders	*GM*	**13.32**	**0.68**	**2.9**	**11.4**	**1.3**	**21.3**
	Min	9.79	0.51	1.3	5.3	0.6	9.7
	Max	16.19	0.99	5.0	20.1	4.5	72.7
Watercart	*GM*	**10.36**	**0.55**	**4.4**	**17.5**	**3.6**	**58.0**
	Min	9.37	0.47	3.3	13.2	2.4	38.7
	Max	11.46	0.63	5.8	23.2	5.4	86.7
Dump trucks	*GM*	**9.88**	**0.43**	**7.1**	**28.5**	**4.4**	**70.0**
	Min	7.23	0.26	2.8	11.4	1.1	16.9
	Max	14.10	0.68	19.4	77.6	15.3	244.1
Excavator		**3.99**	**0.26**	**19.4**	**77.6**	**164.4**	**2630.0**

GM = Geometric mean

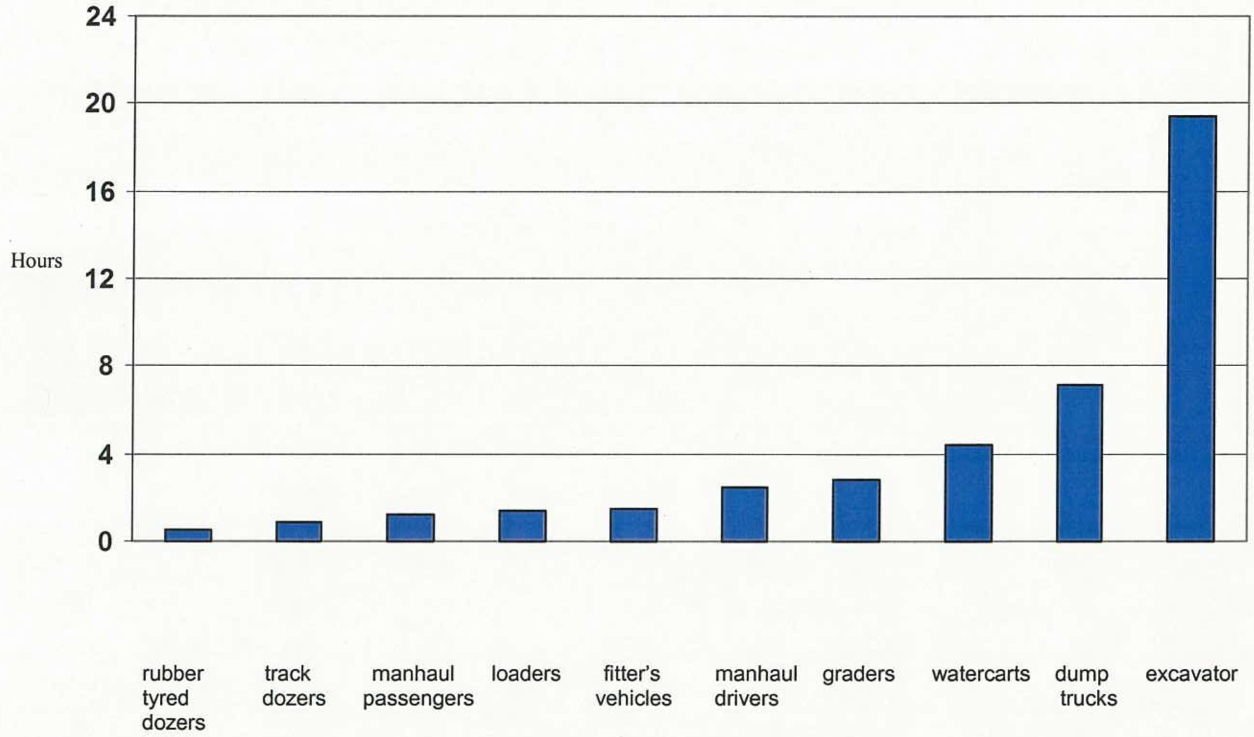


Figure 9 Time to reach ISO Caution Zone – r.m.s. criteria

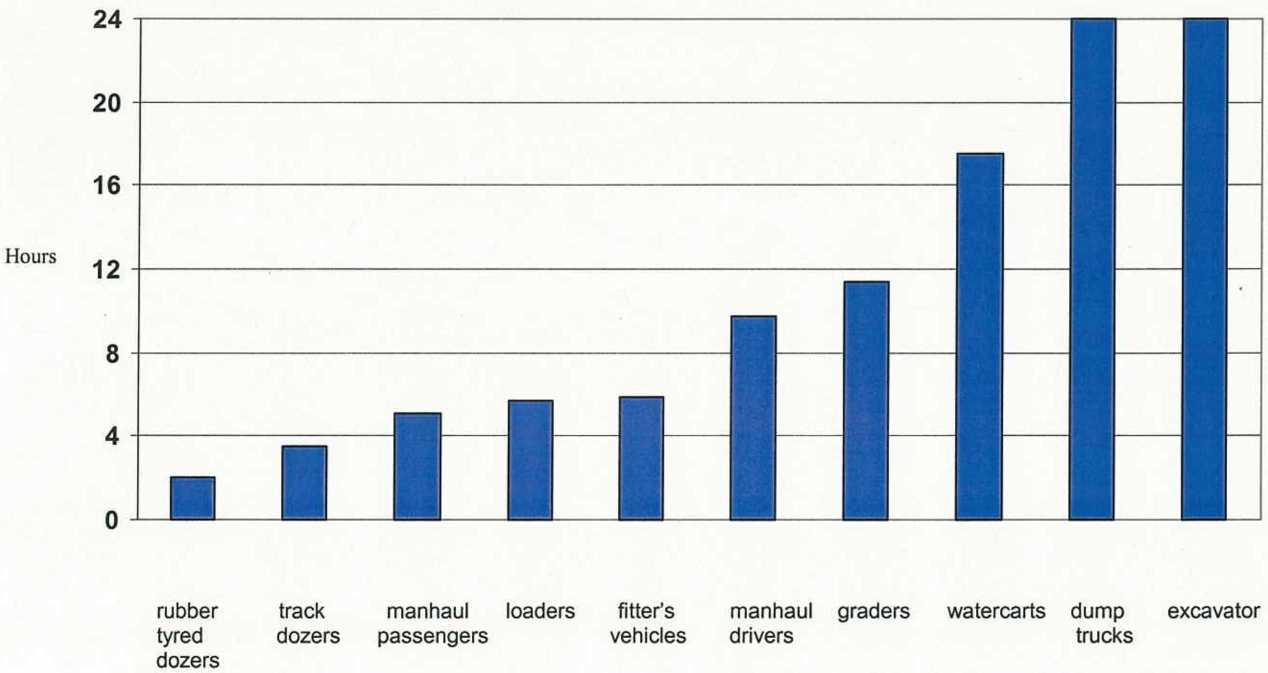


Figure 10 Time to reach ISO Likely Health Risk Zone – r.m.s. criteria

Table 4 **Geometric mean SEAT values for all vehicles except coal loading vehicles**

Sample	No. of samples	SEAT value x	SEAT value y	SEAT value z
Excavator	1	0.96	1.10	0.47
Rubber tyred dozer	3	1.18	1.03	0.71
Dump Trucks	22	0.90	1.13	0.79
Dozers	18	1.09	1.19	0.81
Manhaul passenger	5	1.34	1.02	0.87
Loaders	9	1.11	1.18	0.93
Manhaul driver	2	1.42	1.53	0.96
Watercart	2	1.12	1.13	1.03
Fitter's vehicle	5	1.17	0.99	1.04
Grader	6	1.17	1.27	1.10

Table 5. General statistics - 69 responses from 69 participants on 10 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
41.3 years (average) 23 - 57 years (range)	88 kg (average) 60 -140 kg (range)	1 month - 19 yrs (range)	42 hrs (average) 32 - 50 hrs (range)	19 - yes 46 - no 4 - missing	58 - yes 5 - no 6 - no symptoms

Table 6. Disorders in the last 12 months and 7 days and whether they are considered to be work-related – 73 responses from 69 participants on 10 visits

Disorder	No	Yes – in the last 12 months	Yes – in the last 7 days (numbers incomplete)	Believed to be work-related (numbers incomplete)
Neck	34	39	18	25
Upper back	52	21	8	16
Lower back	14	59	24	43
Hip	48	24	9	14
Knees	41	32	8	15
Ankles and feet	65	8	3	2
Shoulders	45	28	12	14
Elbows	61	12	3	4
Wrists and hands	62	11	5	4

Table 7 **Ratings of the cab, seat and operation of other vehicles - 88 responses from 69 participants on 10 visits**

Displays	Controls	Visibility	Seat suitability	Adjust seat?	Certified to operate different vehicles
48 - good 26 - acceptable 6 - poor 4 - repeats 4 - N/A (passengers)	46 - good 28 - acceptable 5 - poor 1 - missing 4 - repeats 4 - N/A (passengers)	34 - good 37 - acceptable 9 - poor 4 - repeats 4 - N/A (passengers)	41 - good 25 - average 14 - poor 4 - repeats 4 - missing	54 - yes 16 - no 6 - missing 8 - repeats 4 - N/A (passengers)	65 – dozers incl. rubber tyred dozers 59 - trucks 52 - graders 48 - loaders 45 - manhauls 36 - fitter's vehicles 18 - scrapers 11 - excavator 9 - shovel 8 - water cart 3 - fuel carts 3 - dragline 2 - scissor lift truck 1 - bob cat (list incomplete)

Table 8. **Ratings of ride - 95 responses from 69 participants on 10 visits**

Ratings of road conditions	Smoothness of ride	Ride rating using simple rating scale (line)	How did ride make you feel?
29 - good 39 - average 23 - poor 4 - missing	25 - good 55 - average 14 - poor 1 - missing	10 - good 34 - OK 26 - fair 20 - poor 5 - missing	36 - **not uncomfortable** (16 d/trucks, 1 fitters vehicle, 10 track dozers, 1 rubber - tyred dozer, 1 excavator, 3 graders, 4 loaders) 38 - **a little uncomfortable** (8 d/trucks, 2 rubber-tyred dozers, 3 graders, 3 m/haul - passengers, 4 fitters, 1 w/truck, 2 loaders, 14 dozers, 1 manhaul - driver) 9 - **fairly uncomfortable** (1 grader, 4 dozers, 1 d/truck, 1 fitter's vehicle, 1 manhaul - driver, 1 water truck) 2 - **uncomfortable** (2 dozers) 4 - **very uncomfortable** (2 dozers,1 manhaul - passenger 1 water truck) 1 - **extremely uncomfortable** (1 manhaul – passenger) 5 - **missing**

7. DISCUSSION

7.1 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 2000. 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.

7.2 Participants

Sixty-nine participants (68 men and one woman) took part in the Study at the four open-cut mines and the coal loader. The average age of participants (over 41 years) is higher than in many other industries but probably reflects the general workforce age in the NSW coal industry (Table 5, Results). The range of time operators had been working at each site doing their current work (heavy vehicle operation) was one month to 19 years on the job. The majority of operators came from similar work in other industries and only one or two were inexperienced in heavy vehicle operation before being employed in mining.

Fifty-eight of the 69 participants (84%) reported some musculoskeletal disorders (sprains and strains, aches and pains) in the previous 12 months which they believed were related to what they did at work. Low back pain (59 or 85.5%) and/or neck pain (39 or 56.5%) were the most commonly reported disorders. (Tables 5, 6, Results). However, most operators had not taken time off work for these complaints because they did not consider their symptoms severe enough to warrant it.

All operators were certified to drive more than one vehicle on site. The vehicles most commonly driven were dozers, trucks, graders, loaders, manhauls, fitters' vehicles and scrapers (Table 7, Results). As a result many operators are exposed regularly or intermittently to rough rides in these vehicles.

7.3 Opinions on cab design

A large percentage of participants rated cab design as good or acceptable. This included displays (84%), controls (84%), visibility from the cab (80.6%); and vehicle seat suitability (75%). Seventy one percent claimed that they adjusted their seat when they started work in a vehicle. (Table 7, Results).

7.4 Assessment by the Australian Standard

Results for assessment by the Australian Standard are summarised in Table 1 Results. Detailed test results are given in Appendix 1.

Results of analysis by the Australian Standard are expressed in Table 1 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

Only one track dozer ride exceeded the 8 hour boundary under the health criteria (Sample 5,05 Appendix 1, Table A1). The implied exposure limit for this ride would be 4 hours. All other rides would be acceptable for 8 hour or even 16 hours use under the Australian Standard health exposure criteria. The worst average ride was experienced in rubber tyred dozers, mainly due to the large contribution made by vibration in the x- and y-axes as well as a high z-axis component. Track dozers also produced substantial exposure in all three axes.

Fatigue Criteria

Average implied exposure limits for 'fatigue criteria' range from 2.5 hours for the rubber-tyred dozers to 24 hours for the excavator. Fitter's vehicles, track dozers, graders and manhaul passengers all have average 'implied' exposure limits of four hours while loaders, water trucks and manhauls (drivers) were assessed as having eight hour limits. The dump trucks had an average fatigue limit of 5 hours.

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 dump and water trucks 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.

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.

7.5 Assessment by the new International Standard

A summary of the assessment by the International Standard is given in the Results (Table 3) with individual ride values in Tables A3 in Appendix 1.

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.

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

Average results show that rubber tyred dozers and track dozers are likely to cause health effects in less than 4 hours. One track dozer ride reached the likely health risk zone in just over one hour's exposure. Under these criteria only the manhaul drivers, most grader rides water truck, dump truck and excavator (limited data), could be used for 8 hours or more without being a likely health risk.

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

On average, all vehicles except the water and dump trucks and the excavator reached the caution zone in less than four hours. Again, rubber-tyred dozers were assessed as giving the worst ride on average with only 30 minutes exposure before reaching the caution zone (Table 3, Results)

All vehicles except the excavator reached the International Standard (r.m.s. criteria) 'caution zone' on average in less than 8 hours. If adhering strictly to these 'caution zone' criteria it would not be possible to operate most vehicles for a full 8-hour shift.

VDV assessment – likely health risk criteria

Many rides experienced in mine vehicles would qualify for VDV assessment because they include a high proportion of shocks or jolts and jars. Manhaul passengers, dozer operators and fitter's vehicles drivers in particular experience severe jolts and jars.

Rubber tyred dozers, manhaul passengers and some manhaul drivers, fitter's vehicles and many track dozers were assessed as likely health risks for less than 4 hours exposure. The rides from most loaders and manhaul (drivers) and all graders, water trucks, dump trucks and the excavator were assessed as not being a likely health risk for an 8-hour (or more in some cases) exposure time.

VDV assessment – caution zone

All rides except those on dump trucks and excavator reached the VDV caution zone in less than 4 hours. Average rides for all vehicles except the excavator reached the caution zone in less than 8 hours. This result indicates that most vehicles pose a potential health risk due to vibration after, in some cases, only a few minutes exposure. For example, the average manhaul passenger ride reaches the caution zone in only 6 minutes and rubber tyred dozers in 12 minutes.

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

Results for assessment by the British Standard are provided in Table 2 (Results) and Tables A2 (Appendix 1).

The British Standard uses the VDV to assess the cumulative vibration exposure (Section 5.6.2.2, 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.

The manhaul passengers, on average, were assessed as having the worst ride according to this Standard with only 1 hour 24 minutes exposure to reach the action level. Rubber tyred dozers were also rated poorly with 1 hour 48 minutes exposure to reach the action level. Track dozers, fitters' vehicles, and manhaul drivers averages ranged from 4 hours 42 minutes to 10 hours 6 minutes to reach the action limit. These high VDV levels indicate the presence of jolts and jars which could be damaging even with short exposure times.

Other rides, including the excavator, dump trucks, water trucks, graders and loaders did not exceed the action limit, even for a 12-hour shift period.

Within each vehicle class there was a wide range of VDV time limit values. For example, the average loader time to reach action level was 12.21 hours but individual ride exposure limits ranged from a minimum of 0.95 hours (57 minutes) to a maximum of over 24 hours. Therefore caution should be used when referring to the average values.

As there was only a single measurement for one excavator this may not be indicative of rides in other excavators.

Vibration axes used for assessment

Dump trucks, manhauls, water trucks and the fitter's vehicles produced most vibration exposure in the z-axis (up and down) so this was the only axis used for assessment. However, the operators of rubber-tyred dozers, track dozers, loaders, excavator and half the grader rides experienced vibration almost equally in the three axes, x, y and z. In these cases, the contribution from each axis was summed to give the overall vibration exposure as recommended in the British and International Standards.

It should be noted that the one-third octave method used in the Australian Standard has no provision for combining axes.

7.7 Comparison of assessment by different Standards

A comparison between exposure guidelines for different Standards is shown in Table 12. The guidelines for exposure to whole-body vibration vary depending on which Standard is used for assessment. The Australian Standard rates almost all vehicles acceptable for use over an 8-hour shift under the health criteria. The British Standard, which uses the Vibration Dose Value (VDV) for assessment, gives reduced exposure times for rides that contain a high proportion of jolts and jars. Manhaul passengers and rubber tyred dozers reached the action level in less than 2 hours, while track dozers and fitter's vehicles in about 5 hours. Average rides for other vehicles did not reach the action limits in 8 hours or more although some individual rides within each vehicle group reached the action level in much less than 8 hours.

The International Standard recommends the use of both the r.m.s. and VDV for assessment. All vehicles except water trucks, dump trucks and excavator were identified as being potential health risks (i.e. in caution zone) with 4 hours or less (r.m.s.) exposure while rubber tyred and track dozers reached the likely health risk zone in less than 4 hours.

The VDV assessment identified all vehicles except dump trucks and the excavator as producing potentially injurious rides in less than 4 hours. Rubber tyred dozers, manhaul passengers and some manhaul drivers, fitter's vehicles and track dozers were assessed as likely health risks for less than 4 hours exposure

In terms of r.m.s and VDV assessment, exposure time guidelines are lower for the International Standard than those allowed under the Australian Standard.

For example, the time for one manhaul passenger ride (sample no. 2,27) to reach the implied fatigue boundary of the Australian Standard was four hours (Table A1.2 Appendix 1). In order to reach the caution zone using the r.m.s. criteria of the International Standard for the same ride the time limit was 45 minutes (Table A3.2 Appendix 1). This came down to four minutes using the VDV criteria of the International Standard (Table A3.2 Appendix 1).

In terms of 'caution zone' criteria the International Standard is more stringent than the British Standard because it uses a lower VDV exposure threshold.

The ranking of vehicles from worst to best changes depending on whether r.m.s or VDV is used for assessment. Table 7 shows how the VDV assessment places manhaul passenger and driver rides higher in the worst list because they include severe jolts and jars.

Table 9 **Comparison of vehicle assessment rating by the Australian, British and International Standards.**

Worst to best - ranking of vehicle types according to Australian Standard

Vehicle Type	Australian Standard	British Standard.	New International Standard	
	Average time to reach:			
	'Fatigue limit'	'Action level'	r.m.s. 'caution zone'	VDV 'caution zone'
Rubber tyred dozers	3hr	1hr 48 min	1hr 30min	12min
Fitter's vehicles	6hr 42min	5hr 24min	1hr 30min	12min
Track dozers	7hr 12min	4hr 42min	54min	24min
Graders	7hr 12min	18hr 30min	2hr 54min	1hr 18min
Manhauls (passengers)	7hr 48min	1hr 24min	1hr 18min	6min
Loaders	9hr	12hr 12min	1hr 24min	1hr 30min
Water trucks	9hr 30min	24hr	4hr 24min	3hr 36min
Manhauls (drivers)	12hr	10hr 8min	2hr 24min	42min
Dump trucks	17hr 30min	24hr	7hr 6min	4hr 24min
Excavator	24hr	24hr	19hr 24min	24hr

Table 10 **Ranking of vehicle types by the Australian and new International Standards - from worst to best.**

Australian Standard Assessment	International Standard VDV Assessment
Rubber tyred dozers	Manhauls (passengers)
Fitter's vehicles	Rubber-tyred dozers
Track dozers	Fitter's vehicles
Graders	Track dozers
Manhauls (passengers)	Manhauls (drivers)
Loaders	Graders
Water trucks	Loaders
Manhauls (drivers)	Water trucks
Dump trucks	Dump trucks
Excavator	Excavator

7.8 *Factors contributing to rough rides*

There is a range of factors that can be identified as contributing to 'rough rides' in different vehicles. High VDV values indicate a rough ride. The following factors have been identified through observation and discussion with mining personnel:

1. *Type of work/activity*
   - Ripping un-shot partings in dozer
   - Long periods of driving
   - Type of load – coal or overburden particularly when it influences what roads are used
   - Activity of vehicle leading to predominant movement forward (x axis) or sideways (y axis) (rubber tyred dozers, loaders)
   - Numbers of trips and time waiting
   - Slewing sideways in dozers while pushing on mud and inter-burden
   - Ripping hard coal in dozer

2. *Roads/ work surfaces*
   - Rough surfaces
   - Slewing sideways in manhauls on wet and muddy roads
   - Hitting potholes in manhauls

3. *Vehicle suspension including tyres*
   - Generally vehicles with well designed and maintained suspension systems gave a smoother ride than those with lesser suspension systems
   - Lower tyre pressures gave a smoother ride

4. *The design/type of vehicle*
   - Particular classes of vehicles (e.g. scrapers universally are regarded as 'rough' by operators; track dozers tilt and slew and move in all three axes; rubber-tyred dozers and loaders have a lot of side-to-side (y-axis) and fore to aft (x-axis) movement respectively)

5. *Age and condition of the vehicle*
   - Older vehicles (graders at one mine were new and gave a much smoother ride compared to older graders at two other mines)

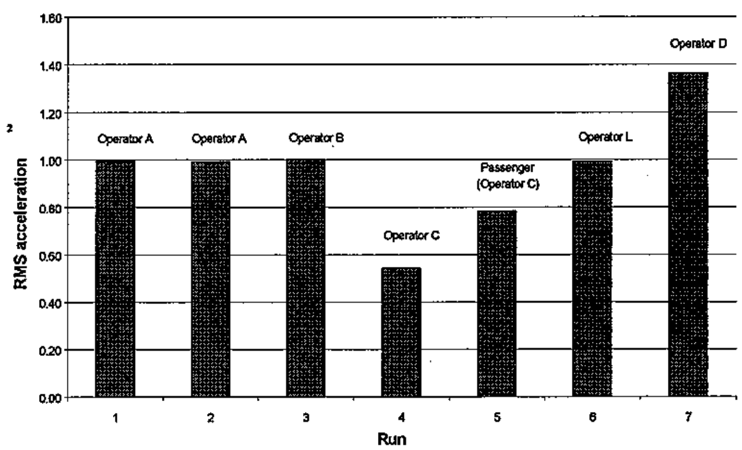
6. *Driver skills and awareness*
    - Speed of travel (underground mine rail transport – see Figure 11, Results)
    - Inexperienced operators
    - Being a passenger in 'troop carriers' (drivers appear to have no indication of the roughness of the ride for the passengers, particularly when they are sitting sideways and unable to brace themselves).

At all facilities operators expressed preferences for different vehicles. However, probably due to drivers' experience and skills and the working conditions, these differences did not show clearly in this analysis.

The numbers of readings were insufficient to confirm if operators' techniques contributed to smoother rides. Some good comparative recordings of operators of rail vehicles have been made subsequently in underground mines (Figure 11 below). The only difference in these rides was time, which varied between 13 minutes (Operator D), 15 minutes (Operators A and B) and 18 minutes (Operator C) on the same run. The fastest run was significantly rougher than the slowest run.

However, the amount of increase in vibration with speed will vary depending on the effectiveness on the vehicle and seat suspension.

Figure 11 - Underground rail personnel transport, combined RMS value for each run



A range of vehicles was measured and the type of work varied considerably; for instance between the dozers and the trucks. The range of factors that could have been measured far exceeded the time available to do so.

In summary, three major factors appear to be the sources of most vibration, and particularly jolts and jars (Figure 12 below). 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. These are:

- ◊ well maintained roads/surfaces
- ◊ appropriate vehicle suspension including correct tyres and tyre pressures
- ◊ 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

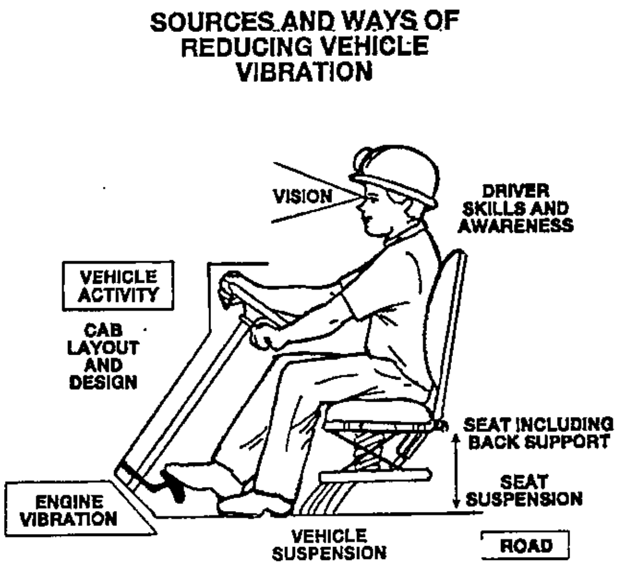


Figure 12.

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

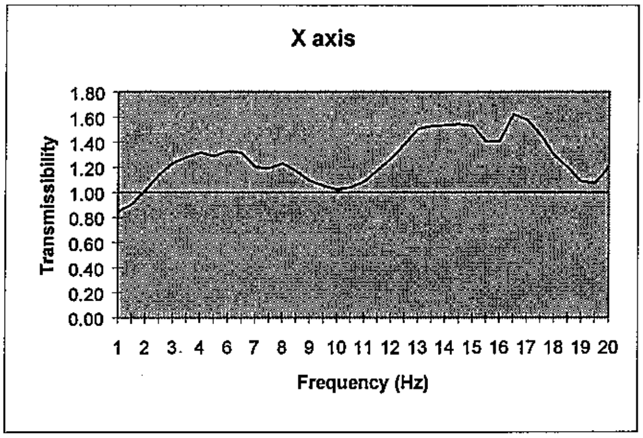
While there were not enough data to determine statistically the contribution of different factors, these findings suggest that these factors were the most important factors contributing to improved ride quality.

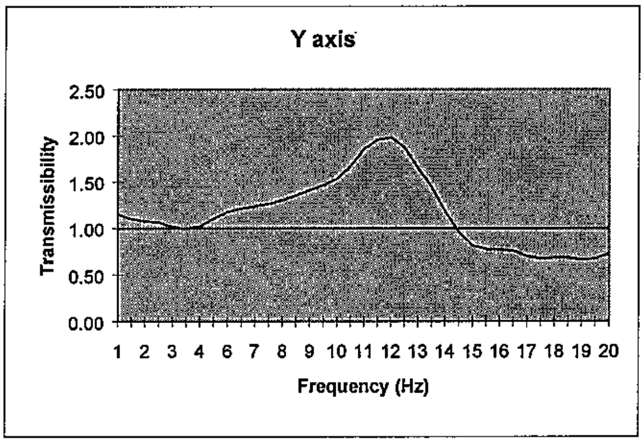
7.9 Seat Damping Performance

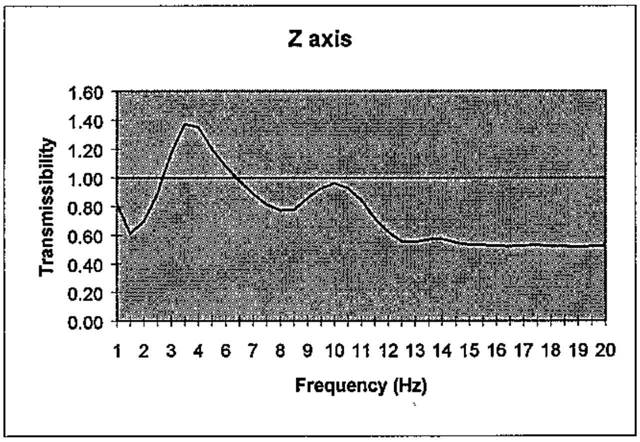
7.9.1 Transmissibility

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 track dozer seat across the frequencies up to 20 Hz 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. Unfortunately, due to seat resonance, the vibration transmitted through the seat may be amplified at certain frequencies. This commonly occurs around 2 - 4 Hz in the z-axis. Thus they will increase vibration exposure at these frequencies. For example, the data for the dozer ride (ripping and pushing coal), in Figure 13 there is amplification of the vibration in the z-axis, which has its maximum at about 3.5 Hz. The chart shows that beyond about 6 Hz, the seat is reducing vibration levels transmitted to the driver. The x-axis shows amplification of the vibration levels transmitted to the driver at all frequencies above 2 Hz indicating a lack of damping in the forward to back seat movement. Performance in the y-axis is also poor because the seat is increasing the vibration levels up to about 15 Hz.

Figure 13. Transmissibility Chart for seat in track dozer pushing and ripping coal







7.9.2 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:

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

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 4 (Results). Most seats performed well in the z-axis with fairly good vibration attenuation achieved for the excavator, dozers, and dump trucks. Manhaul (driver) and loader seats achieved some attenuation in the z-axis. Water trucks, fitter's vehicles and graders on average amplified the vibration level in the z- axis. With the exception of dump trucks all seats performed poorly in the x- and y-axes giving average SEAT values above 1.0 in most cases.

Worst results were achieved for manhaul passenger and driver seats. The performance of different makes and models of seats in this study could not be differentiated by these tests. This comparison would require controlled testing conducted on a representative test track.

The results indicate that seating does not (and perhaps cannot) solve all the vibration problems. More might be gained from improving cab design and better-engineered 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.

7.10 Operators' ratings of ride

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

- Overall 71.6% of operators rated the road conditions as good or average

- At one mine no one rated the roads as good with over half of the operators rating the roads as poor.
- The rides that were measured were considered to be relatively smooth or average by 84.2% of operators. Our data indicate that these rides were generally much rougher than the operators reported.

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

There was a poor correlation between operators' ratings of the ride using the British Standards Institution (BSI) rating scale (Figure 5, Methods) and the measured vibration on all vehicles. Fifty-eight participants out of 74 (78.3%) described their ride as not uncomfortable or a little uncomfortable (Table A5, Appendix 1) indicating a weighted r.m.s. value of 0.63m/s^2 or less on the BSI Scale. When compared with the measured results only 28 rides of the 74 rides (37.8%) were at or below 0.63 m/s^2 and would be classified as not or a little uncomfortable. Therefore most 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. 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.

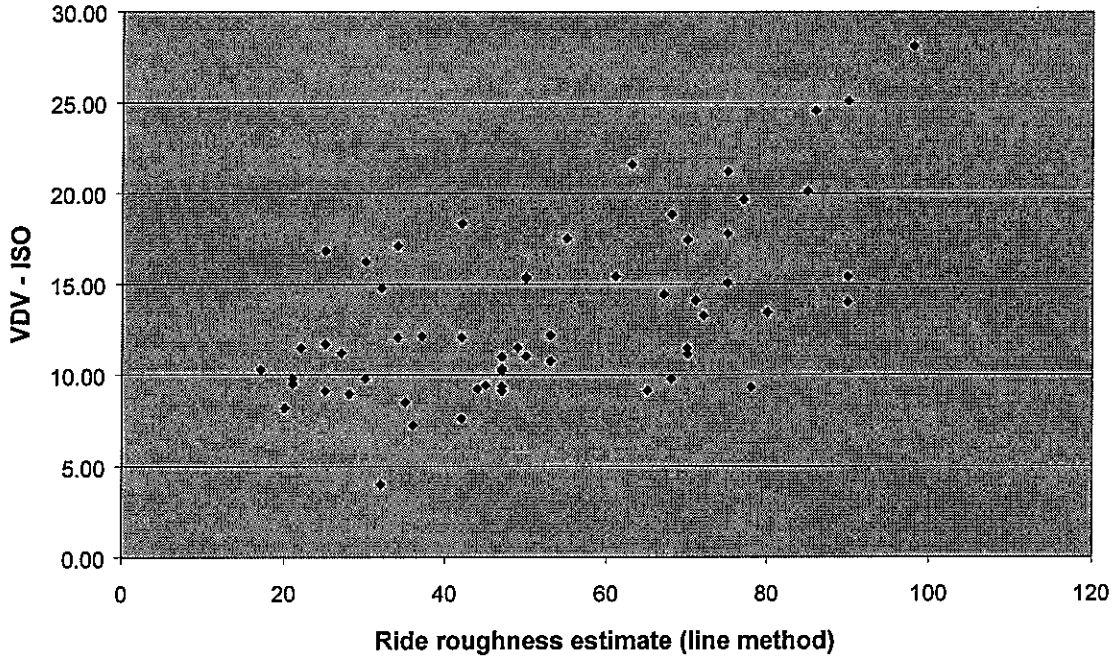
If the word 'rough' is substituted for 'uncomfortable', as it was in some of the later interviews at underground mines, there seems to be a slightly better correlation with the measured vibration readings.

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

The simple rating scale (Figure 6, Methods) yielded better results. The VDV correlated moderately well (r=0.61) 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 A5 (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



7.11 Summary of results

1. The exposure to whole-body vibration (WBV) experienced by operators of most vehicles at open-cut mines and the coal loader was found to be within permissible times for health criteria for an eight hour shift according to the Australian Standard AS 2670.1 - 1990. However, the fatigue (*Fatigue decreased proficiency boundary*) limits ranged on average from 2.5 hours for rubber tyred dozers, 4 hours for fitter's vehicles, track dozers, graders and manhaul passengers and 8 hours or more for loaders, water carts, manhaul drivers, dump trucks and excavator.

2. 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 dump trucks, water

trucks and the excavator exceeded this crest factor limit. Therefore this Standard may not be valid when used to analyse these rides.

3. 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.

4. All vehicles except for the excavator reached the International Standard (r.m.s. criteria) 'caution zone' on average in less than 8 hours. Fitter's vehicles, loaders, manhaul passengers, track dozers and rubber tyred dozers on average reached the 'likely health risk zone' in less than 8 hours using the r.m.s. criteria.

5. When VDV criteria (International Standard) are applied, average rides for all vehicles except the excavator reached the caution zone in less than 8 hours and all except most water trucks, dump trucks and the excavator reached it in less than 4 hours. In terms of the VDV 'likely health risk' criteria rubber tyred dozers, manhaul passengers, fitter's vehicles and half the track dozer rides reached this limit in less than 8 hours.

6. When the British Standard VDV criteria are applied, manhaul passengers, rubber tyred dozers, track dozers, and fitter's vehicles on average gave rides that reached the 'action level'(15m/sec$^{1.75}$) in less than 8 hours.

7. The VDVs varied widely. All rides in manhauls (passengers), fitter vehicles and rubber-tyred dozers, and in most track dozers produced high VDVs (above 15m/sec$^{1.75}$). Some rides in loaders, graders and manhauls (drivers) gave high values while no trucks exceeded this value for an 8-hour shift. Track dozers ripping, manhaul rides (with troop carrier style seating for passengers) and a fitter's vehicle were worst, giving very high VDVs of over 25.

8. 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).

9. 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.

10. There was a poor correlation between operators' ratings of the ride using the British Standards Institution rating scale and the measured vibration on all vehicles. The simple rating scale yielded better results. The VDV correlated moderately well (r=0.61) with the subjective rating by operators. Most operators and some passengers underrated the roughness of most rides. The roughest rides were reported in dozers and a manhaul (Tables A5, Appendix 1).

11. Fifty-eight of the 69 participants (84%) reported some musculoskeletal disorders (sprains and strains, aches and pains) in the previous 12 months which they believed were related to what they did at work. Twenty-four (34.8%) and 18 (26%) participants reported low back pain and neck pain respectively in the last week. Low back pain (59 or 85.5%) and/or neck pain (39 or 56.5%) were the most commonly reported disorders in the previous 12 months. (Tables 5, 6 Results). However, most operators had not taken time off work for these complaints because they did not consider their symptoms severe enough to warrant it.

12. Most seats performed well in the z-axis (up/down), especially the seats in the dozers. However, only the seats in the dump trucks performed consistently well in the x-axis (fore/aft). No seats performed well in all three axes and most performed poorly in the y-axis (side to side) (Table A4, Results).

13. The results indicate that a range of factors is likely to contribute to high VDV values. 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.

14. The results indicate that seating does not solve all the vibration problems. Too much may be expected from the seat while the basic design of the vehicle remains unchanged. However, the manufacturers must carefully consider the shape of the seat and backrest (particularly the lumbar support) as these are believed to be important in reducing the detrimental effects of vibration on the operator.

15. There was evidence that cab design increased operators' complaints of discomfort and reduced the benefits of good seating. In some vehicles (track dozers and graders in particular) the location of controls and the need to see behind or down to the front in order to see clearly meant that operators adopted awkward and potentially damaging postures.

16. Unrelieved sitting posture (like other postures) leads to increased reports of musculoskeletal discomfort and disorders. This is particularly the case with truck drivers. Operators should be encouraged to take whatever opportunities they can to get out of their seats and move around during a working day. Five minutes every half hour or so is probably sufficient to reduce discomfort to a tolerable level during an eight-hour shift. The more varied the working postures and movements the less likely operators are to experience symptoms of strain.

7.12 Factors for consideration

7.12.1 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 reportedly felt by operators. However, the requirement for operators to turn and look behind them (dozers) or to look down in front (graders) clearly accentuated discomfort due to low back or neck disorders. Serious consideration should be given to improving cab design so that the operator can see clearly and operate controls without having to adopt awkward and potentially damaging postures.

Although operating trucks seems to be the least hazardous job in terms of exposure to vibration in open-cut mines there are still a large number of truck drivers who report back pain and other musculoskeletal symptoms. One factor that is different for truck drivers is the unrelieved nature of the work, which is also very repetitive. Despite the obvious discomfort many operators of dozers, loaders and graders reported, most preferred these vehicles largely because of the variety of work they encompassed. Also it was observed that operators of vehicles other than trucks had more flexibility in their work routines, which allowed for more regular work breaks.

As mentioned in the Introduction 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 it is advisable that all operators take whatever opportunities they can within their work routines to get out of their seats and move around. Five minutes every half hour or so is probably sufficient to reduce discomfort to a tolerable level although in shifts longer than eight hours breaks may need to be considerably longer than this.

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, however, 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. The first 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 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. This is a straight forward situation where cause and effect are seen to be linked.

The third situation is where pain arises after an extended period of moderate jolts and jars such as bulldozer ripping. 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 peak limit. The contribution of prolonged lower 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. It would seem that most drivers can operate the machines they prefer and this is important for job satisfaction.

7.12.2 Adoption of the new 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; ensuring operators take regular short breaks out of the vehicle seat; 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.

7.12.3. 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:

- The Australian Standard permits apparently harmful WBV exposures and therefore is not helpful in injury prevention. However, 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 is more reliable to ask a person about the roughness of a 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.

- Improved cab design so that the operator can see clearly and operate controls without having to adopt awkward and potentially damaging postures has been achieved over the last few years but more could be done in this area. Improved vehicle suspension and/or isolation of the cab from vibration generated by the machine and its activity must be a next step.

- Much effort has gone into reducing whole-body vibration exposure by specialised seating manufacturers but it appears that seating cannot solve all the problems. In particular the problems of vibration in the x- and y-axes (fore/aft and side to side) will prove difficult to solve, as some researchers have already found. Some further effort from vehicle manufacturers is required. However, 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.

- 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.

- Speed can accentuate the ride roughness under certain 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.

- Training of operators and drivers in ways of avoiding potentially harmful vibration could prove useful and cost-effective. It appears that 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 suspension systems, is likely to be important in reducing the generation and transmission of vibration from the vehicles to the operator. Seating should be regarded as a major component and maintained as such by specialists.

7.13 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. *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 (a minimum of one metre clearance seat to roof, preferably more)
    - 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
- 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.

7.14 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.

8. 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 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 and would classify most rides as acceptable. 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. If the new International Standard is adopted in Australia, some recommended exposures would drop by more than two thirds. 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 good agreement with the operators' rating of rides and the VDV using the simple rating scale. 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. As well it is likely that unrelieved sitting posture (like other postures) leads to increased reports of musculoskeletal discomfort and disorders.

Most seats performed well in the z-axis (up/down), fewer performed consistently well in the x-axis (fore/aft) and most performed poorly in the y-axis (side to side). No seats performed well in all three axes. These results indicate 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 all appeared to contribute to what participants considered to be 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 speed limitations, effective road maintenance programs; appropriate design of vehicles; effective maintenance of vehicles and miscellaneous issues such as shot firing standards, regular rotation of operators on vehicles and regular breaks out of the seat/cab.

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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31 May 2000

9. ACKNOWLEDGEMENTS

The research team would like to thank the following people for their help, support and patience in the conducting of this Study:

- Mr Ken Cram (Liaison, JCB H&ST)
- Ms Sharon Buckley (Secretariat, JCB H&ST)
- Mr Ian Farrar (Chairman, JCB H&ST)
- Personnel at each of the facilities visited but most particularly:
  Mr Bob Brough (MTCL),
  Mr Warwick Lidbury (Bulga),
  Mr Brian Morgan (Howick),
  Ms Liz Sanderson and Ms Pam Simpson (Drayton),
  Mr Chris Manson (Hunter Valley No1),
  Mr Jeff Carlisle and Mr Toby Tyler (Cooranbong),
  Mr Ron Turner and Mr Dave McPherson (Ulan),
  Mr Owen Salisbury (Baal Bone) and
  Mr Stuart Waite and Mr John Spicer (Newstan).
- all staff and employees at the nine facilities who helped us in a number of ways as participants, drivers and technical support.
- Dr Michael Harrap, Dr Marat Tahtali and Mr Andrew Roberts, the Acoustic and Vibration Centre, Australian Defence Academy, Canberra
- Mr Anthony Rose, AR Technologies, Sydney
- Mr Gerard Fay, Technical Assistant for nine months

10. References and Bibliography

References

Andersson, G.B.J. (1981) Epidemiologic aspects on low-back pain in industry. *Spine*, 6 (1), 53-60.

Australian Road Research Board, (1993) *Unsealed Road Manual - Guidelines for Good Practice*, (Commonwealth Office of Local Government, Department of Defence - Army and the Australian Roads Research Board, Canberra).

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

BS 6841 : 1987, *Guide to measurement and evaluation of human exposure to whole-body mechanical vibration and repeated shock*. British Standards Institute, London.

Bongers, P.M.; Boshuizen, H.C.; Hulsof, C.T.J. & Koemeester, A.P.; (1988), "Back disorders in crane operators exposed to whole-body vibration", *Int Arch Occup Environ Health*, 60, 129-137

Bongers, P.M.; Boshuizen, H.C.; Hulsof, C.T.J. & Koemeester, A.P.; (1988), "Long-term sickness absence due to back disorders in crane operators exposed to whole-body vibration", *Int Arch Occup Environ Health*, 61. 59-64

Bongers, P.M., A.P Hulsof, C.T.J.; Dijkstra, L.; Boshuizen, H.C.; Groenhout, H.J.M. & Valken, E.; (1990), "Back pain and exposure to whole body vibration in helicopter pilots", *Ergonomics*,. 33 (8) 1007-1026

Bongers, P.M.; Boshuizen, H.C.; & Hulsof, C.T.J.; (1990), "Self-reported back pain in tractor drivers exposed to whole-body vibration", *Int Arch Occup Environ Health*, 62, 109-115

Boshuizen, H.C.; Hulsof, C.T.J. & Bongers, P.M.; (1990), "Long-term sick leave and disability pensioning due to back disorders of tractor drivers exposed to whole-body vibration", *Int Arch Occup Environ Health*, 62, 117-122

Boshuizen, H.C.; Bongers, P.M.; & Hulsof, C.T.J. (1992), "Self-reported back pain in fork-lift truck and freight-container tractor frivers exposed to whole-body vibration", *Spine*,17 (1) 59-65

Brendstrup, T. & Biering-Sorensen, F.; (1987), "Effect of fork-lift driving on low-back trouble", *Scand J Work Environ Health*, 13, 445-452

Burdof, A. & Zondervan, H.; (1990), "An epidemiological study of low-back pain in crane operators", *Ergonomics*, 33 (8) 981-987

Coffey and Partners Int. P/L, (1994), *Underground Roads Manual. Construction and Maintenance. Report No 2197/6-AA,* (C3026 AMIRA, Melbourne).

Cross, J., (1993), "Whole Body Vibration in Underground Mining", Department of Safety Science, University of NSW for the Department of Mineral Resources.

Cross, J. & Walters, M. (1994) " Vibration and jarring as a cause of back injury in the NSW coal mining industry", *Safety Science,* 17, 269-274.

Deacon, A.J, (1990) Report on Open-Cut Seating for Mobile Equipment Operators. Tarong Coal on behalf of the Queensland Coal Association, March.

Department of Mineral Resources (1995) Coal Mining Inspectorate *Guideline for Free Steered Vehicles, MDG No:1* , (NSW DMR).

Dupuis, H.; Hartung, E. & Haverkamp. M.; (1991), "Acute effects of transient vertical whole-body vibration", *Int Arch Occup Environ Health*, 63, 261-265

Dupuis, H., and Zerlett G., 1987, Whole-body vibration and disorders of the spine. *International Archives of Occupational and Environmental Health*, 59, 232-336.

Frymoyer, J., Pope, M., Clements, J., Wilder D., Macpherson, B., Ashikaga, T., (1983) Risk factors in low back pain, *Journal of Bone and Joint Surgery,* 65-A, 213-218.

Gagliardi, J.C.; Utt, W.K.; (1993), "Vibration testing of off-road vehicle seats", *US Bureau of Mines.* Pittsburgh, PA

Griffin, M.J., (1990) *Handbook of Human Vibration*, Academic Press Limited.

Griffin, M.; (1993), "Seminar on: Human vibrations - The effects of vibrations on people at work' Worksafe Australia, Acoustic and Vibration Centre (ADFA), La Trobe University.

Griffin M.J. and Whitham E.M. 1980a, Discomfort produced by impulsive whole-body vibration, *Journal of Acoustical Society of America,* 68:1277-1284

Griffin M.J. and Whitham E.M. 1980b, Time-dependency of whole-body vibration discomfort, *Journal of Acoustical Society of America,* 68:1522-1523

Hulsof, C. & van Zanten, V.; (1987), "Whole-body vibration and low-back pain", *Int Arch Occup Environ Health*, 59, 205-220

Hutton, S.G. & Brubaker, R.; (1982), "Vibration effects on mine workers", CIM Bulletin, February, 85-93

ISO/DIS 2631-1.2 - 1997, *International Standard. Mechanical vibration and shock - Evaluation of human exposure to whole-body vibration.* International Standards Office, Geneva.

Johanning, E.; (1991), "Back disorders and health problems among subway train operators exposed to whole-body vibration", *Scand J Work Environ Health*, 17, 414-9

Kelsey, J., and Hardy, J., 1975, Driving of motor vehicles as a risk factor for acute herniated lumbar disc, *American Journal of Epidemiology*, 102, 63-73.

Kjellberg, A. & Wikstrom, B.O.; (1985), "Whole-body vibration: exposure time and acute effects - a review", *Ergonomics*, 28 (3) 535-544

Kjellberg, A.; Wikstrom, B.O. & Dimberg, U.; (1985), "Whole-body vibration: exposure time and acute effects - experimental assessment of discomfort", *Ergonomics*, 28, (3) 545-554

Kjellberg, A. & Wikstrom, B.O.; (1987), "Acute effects of whole-body vibration", *Scand J Work Environ Health*, 13, 243-246

Love, A.C.; Unger, R.L.; Bobick, T.G. & Fowkes, R.S.; (1992), "A summary of current bureau research into the effects of whole-body vibration and shock on operators of underground mobile equipment", *US Bureau of Mines.* Pittsburgh, PA

McPhee B, (1993). *Ergonomics for the Control of Sprains and Strains in Mining.* Worksafe Australia and the Joint Coal Board, Sydney.

McPhee B, and Knowles J. (1992) Ergonomics in underground coal mining in NSW. Proceedings of the 28th Annual Conference of the Ergonomics Society of Australia, Melbourne, pp 252-257.

Oh, X. and Middlin, A., (1991), "Reduction of Personnel Vibration Hazards in Underground Coal Mines", National Energy Research, Development and Demonstration Program, Grant Report No. 1037 March 1991.

Oh, X. and Middlin, A., (1991), "Seating for Open-cut Moble Equipment Operators", Australian Coal Association Research Program, Grant Report No. 1339, August 1991.

Pelmear, P.L.; Roos, J.O. & Maehle, W.M.; (1992), "Occupationally-induced scleroderma", *J. Occup Med*, January, 20-25

Riihimaki, H.; Tola, S.; Videman, T. & Hanninen, K.; (1989), "Low-back pain and occupation. A cross-sectional questionnaire study of men in machine operating, dynamic physical work, and sedentary work", *Spine*, Vol. 14, No. 2, 204-209

Seidel, H. & Heide, R.; (1986), "Long-term effects of whole-body vibration: a critical survey of the literature", *Int Arch Occup Environ Health*, 58, 1-26

Seidel, H.; Bluethner, R. & Hinz, B.; (1986), "Effects of sinusoidal whole-body vibration on the lumbar spine: the stress-strain relationship", *Int Arch Occup Environ Health*, 57, 207-223

Village, J.; (1989) "Ergonomic and environmental assessment of haulage trucks for design improvements", *Proceedings of the Annual Conference of the Human Factors Association of Canada.*

Village, J.; Morrison, J.B. & Leong, D.K.N.; (1989), "Whole-body vibration in underground load-haul-dump vehicles", *Ergonomics*, 32 (10), 1167-1183

Westgaard, R. and Åaras, A., (1984) Postural strain as a causal factor in the development of musculoskeletal illness, *Applied Ergonomics*, 15, 162-174.

Wickstrom, G.; (1978), "Effect of work on degenerative back disease", *Scand J Work Environ Health*, Suppl 1, 1-12

Books, Standards and papers

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

BS 6841 : 1987, *Guide to measurement and evaluation of human exposure to whole-body mechanical vibration and repeated shock.* British Standards Institute, London.

Foster G., Harrap M, Long A. and Fay G., 1995. *A flexible system for measurement and analysis of human vibration data according to Australian and British Standards.* Proceedings of the Australian Institute of Occupational Hygiene Annual Conference, Adelaide, November, p152.

Griffin, M.J., 1990, *Handbook of Human Vibration*, Academic Press Limited

Griffin, M. J, 1993a, *Vibration and Health, Proceedings of a Seminar on Human Vibrations. The Effect of Vibrations on People at Work,* Worksafe Australia, Acoustics and Vibration Centre (ADFA), and La Trobe University, Sydney, Canberra and Melbourne.

Griffin, M.J., 1993b, *Ride and Comfort in Vehicles, Proceedings of a Seminar on Human Vibrations. The Effect of Vibrations on People at Work,* Worksafe Australia, Acoustics and Vibration Centre (ADFA), and La Trobe University, Sydney, Canberra and Melbourne.

ISO/DIS 2631-1.2 - 1997, *International Standard. Mechanical vibration and shock - Evaluation of human exposure to whole-body vibration.* International Standards Office, Geneva.

McPhee B. (1992) Ergonomics Project (Application and evaluation of ergonomics in coal mines). Report to the National Energy Research, Development and Demonstration Council (NERDDC), sponsored by the Joint Coal Board of NSW and the National Institute of Occupational Health and Safety. 2 Volumes.

Proceedings of the International Conference on Whole-body Vibration Injuries. 1998, Journal of Sound and Vibration (Griffin M J and Bovenzi M Eds). Vol 215, No 4, pp 593 - 996.

Publications and presentations from the Vibration Project

** Copies are attached in Appendix 2*

1. Foster G., Harrap M, Long A. and Fay G. 1995. *A flexible system for measurement and analysis of human vibration data according to Australian and British Standards.* Proceedings of the Australian Institute of Occupational Hygiene Annual Conference, Adelaide, p152. *

2. Long, A., Foster G., Fay G. and McPhee B. 1995. *Measuring Whole-Body Vibration Exposure in Mining.* Proceedings of the 31st Annual Conference of the Ergonomics Society of Australia, Adelaide, pp 29-36. *

3. McPhee B. 1995. *Review of Exposure to Whole-Body Vibration (WBV) and Back Disorders in Mineworkers.* Proceedings of the 31st Annual Conference of the Ergonomics Society of Australia, Adelaide, pp 37-44. *

4. McPhee BJ, Long AF, Foster G, Fay G. 1996 *Exposure to Whole-body Vibration (WBV) and Back Disorders in Mineworkers.* Abstract. Proceedings of the 25th Triennial International Congress on Occupational Health, Stockholm, Sweden, Vol 2, p 341.

5. McPhee B. 1997. *Seating, comfort and injuries in off-road mining vehicles.* Proceedings of the 13th Triennial Congress of the International Ergonomics Association, Tampere, Finland, Vol 4, pp 84-86.

6. McPhee B., Foster G. and Long A. 1998. *A comparison of rides on different vehicles using three current Standards for Whole-body Vibration (WBV) exposures.* Proceedings of the Annual Conference of the Ergonomics Society of Australia, October, Melbourne, pp 46-53. *

7. McPhee B., Foster G. and Long A. 1999. *Rough rides on mining vehicles - preliminary results of a study of Whole-body Vibration (WBV) in underground and open-cut coal mines in NSW.* Presentation at the Project Results Seminar conducted by the Joint Coal Board Health and Safety Trust, Belmont, NSW.

8. McPhee B., Foster G. and Long A. 1999. *A comparison of rides on coal mining vehicles using two Standards for Whole-body Vibration - Preliminary results.* Presentation at the NSW Mining and Quarrying Industry Occupational Health and Safety Conference, Terrigal, NSW.

9. McPhee B., Foster G. and Long A. 1999. *Assessment of whole-body vibration exposure using Australian and International Standards – a case study.* Proceedings of the Annual Conference of the Ergonomics Society of Australia, October, Perth, pp 99-106. *

APPENDIX 1

APPENDIX 1 TABLES

Table A1.1 Australian Standard Assessment: Third-octave method, permissible time limits

(ranked according to increasing permissible time - fatigue criteria, ***worst to best***)

Sample	Activity	Comb. axis RMS acceleration	Boundary exceeded fatigue (hr)	Boundary exceeded health (hr)	Implied exposure limit fatigue (hr)	Implied exposure limit health (hr)	Interpolated limits fatigue (hr)	Interpolated limits health (hr)	Worst axis
Rubber tyred dozers									
4,13	travel, push road	1.36	4	8	2.5	4	3.0	8.0	x
4,14	pushing overburden	1.50	4	16	2.5	8	3.0	10.0	x
3,15	overburden shovel	1.23	4	16	2.5	8	4.0	13.0	y
	Geometric mean	***1.36***	***4***	***13***	***2.5***	***6***	***3.3***	***10.1***	
	Minimum value	***1.23***	***4***	***8***	***2.5***	***4***	***3.0***	***8.0***	
	Maximum value	***1.50***	***4***	***16***	***2.5***	***8***	***4.0***	***13.0***	
Fitters vehicle									
5,08	maintenance run	1.35	8	16	4	8	4.6	13.1	z
2,30	maintenance run	0.98	8	16	4	8	4.9	13.6	z
4,17	maintenance run	0.84	8	24	4	16	7.5	20.5	z
5,03	maintenance run	0.84	8	24	4	16	7.5	20.5	z
3,08	maintenance run	0.81	16	24	8	16	10.6	24.0	z
	Geometric mean	***0.94***					***6.7***	***17.8***	
	Minimum value	***0.81***					***4.6***	***13.1***	
	Maximum value	***1.35***					***10.6***	***24.0***	
Track dozers									
5,05	pushing o/b	1.48	2.5	8	1	4	2.0	7.0	z
4,04	ripping & rushing partings	1.98	4	16	2.5	8	4.0	13.0	x
4,15	ripping & pushing	1.66	4	16	2.5	8	4.0	13.0	x
4,08	ripping & pushing hard rock	1.79	8	16	4	8	5.0	14.0	x
5,09	pushing soft o/b	1.34	8	16	4	8	5.0	13.0	z
2,20	pushing mud	1.17	8	16	4	16	6.0	16.0	z
2,25	pushing overburden	1.40	8	16	4	16	6.0	16.0	x
2,28	ripping hard coal	1.26	8	16	4	16	6.0	16.0	z
3,21	battering	1.04	8	24	4	16	6.0	17.0	z
5,06	roadmaking, R & P o/b	1.11	8	16	4	16	6.0	16.0	z
2,10	ripping & pushing coal	1.13	8	24	4	16	6.8	19.0	x
1,03	coal heap stacking	1.01	8	24	4	16	7.3	20.4	x
1,15	loading train	1.01	8	24	4	16	7.8	21.5	z
3,11	pushing & ripping o/b	1.08	8	24	4	16	8.0	22.0	z
2,05	ripping & pushing o/b	0.85	16	24	8	16	8.2	22.0	y
2,15	pushing coal	1.02	16	24	8	16	9.0	23.0	x
1,02	coal heap stacking	0.83	16	24	8	16	10.9	22.4	x
3,16	pushing partings	0.95	16	24	8	24	11.0	24.0	z
1,04	coal heap stacking	0.72	16	24	8	16	11.1	20.5	z
2,19	pushing overburden	0.97	16	24	8	24	12.0	24.0	x
3,03	overburden	0.62	16	24	16	24	16.0	24.0	z
2,09	pushing overburden	0.53	24	24	16	24	22.0	24.0	z
	Geometric mean	***1.08***	***9***	***20***	***5***	***14***	***7.2***	***17.8***	
	Minimum value	***0.53***	***3***	***8***	***1***	***4***	***2.0***	***7.0***	
	Maximum value	***1.98***	***24***	***24***	***16***	***24***	***22.0***	***24.0***	

x-axis = front to back; y-axis = side to side, z-axis = up and down

* all axes are the same

APPENDIX 1 TABLES

Table A1.2 Australian Standard Assessment: Third-octave method, permissible time limits

(ranked according to increasing permissible time - fatigue criteria, ***worst to best***)

Sample	Activity	z-axis RMS acceleration	Boundary exceeded fatigue (hr)	Boundary exceeded health (hr)	Implied exposure limits fatigue (hr)	Implied exposure limits health (hr)	Interpolated limits fatigue (hr)	Interpolated limits health (hr)	Worst axis
Graders									
3,19	grading roads	1.11	4	16	2.5	8	3.7	10.4	z
3,23	grading roads	1.14	4	16	2.5	8	3.7	10.0	z
3,17	grading roads	1.04	8	16	4	8	4.8	13.6	z
4,03	grading roads	1.00	8	24	4	16	6.8	18.0	z
2,26	grading roads	0.40	24	24	16	24	17.4	24.0	z
2,33	grading roads	0.38	24	24	16	24	18.3	24.0	z
	Geometric mean	***0.76***					***7.2***	***15.7***	
	Minimum value	***0.38***					***3.7***	***10.0***	
	Maximum value	***1.14***					***18.3***	***24.0***	
Manhaul Passenger									
2,17	passenger	1.22	8	16	4	8	5.7	15.4	z
2,27	passenger	1.17	8	16	4	8	6.0	16.0	z
2,32	passenger	1.14	8	24	4	16	6.3	16.7	z
2,31	passenger	1.09	8	24	4	16	6.7	17.9	z
4,19	passenger	0.44	24	24	16	24	20.5	24.0	z
	Geometric mean	***0.95***					***7.8***	***17.8***	
	Minimum value	***0.44***					***5.7***	***15.4***	
	Maximum value	***1.22***					***20.5***	***24.0***	
Loaders									
5,04	push, travel, dump o/	1.16	8	16	4	8	5.2	15.1	y
5,07	loading overburden	0.97	8	24	4	16	7.2	20.1	x
2,21	loading coal	0.85	8	24	4	16	7.7	21.4	x
3,20	loading coal	0.82	16	24	8	16	8.2	22.2	x
3,22	loading overburden	0.81	16	24	8	16	9.4	23.1	y
2,22	loading coal	0.76	16	24	8	24	10.5	24.0	x
3,18	loading coal	0.74	16	24	8	24	10.8	24.0	y
5,02	loading coal	0.75	16	24	8	24	11.4	24.0	y
2,14	loading coal	0.68	16	24	8	24	13.7	24.0	x
	Geometric mean	***0.83***					***9.0***	***21.8***	
	Minimum value	***0.68***					***5.2***	***15.1***	
	Maximum value	***1.16***					***13.7***	***24.0***	
Watercart									
4,16	watering roads	0.69	8	24	4	16	7.6	20.9	z
2,29	watering roads	0.42	16	24	8	24	15.9	24.0	z
	Geometric mean	***0.75***					***8.8***	***18.9***	
	Minimum value	***0.22***					***3.7***	***10.0***	
	Maximum value	***1.16***					***24.0***	***24.0***	
Manhaul Driver									
2,16	driver	0.74	16	24	8	16	10.0	23.8	z
3,09	driver	0.69	16	24	8	16	14.4	24.0	z
	Geometric mean	***0.71***					***12.0***	***23.9***	
	Minimum value	***0.69***					***10.0***	***23.8***	
	Maximum value	***0.74***					***14.4***	***24.0***	

x-axis = front to back; y-axis = side to side, z-axis = up and down

* all axes are the same

APPENDIX 1 TABLES

Table A1.3 Australian Standard Assessment: Third-octave method, permissible time limits

(ranked according to increasing permissible time - fatigue criteria, ***worst to best***)

Sample	Activity	Z-axis RMS acceleration	Boundary exceeded fatigue (hr)	Boundary exceeded health (hr)	Implied exposure limits fatigue (hr)	Implied exposure limits health (hr)	Interpolated limits fatigue (hr)	Interpolated limits health (hr)	Worst axis
Dump trucks									
4,02	loading overburden	0.52	8	24	4	16	7.9	21.9	z
2,08	overburden & coal	0.67	8	24	4	16	8.0	22.1	z
5,01	loading overburden	0.48	16	24	8	24	11.1	24.0	z
2,24	loading overburden	0.52	16	24	8	24	11.3	24.0	z
2,07	loading overburden	0.51	16	24	8	24	14.8	24.0	z
2,11	loading topsoil	0.41	24	24	16	24	16.5	24.0	z
2,13	loading coal	0.39	24	24	16	24	16.8	24.0	z
2,06	loading overburden	0.40	24	24	16	24	16.8	24.0	z
3,13	loading overburden	0.42	24	24	16	24	18.6	24.0	z
3,01	loading overburden	0.43	24	24	16	24	18.8	24.0	z
3,14	loading overburden	0.46	24	24	16	24	19.1	24.0	z
3,02	loading overburden	0.47	24	24	16	24	19.4	24.0	z
2,04	loading coal	0.35	24	16	16	24	19.8	24.0	z
4,01	loading overburden	0.39	24	24	16	24	20.0	24.0	z
4,11	loading coal	0.40	24	24	16	24	20.3	24.0	z
2,12	loading coal	0.38	24	24	16	24	20.9	24.0	z
3,07	loading overburden	0.43	24	24	16	24	21.2	24.0	z
3,05	loading overburden	0.37	24	24	16	24	21.3	24.0	z
3,10	loading overburden	0.36	24	24	16	24	21.4	24.0	z
2,18	loading coal	0.37	24	24	16	24	23.3	24.0	z
2,02	overburden & coal	0.27	24	24	24	24	24.0	24.0	z
3,12	loading overburden	0.27	24	24	24	24	24.0	24.0	z
4,12	loading overburden	0.34	24	24	24	24	24.0	24.0	z
	Geometric mean	***0.41***					***17***	***24***	
	Minimum value	***0.27***					***8***	***22***	
	Maximum value	***0.67***					***24***	***24***	
Excavator									
3,04	loading overburden	0.22	24	24	24	24	24.0	24.0	x

x-axis = front to back; y-axis = side to side, z-axis = up and down

* all axes are the same

APPENDIX 1 TABLES

Table A2.1 British Standard Assessment: Vibration Dose Values (VDV)

(ranked according to increasing time to reach VDV action level - ***worst to best***)

Sample	Activity	VDV 8hr (full shift) (m/sec$^{1.75}$)	Time to reach action limit** (hr)	Axis
Manhaul passenger				
2,27	passenger	26.95	0.77	z
2,31	passenger	24.56	1.11	z
2,32	passenger	24.03	1.21	z
2,17	passenger	23.24	1.39	z
4,19	passenger	23.16	1.41	z
	Geometric mean	***26.95***	***1.41***	
	Minimum value	***23.16***	***0.77***	
	Maximum value	***26.95***	***1.41***	
Rubber tyred dozers				
4,13	travel, push road	24.50	1.12	combined
4,14	pushing overburden	21.03	2.07	combined
3,15	o/b shovel	19.76	2.66	combined
	Geometric mean	***21.67***	***1.84***	
	Minimum value	***19.76***	***1.12***	
	Maximum value	***24.50***	***2.66***	
Track dozers				
4,08	ripping & pushing hard rock	28.44	0.62	combined
5,05	pushing o/b	26.39	0.84	combined
4,04	ripping & rushing partings	25.47	0.96	combined
4,15	ripping & pushing	21.41	1.93	combined
5,09	pushing soft o/b	21.32	1.96	combined
2,25	pushing overburden	19.35	2.89	combined
2,20	pushing mud	19.31	2.91	combined
5,06	roadmaking, R & P o/b	18.04	3.83	combined
2,28	ripping hard coal	17.87	3.98	combined
1,15	loading train	17.16	4.09	combined
1,03	coal heap stacking	17.09	4.16	combined
3,21	battering	17.37	4.45	combined
2,10	ripping & pushing coal	16.53	5.43	combined
2,15	pushing coal	15.88	6.37	combined
3,11	pushing & ripping o/b	15.20	7.59	combined
1,02	coal heap stacking	14.43	8.18	combined
3,16	pushing partings	14.33	9.61	combined
2,19	pushing overburden	14.15	10.10	combined
2,05	ripping & pushing o/b	13.12	13.66	combined
1,04	coal heap stacking	11.9	17.67	combined
3,03	overburden	11.54	22.88	combined
2,09	pushing overburden	11.18	25.95	combined
	Geometric mean	***17.05***	***4.68***	
	Minimum value	***11.18***	***0.62***	
	Maximum value	***28.44***	***25.95***	

APPENDIX 1 TABLES

Table A2.2 British Standard Assessment: Vibration Dose Values (VDV)

(ranked according to increasing time to reach VDV action level - ***worst to best***)

Sample	Activity	VDV 8hr (full shift) ($m/sec^{1.75}$)	Time to reach action limit** (hr)	Axis
Fitters vehicle				
5,08	maintenance run	29.90	0.51	z
2,30	maintenance run	17.98	3.88	z
5,03	maintenance run	17.42	4.39	z
3,08	maintenance run	16.57	5.37	z
4,17	maintenance run	16.32	5.71	z
	Geometric mean	***17.98***	***5.37***	
	Minimum value	***16.32***	***0.51***	
	Maximum value	***29.90***	***5.71***	
Manhaul driver				
2,16	driver	15.93	6.28	z
3,09	driver	14.14	10.14	z
	Geometric mean	***15.93***	***10.14***	
	Minimum value	***14.14***	***6.28***	
	Maximum value	***15.93***	***10.14***	
Loaders				
5,07	loading overburden	25.58	0.95	comb
5,04	push, travel, dump o/b	17.43	4.39	comb
2,21	loading coal	13.30	12.96	comb
2,22	loading coal	12.08	18.99	comb
3,22	loading overburden	11.87	20.38	comb
3,20	loading coal	11.84	20.64	comb
5,02	loading coal	11.60	22.35	comb
3,18	loading coal	11.40	23.95	comb
2,14	loading coal	11.15	26.23	comb
	Geometric mean	***13.49***	***12.21***	
	Minimum value	***11.15***	***0.95***	
	Maximum value	***25.58***	***26.23***	
Graders				
4,03	grading roads	14.12	10.19	comb
3,23	grading roads	14.04	10.44	comb
3,17	grading roads	13.67	11.59	comb
3,19	grading roads	13.10	13.74	comb
2,33	grading roads	9.66	46.59	comb
2,26	grading roads	9.48	50.22	comb
	Geometric mean	***12.17***	***18.46***	
	Minimum value	***9.48***	***10.19***	
	Maximum value	***14.12***	***50.22***	

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Table A2.3 British Standard Assessment: Vibration Dose Values (VDV)

(ranked according to increasing time to reach VDV action level - ***worst to best***)

Sample	Activity	VDV 8hr (full shift) ($m/sec^{1.75}$)	Time to reach action limit** (hr)	Axis
Watercart				
4,16	watering roads	10.68	31.11	comb
2,29	watering roads	9.10	59.10	comb
	Geometric mean	***9.86***	***42.88***	
	Minimum value	***9.10***	***31.11***	
	Maximum value	***10.68***	***59.10***	
Dump trucks				
2,24	loading overburden	12.98	14.25	z
2,08	overburden & coal	12.58	16.19	z
4,02	loading overburden	11.34	24.46	z
4,01	loading overburden	10.94	28.30	z
2,11	loading topsoil	10.30	35.92	z
2,12	loading coal	10.07	39.40	z
2,07	loading overburden	9.93	41.59	z
3,02	loading overburden	9.80	43.92	z
2,13	loading coal	9.57	48.34	z
2,06	loading overburden	9.54	48.93	z
5,01	loading overburden	9.48	50.23	z
3,01	loading overburden	9.18	57.03	z
4,11	loading coal	9.11	58.88	z
4,12	loading overburden	9.09	59.28	z
3,13	loading overburden	8.93	63.72	z
2,04	loading coal	8.67	71.52	z
3,07	loading overburden	8.64	72.58	z
2,18	loading coal	8.59	74.40	z
3,14	loading overburden	8.40	81.27	z
3,05	loading overburden	7.97	100.49	z
3,10	loading overburden	7.45	131.45	z
3,12	loading overburden	6.86	182.54	z
2,02	overburden & coal	6.85	184.32	z
	Geometric mean	***9.28***	***54.5***	
	Minimum value	***6.85***	***14.3***	
	Maximum value	***12.98***	***184.3***	
Excavator				
3,04	loading overburden	4.04	1526.88	comb

APPENDIX 1 TABLES

Table A3.1 International Standard (ISO 2631-1.2): Caution Zone and Likely Health Risk Zone.

(ranked according to increasing time to reach caution zone-***worst to best***)

Sample	Activity	VDV comb-axis (m/sec$^{1.75}$)	Wt. RMS (comb) acceleration (m/s^2)	Axis	(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)
Rubber tyred dozers								
3,15	o/b shovel	19.80	1.51	combined	0.57	2.29	0.27	4.35
4,13	travel, push road	24.59	1.62	combined	0.50	2.00	0.11	1.83
4,14	pushing overburden	21.23	1.73	combined	0.43	1.74	0.21	3.29
	Geometric mean	***21.78***	***1.62***		***0.50***	***2.00***	***0.19***	***2.97***
	Minimum value	***19.80***	***1.51***		***0.43***	***1.74***	***0.11***	***1.83***
	Maximum value	***24.59***	***1.73***		***0.57***	***2.29***	***0.27***	***4.35***
Track dozers								
2,20	pushing mud	18.84	2.22	combined	0.26	1.06	0.33	5.31
4,04	ripping & rushing partings	25.02	2.17	combined	0.28	1.11	0.11	1.70
4,08	ripping & pushing hard rock	28.13	2.10	combined	0.30	1.19	0.07	1.07
4,15	ripping & pushing	21.61	1.86	combined	0.38	1.52	0.19	3.07
5,05	pushing o/b	27.35	1.60	combined	0.51	2.05	0.07	1.19
2,25	pushing overburden	19.67	1.58	combined	0.53	2.10	0.28	4.46
5,09	pushing soft o/b	21.72	1.50	combined	0.58	2.34	0.19	3.00
2,28	ripping hard coal	18.63	1.40	combined	0.67	2.67	0.35	5.54
2,10	ripping & pushing coal	16.83	1.25	combined	0.83	3.33	0.52	8.32
3,11	pushing & ripping o/b	15.33	1.23	combined	0.86	3.43	0.76	12.10
5,06	roadmaking, R & P o/b	18.34	1.23	combined	0.86	3.45	0.37	5.91
3,21	battering	17.44	1.21	combined	0.89	3.55	0.45	7.23
2,15	pushing coal	16.24	1.18	combined	0.94	3.76	0.60	9.61
2,19	pushing overburden	14.01	1.15	combined	0.98	3.93	1.08	17.32
3,16	pushing partings	14.43	1.08	combined	1.12	4.48	0.96	15.42
1,15	loading train	17.16	1.01	combined	1.30	5.10	1.12	17.92
1,03	coal heap stacking	17.09	1.01	combined	1.30	5.10	0.84	13.50
2,05	ripping & pushing o/b	13.45	0.96	combined	1.41	5.65	1.28	20.42
1,02	coal heap stacking	14.43	0.83	combined	1.90	7.60	0.96	15.39
1,04	coal heap stacking	11.9	0.72	combined	2.50	10.00	2.09	33.43
3,03	overburden	11.47	0.71	combined	2.61	10.43	2.41	38.62
2,09	pushing overburden	11.15	0.63	combined	3.34	13.36	2.70	43.22
	Geometric mean	***17.17***	***1.23***		***0.87***	***3.48***	***0.51***	***8.19***
	Minimum value	***11.15***	***0.63***		***0.26***	***1.06***	***0.07***	***1.07***
	Maximum value	***28.13***	***2.22***		***3.34***	***13.36***	***2.70***	***43.22***

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Table A3.2 International Standard (ISO 2631-1.2): Caution Zone and Likely Health Risk Zone.

(ranked according to increasing time to reach caution zone - ***worst to best***)

Sample	Activity	VDV comb-axis (m/sec$^{1.75}$)	Wt. RMS (comb) acceleration (m/s^2)	Axis	(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)
Manhaul passenger								
2,17	passenger	25.12	1.21	z	0.89	3.55	0.10	1.68
2,27	passenger	28.57	1.30	z	0.77	3.09	0.06	1.00
2,31	passenger	25.63	1.16	z	0.97	3.89	0.10	1.55
2,32	passenger	25.67	1.18	z	0.95	3.78	0.10	1.54
4,19	passenger	23.91	0.50	z	5.33	21.30	0.13	2.04
	Geometric mean	**25.74**	**1.01**		**1.27**	**5.10**	**0.10**	**1.52**
	Minimum value	**23.91**	**0.50**		**0.77**	**3.09**	**0.06**	**1.00**
	Maximum value	**28.57**	**1.30**		**5.33**	**21.30**	**0.13**	**2.04**
Loaders								
2,14	loading coal	11.20	0.77	combined	2.21	8.85	2.66	42.52
2,21	loading coal	13.24	1.00	combined	1.30	5.22	1.36	21.72
2,22	loading coal	12.16	0.89	combined	1.66	6.66	1.91	30.52
5,02	loading coal	11.68	0.91	combined	1.57	6.28	2.25	35.93
5,04	push, travel, dump o/b	17.78	1.29	combined	0.78	3.13	0.42	6.69
5,07	loading overburden	15.38	1.10	combined	1.07	4.28	0.75	11.95
3,18	loading coal	11.50	0.86	combined	1.76	7.05	2.39	38.20
3,20	loading coal	12.12	0.96	combined	1.42	5.66	1.94	31.00
3,22	loading overburden	12.17	0.93	combined	1.50	5.98	1.90	30.46
	Geometric mean	**12.88**	**0.96**		**1.42**	**5.68**	***1.52***	***24.27***
	Minimum value	**11.20**	**0.77**		**0.78**	**3.13**	***0.42***	***6.69***
	Maximum value	**17.78**	**1.29**		**2.21**	**8.85**	**2.66**	***42.52***
Fitters vehicle								
2,30	maintenance run	20.14	0.89	z	1.63	6.52	0.25	4.06
3,08	maintenance run	17.50	0.87	z	0.64	2.56	0.45	7.12
5,03	maintenance run	18.35	0.83	z	1.90	7.60	0.37	5.89
5,08	maintenance run	31.62	1.43	z	1.74	6.94	0.04	0.67
4,17	maintenance run	17.80	0.82	z	1.95	7.80	0.42	6.66
	Geometric mean	**20.52**	**0.94**		**1.46**	**5.85**	**0.24**	**3.77**
	Minimum value	**17.50**	**0.82**		**0.64**	**2.56**	**0.04**	**0.67**
	Maximum value	**31.62**	**1.43**		**1.95**	**7.80**	**0.45**	**7.12**

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Table A3.3 International Standard (ISO 2631-1.2): Caution Zone and Likely Health Risk Zone.

(ranked according to increasing time to reach caution zone-***worst to best***)

Sample	Activity	VDV comb-axis (m/sec$^{1.75}$)	Wt. RMS (comb) acceleration (m/s^2)	Axis	(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)
Manhaul driver								
2,16	driver	17.09	0.73	z	2.42	9.68	0.49	7.83
3,09	driver	14.77	0.73	z	2.46	9.85	0.88	14.05
	Geometric mean	**15.89**	**0.73**		**2.44**	**9.76**	**0.66**	**10.49**
	Minimum value	**14.77**	**0.73**		**2.42**	**9.68**	**0.49**	**7.83**
	Maximum value	**17.09**	**0.73**		**2.46**	**9.85**	**0.88**	**14.05**
Graders								
2,26	grading roads	9.81	0.58	combined	3.89	15.55	4.51	72.16
2,33	grading roads	9.79	0.51	combined	5.03	20.12	4.55	72.72
3,17	grading roads	15.42	0.63	z	3.34	13.38	0.74	11.82
3,19	grading roads	15.07	0.73	z	2.48	9.92	0.81	12.96
3,23	grading roads	16.19	0.72	z	2.50	10.00	0.61	9.72
4,03	grading roads	15.43	0.99	combined	1.34	5.35	0.74	11.78
	Geometric mean	**13.32**	**0.68**		**2.86**	**11.42**	***1.33***	***21.25***
	Minimum value	**9.79**	**0.51**		**1.34**	**5.35**	***0.61***	***9.72***
	Maximum value	**16.19**	**0.99**		**5.03**	**20.12**	***4.55***	***72.72***
Watercart								
2,29	watering roads	9.37	0.47	z	5.80	23.18	5.42	86.74
4,16	watering roads	11.46	0.63	z	3.29	13.18	2.42	38.75
	Geometric mean	**10.36**	**0.55**		**4.37**	**17.48**	***3.62***	***57.98***
	Minimum value	**9.37**	**0.47**		**3.29**	**13.18**	***2.42***	***38.75***
	Maximum value	**11.46**	**0.63**		**5.80**	**23.18**	***5.42***	***86.74***

APPENDIX 1 TABLES

Table A3.4 International Standard (ISO 2631-1.2): Caution Zone and Likely Health Risk Zone.

(ranked according to increasing time to reach caution zone - ***worst to best***)

Sample	Activity	VDV comb-axis ($m/sec^{1.75}$)	Wt. RMS (comb) acceleration (m/s^2)	Axis	(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)
Dump trucks								
2,02	overburden & coal	7.61	0.26	z	19.41	77.63	12.43	198.81
2,04	loading coal	9.11	0.39	z	8.69	34.74	6.08	97.20
2,06	loading overburden	10.23	0.43	z	7.07	28.27	3.81	60.95
2,07	loading overburden	11.01	0.49	z	5.46	21.85	2.84	45.51
2,08	overburden & coal	13.27	0.68	z	2.84	11.37	1.35	21.58
2,11	loading topsoil	10.98	0.44	z	6.87	27.47	2.88	46.01
2,12	loading coal	9.16	0.37	z	9.75	39.00	5.92	94.74
2,13	loading coal	10.29	0.41	z	7.77	31.09	3.72	59.51
2,18	loading coal	9.23	0.38	z	8.96	35.83	5.74	91.92
2,24	loading overburden	14.10	0.55	z	4.33	17.30	1.06	16.89
3,01	loading overburden	9.80	0.46	z	6.25	25.00	4.53	72.47
3,02	loading overburden	10.34	0.51	z	5.06	20.26	3.65	58.41
3,05	loading overburden	8.51	0.39	z	8.80	35.20	7.96	127.40
3,07	loading overburden	9.11	0.47	z	5.92	23.66	6.07	97.04
3,10	loading overburden	8.20	0.36	z	10.06	40.25	9.25	148.08
3,12	loading overburden	7.23	0.31	z	13.96	55.85	15.25	244.07
3,13	loading overburden	9.33	0.45	z	6.53	26.13	5.50	88.05
3,14	loading overburden	8.96	0.47	z	5.87	23.49	6.47	103.44
5,01	loading overburden	10.76	0.45	z	6.45	25.80	3.12	49.93
4,01	loading overburden	12.03	0.42	z	7.50	30.01	1.99	31.89
4,02	loading overburden	12.05	0.55	z	4.30	17.18	1.98	31.71
4,11	loading coal	9.53	0.44	z	6.83	27.33	5.07	81.04
4,12	loading overburden	9.45	0.38	z	8.95	35.79	5.24	83.84
	Geometric mean	***9.88***	***0.43***		***7.13***	***28.53***	***4.38***	***70.02***
	Minimum value	***7.23***	***0.26***		***2.84***	***11.37***	***1.06***	***16.89***
	Maximum value	***14.10***	***0.68***		***19.41***	***77.63***	***15.25***	***244.07***
Excavator								
3,04	loading overburden	3.99	0.26	combined	19.41	77.64	164.37	2629.97

APPENDIX 1 TABLES

Table A4.1 Vehicle SEAT values not including coal loading vehicles

Sample	Seat Type	SEAT value x	SEAT value y	SEAT value z
Dump Trucks				
3,10	Manufacturer 1 seat & base air -dished	0.91	1.17	0.60
3,12	Manufacturer 1 seat & base air -dished	0.99	0.91	0.62
4,11	Unidentified seat & base air - dished	0.89	1.14	0.64
3,14	Manufacturer 1 seat & base air -dished	0.93	1.16	0.66
3,05	Manufacturer 1 seat & base air -dished	0.93	1.13	0.67
3,07	Manufacturer 1 seat & base air -dished	0.89	1.08	0.68
3,02	Manufacturer 1 seat & base air -dished	0.89	1.15	0.70
4,12	Unidentified seat & base air - dished	0.98	1.14	0.70
2,13	Manuf 3 seat & base air/comp - new rated 'good'	0.41	0.59	0.75
3,13	Manufacturer 1 seat & base air - dished	0.91	1.26	0.75
4,01	Unidentified seat & base air - dished	0.96	1.20	0.77
2,04	Manuf 2 seat & base air/comp - new rated 'good'	0.96	1.28	0.80
3,01	Manufacturer 1 seat & base air - dished	0.88	1.12	0.80
2,02	Manufacturer 3 seat & base air/comp - new 'v. good'	0.98	1.27	0.81
2,06	Manufacturer 3 seat & base air/comp - new 'v. good'	0.95	1.22	0.81
4,02	Unidentified seat & base air - dished	0.63	1.17	0.86
2,07	Manufacturer 3 seat and base air/shock - new	0.96	1.16	0.90
5,01	Manufacturer 1 seat and base - type unknown	1.13	1.08	0.91
2,18	Manufacturer 3 seat and base air/shock - new	1.06	1.15	0.96
2,08	Manufacturer 3 seat & base air/comp - new	0.94	1.19	1.04
2,12	Manufacturer 3 seat & base air/comp - new	1.00	1.18	1.07
2,24	Manufacturer 3 seat and base air/shock - new	0.91	1.36	1.20
	Geometric mean	**0.90**	**1.13**	**0.79**
Track Dozers				
4,04	Manufacturer 3 seat & base mechanical	1.11	1.21	0.56
4,15	Manufacturer 3 seat & base mechanical	1.15	1.23	0.57
4,08	Manufacturer 3 seat & base mechanical	1.12	1.28	0.64
3,16	Manufacturer 3 seat & base mechanical-dished	1.14	1.22	0.69
2,09	Manufacturer 3 seat & base air/comp - new	0.98	1.16	0.70
2,19	Manufacturer 3 seat & base air/comp - new	0.99	1.21	0.71
2,25	Manufacturer 3 seat & base air/comp - new	1.19	1.15	0.72
2,15	Manufacturer 3 seat & base air/comp - new	1.13	1.12	0.75
3,11	Manufacturer 3 seat & base mechanical - dished	1.06	1.23	0.75
2,10	Manufacturer 3 seat & base air/comp - new	1.07	1.16	0.82
2,05	Manufacturer 3 seat & base air/comp - new	1.04	1.07	0.87
3,21	Manufacturer 3 seat & base mechanical - dished	1.10	1.22	0.88
2,20	Manufacturer 3 seat & base air/comp - new	1.10	1.22	0.93
2,28	Manufacturer 3 seat & base air/comp - new	1.09	1.14	0.93
3,03		1.01	1.18	0.93
5,05	Manufacturer 1 seat & base - air	1.23	1.24	1.12
5,06	Manufacturer 3 seat & base - mechanical	1.03	1.23	1.13
5,09	Manufacturer 1 seat & base - air	1.09	1.24	1.22
	Geometric mean	**1.09**	**1.19**	**0.81**
Rubber tyred dozers				
4,13	Manufacturer 3 seat & base mechanical - dished	1.4	0.79	0.33
4,14	Manufacturer 3 seat & base mechanical - dished	1.16	1.14	0.91
3,15	Manufacturer 3 - seat & base type unidentified	1.01	1.22	1.20
	Geometric mean	**1.18**	**1.03**	**0.71**

APPENDIX 1 TABLES

Table A4.2 Vehicle SEAT values not including coal loading vehicles

Sample	Seat Type	SEAT value x	SEAT value y	SEAT value z
Loaders				
5,02	Manufacturer 1 seat & base - air	1.1	1.18	0.72
2,22	Manufacturer 2 seat & base - air	1.08	1.21	0.75
5,04	Manufacturer 3 seat & base - mechanical	1.24	1.17	0.84
3,20	Manufacturer 1 seat & base - air	1.07	1.08	0.87
5,07	Manufacturer 1 seat & base - air	1.09	1.19	1.03
3,22	Manufacturer 1 seat & base - air	1.12	1.23	1.04
3,18	Manufacturer 1 seat & base - air	1.13	1.23	1.05
2,21	Manufacturer 2 seat & base - air	1.11	1.22	1.08
2,14	Manufacturer 2 seat & base - air	1.03	1.12	1.12
	Geometric mean	**1.11**	**1.18**	**0.93**
Excavator				
3,04	Unidentified seat & base - air suspension - dished	**0.96**	**1.10**	**0.47**
Fitter's vehicle				
4,17	Standard seat vehicle manufacturer no suspension	1.65	1.07	0.93
2,30	Standard seat vehicle manufacturer no suspension	1.21	1.06	0.93
3,08	Standard seat vehicle manufacturer no suspension	1.04	1.05	0.95
5,03	Standard seat vehicle manufacturer no suspension	1.23	0.92	1.07
5,08	Standard seat vehicle manufacturer no suspension	0.86	0.88	1.41
	Geometric mean	**1.17**	**0.99**	**1.04**
Manhaul passenger				
2,31	Standard seat vehicle manufacturer no suspension	1.15	1.17	0.82
4,19	Standard seat vehicle manufacturer no suspension	1.49	1.1	0.83
2,27	Standard seat vehicle manufacturer no suspension	1.03	1.11	0.85
2,17	Standard seat vehicle manufacturer no suspension	1.95	0.67	0.93
2,32	Standard seat vehicle manufacturer no suspension	1.24	1.15	0.95
	Geometric mean	**1.34**	**1.02**	**0.87**
Manhaul driver				
2,16	Standard seat vehicle manufacturer no suspension	1.36	1.16	0.95
3,09	Standard seat vehicle manufacturer no suspension	1.48	2.02	0.96
	Geometric mean	**1.42**	**1.53**	**0.96**
Grader				
2,26	Manufacturer 2 seat & base air/shock - old	1.11	1.25	0.88
4,03	Manufacturer 3 seat & base mechanical - dished	1.29	1.24	0.93
2,33	Manufacturer 2 seat & base air/shock - old	1.11	1.21	1.10
3,23	Manufacturer 3 seat & base mechanical - old	1.15	1.36	1.22
3,17	Manufacturer 3 seat & base mechanical - old	1.16	1.25	1.23
3,19	Manufacturer 3 seat & base mechanical - old	1.23	1.31	1.29
	Geometric mean	**1.17**	**1.27**	**1.10**
Watercart				
4,16	Manufacturer 3 seat & base mechanical - dished	1.2	1.15	1.01
2,29	Manufacturer 3 seat & base air/shock - new	1.05	1.11	1.06
	Geometric mean	**1.12**	**1.13**	**1.03**

APPENDIX 1 TABLES

Table A5.1 Measured versus individuals' ratings of ride

(ranked according to increasing ISO VDV – ***worst to best***)

Sample	Activity	AS-fatigue Z-axis (hr)	BS VDV action level (hr)	VDV (ISO)	AS Wt RMS accel. (m/s²)	ISO guidance for 8 hr exposure	Operator's ride roughness rating	Rating of ride British Std.Inst. comfort rating	Operator's comments on ride
Rubber tyred dozers									
3,15	o/b shovel	4	2.66	19.80	1.23	likely health risk	ok	not uncomfortable	good road - graded, soft spots & large rocks, rough vehicle
4,14	pushing overburden	3	2.07	21.23	1.50	likely health risk	fair	little uncomfortable	poor road, correg. soft spots, rocks, poor ride
4,13	travel, push road	3	1.12	24.59	1.36	likely health risk	poor	little uncomfortable	avg road, soft spots, poor ride
	Geometric mean	***3***	***1.84***	***21.78***	***1.36***				
	Minimum value	***3***	***1.12***	***19.80***	***1.23***				
	Maximum value	***4***	***2.66***	***24.59***	***1.50***				
Track dozers									
2,09	pushing overburden	22	25.95	11	0.53	in caution zone	fair	not uncomfortable	avg ride, spreading grading digging o/b
3,03	overburden	16	22.88	11	0.62	in caution zone	good	not uncomfortable	good road, avg ride
2,05	ripping & pushing o/b	8	13.66	13	0.85	likely health risk	poor	not uncomfortable	rougher than normal, ripping and pushing o/b
2,19	pushing overburden	12	10.10	14	0.97	likely health risk	poor	fairly uncomfort.	avg ride, pushing o/b, no breaks
3,16	pushing partings	11	9.61	14	0.95	likely health risk	fair	little uncomfortable	avg road conditions, soft spots & rocks, easy pushing
3,11	pushing & ripping o/b	8	7.59	15	1.08	likely health risk	ok	little uncomfortable	avg road, rough on tip, avg ride
2,15	pushing coal	9	6.37	16	1.02	likely health risk	ok	little uncomfort.	good ride, pushing coal, several breaks
2,10	ripping & pushing coal	7	5.43	17	1.13	likely health risk	good	not uncomfortable	good ride, ripping and pushing coal
3,21	battering	6	4.45	17	1.04	likely health risk	fair	little uncomfortable	good road conditions, some soft spots, easy to push
5,06	roadmaking, R & P o/b	6	3.83	18	1.11	likely health risk	ok	not uncomfortable	typical ride
2,28	ripping hard coal	6	3.98	19	1.26	likely health risk	good	little uncomfort.	avg ride, hard coal ripping 90%, push10%, 1st gear only.
2,20	pushing mud	6	2.91	19	1.17	likely health risk	fair	little uncomfort.	rough in spots, push mud, road making, wet, no breaks
2,25	pushing overburden	6	2.89	20	1.40	likely health risk	poor	uncomfortable	avg ride, pushing o/b, not shot well, heavy, big rocks
4,15	ripping & pushing	4	1.93	22	1.66	likely health risk	fair	fairly uncomfortable	avg road condition, avg ride
5,09	pushing soft o/b	5	1.96	22	1.34	likely health risk	fair	little uncomfort.	soft surface, slewing
4,04	rip & push partings	4	0.96	25	1.98	likely health risk	ok	uncomfortable	very poor surface conditions, large rocks, poor ride
5,05	pushing o/b	2	0.84	27	1.48	likely health risk	ok	not uncomfortable	working in rough area
4,08	rip & push hard rock	5	0.62	28	1.79	likely health risk	poor	uncomfortable	poor surface, large hard rocks, poor ride
	Geometric mean	***7***	***4.27***	***18***	***1.13***				
	Minimum value	***2***	***0.62***	***11***	***0.53***				
	Maximum value	***22***	***25.95***	***28***	***1.98***				

APPENDIX 1 TABLES

Table A5.2 Measured versus individuals' ratings of ride

(ranked according to increasing ISO VDV – ***worst to best***)

Sample	Activity	AS-fatigue Z-axis (hr)	Time to reach BS VDV action level (hr)	VDV (ISO)	AS Wt RMS accel. (m/s²)	ISO guidance for 8 hr exposure	Operator's ride roughness rating	Rating of ride British Std.Inst. comfort rating	Operator's comments on ride
Manhaul passenger									
4,19	passenger	20	1.41	24	0.44	likely health risk	fair	little uncomfortable	avg road, avg ride
2,17	passenger	6	1.39	25	1.22	likely health risk	poor	extremely uncomf.	rough in parts, around mine 50 km/h main haul road
2,31	passenger	7	1.11	26	1.09	likely health risk	fair	little uncomfort.	avg ride, passenger, dump to shovel & exits
2,32	passenger	6	1.21	26	1.14	likely health risk	ok	little uncomfort.	avg ride,
2,27	passenger	6	0.77	29	1.17	likely health risk	fair	very uncomfort.	passenger drive from muster area to pit, avg
	Geometric mean	***8***	***6.28***	***29***	***0.88***				
	Minimum value	***6***	***0.77***	***15***	***0.44***				
	Maximum value	***20***	***10.14***	***29***	***1.22***				
Loaders									
2,14	loading coal	14	26.23	11.20	0.68	caution zone	ok	not uncomfortable	avg to good ride, wet, loading gravel, coal, mud
3,18	loading coal	11	23.95	11.50	0.74	likely health risk	ok	not uncomfortable	avg road surface
5,02	loading coal	11	22.35	11.68	0.75	likely health risk	good	little uncomfortable	bumpy road
3,20	loading coal	8	20.64	12.12	0.82	likely health risk	ok	not uncomfortable	avg road conditions but dusty
2,22	loading coal	11	18.99	12.16	0.76	likely health risk	-	not uncomfortable	
3,22	loading overburden	9	20.38	12.17	0.81	likely health risk	fair	not uncomfortable	avg ride, good road conditions
2,21	loading coal	8	12.96	13.24	0.85	likely health risk	-	-	avg ride, loading coal, mud, no breaks
5,07	loading overburden	7	0.95	15.38	0.97	likely health risk	ok	little uncomfortable	typical ride
5,04	push, travel, dump o/b	5	4.39	17.78	1.16	likely health risk	fair	little uncomfortable	typical ride
	Geometric mean	***9***	***12.21***	***12.88***	***0.83***				
	Minimum value	***5***	***0.95***	***11.20***	***0.68***				
	Maximum value	***14***	***26.23***	***17.78***	***1.16***				
Fitters vehicle									
3,08	maintenance run	11	5.37	18	0.81	likely health risk	fair	little uncomfortable	good road, some water, soft spots, potholes
4,17	maintenance run	7	5.71	18	0.84	likely health risk	-	little uncomfortable	avg road corregations, sometimes rough, good ride
5,03	maintenance run	8	4.39	18	0.84	likely health risk	good	not uncomfortable	typical ride
2,30	maintenance run	5	3.88	20	0.98	likely health risk	poor	fairly uncomfort.	avg ride around mine, stat.checks, rougher vehicle
5,08	maintenance run	5	0.51	32	1.35	likely health risk	fair	little uncomfortable	rough ride
	Geometric mean	***7***	***5.37***	***1***	***0.94***				
	Minimum value	***5***	***0.51***	***18***	***0.81***				
	Maximum value	***11***	***5.71***	***32***	***1.35***				
Manhaul driver									
3,09	driver	14	10.14	15	0.69	caution zone	ok	little uncomfortable	avg road some soft spots, avg ride
2,16	driver	10	6.28	17	0.74	likely health risk	ok	fairly uncomfort.	rough muddy slippery, 40-50km/h, slower than usual
	Geometric mean	***12***	***8***	***16***	***0.71***				
	Minimum value	***10***	***6***	***15***	***0.69***				
	Maximum value	***14***	***10***	***17***	***0.74***				

APPENDIX 1 TABLES

Table A5.3 Measured versus individuals' ratings of ride

(ranked according to increasing ISO VDV – ***worst to best***)

Sample	Activity	AS-fatigue Z-axis (hr)	BS VDV action level (hr)	VDV (ISO)	AS Wt RMS accel. (m/s^2)	ISO guidance for 8 hr exposure	Operators' ride roughness rating	Rating of ride British Std Inst. comfort rating	Operator's comments on ride
Graders									
2,33	grading roads	18	46.59	9.79	0.38	in caution zone	fair	little uncomfort.	grading road, average ride (uncomfortable posture)
2,26	grading roads	17	50.22	9.81	0.40	in caution zone	good	not uncomfortable	good ride, grading & repair to road
3,19	grading roads	4	13.74	15.07	1.11	in caution zone	fair	fairly uncomfortable	average road conditions
3,17	grading roads	5	11.59	15.42	1.04	in caution zone	poor	not uncomfortable	soft spots but generally good conditions
4,03	grading roads	7	10.19	15.43	1.00	likely health risk	fair	little uncomfortable	poor road, pot holes, soft spots, rougher than most
3,23	grading roads	4	10.44	16.19	1.14	in caution zone	fair	not uncomfortable	average road conditions
	Geometric mean	***7***	***18.46***	***13.32***	***0.76***				
	Minimum value	***4***	***10.19***	***9.79***	***0.38***				
	Maximum value	***18***	***50.22***	***16.19***	***1.14***				
Watercart									
2,29	watering roads	16	59.10	9.37	0.42	in caution zone	ok	fairly uncomfort.	average ride, watering roads, poor cab layout.
4,16	watering roads	8	31.11	11.46	0.69	in caution zone	fair	little uncomfortable	poor roads in tip & shovel areas, poor ride, soft spots
	Geometric mean	***9***	***43***	***10.36***	***0.74***				
	Minimum value	***4***	***31***	***9.37***	***0.22***				
	Maximum value	***24***	***59***	***11.46***	***1.16***				

APPENDIX 1 TABLES

Table A5.4 Measured versus individuals' ratings of ride (ranked according to increasing ISO VDV – *worst to best*)

Sample	Activity	AS-fatigue Z-axis (hr)	Time to reach BS VDV action level (hr)	VDV (ISO)	AS Wt RMS accel. (m/s^2)	ISO guidance for 8 hr exposure	Operator's ride roughness rating	Rating of ride British Std Inst. comfort rating	Operator's comments on ride
Dump trucks									
3,12	loading overburden	24	182.54	7.23	0.27	below caution zone	ok	little uncomfortable	average to poor road, pot holes & soft spots
2,02	overburden & coal	24	184.32	7.61	0.27	below caution zone	ok	not uncomfortable	avg ride for this seam 2ob, 2coal
3,10	loading overburden	21	131.45	8.20	0.36	below caution zone	good	not uncomfortable	poor road, soft spots, cambered corners, poorly maint.
3,05	loading overburden	21	100.49	8.51	0.37	below caution zone	ok	not uncomfortable	average road, potholes, average ride
3,14	loading overburden	19	81.27	8.96	0.46	in caution zone	ok	little uncomfortable	poor road conditions, soft spots, poor after rain
2,04	loading coal	20	71.52	9.11	0.35	below caution zone	ok	not uncomfortable	avg ride coal loader to hopper
3,07	loading overburden	21	72.58	9.11	0.43	in caution zone	good	not uncomfortable	good road newly graded, good ride
2,12	loading coal	21	39.40	9.16	0.38	below caution zone	fair	not uncomfortable	good ride, loading wet coal, slippery, rough vehicle
2,18	loading coal	23	74.40	9.23	0.37	below caution zone	ok	not uncomfortable	avg ride, loading and tipping wet coal
3,13	loading overburden	19	63.72	9.33	0.42	in caution zone	poor	little uncomfortable	good conditions, a few soft spots, average ride
4,12	loading overburden	24	59.28	9.45	0.34	below caution zone	ok	not uncomfortable	poor road, soft spots, average ride, average ride
4,11	loading coal	20	58.88	9.53	0.40	below caution zone	good	not uncomfortable	average road, excellent ride.
3,01	loading overburden	19	57.03	9.80	0.43	in caution zone	ok	not uncomfortable	good road, some soft spots, average ride
2,06	loading overburden	17	48.93	10.23	0.40	below caution zone	ok	little uncomfortable	avg ride ob some road vibration
2,13	loading coal	17	48.34	10.29	0.39	below caution zone	good	not uncomfortable	excellent ride, good vehicle, coal, wet (see SEAT value)
3,02	loading overburden	19	43.92	10.34	0.47	in caution zone	ok	little uncomfortable	good road, average ride
5,01	loading overburden	11	50.23	10.76	0.48	in caution zone		little uncomfortable	fair, a little uncomfortable
2,11	loading topsoil	17	35.92	10.98	0.41	below caution zone	ok	little uncomfortable	avg ride, ob (top soil)
2,07	loading overburden	15	41.59	11.01	0.51	in caution zone	ok	not uncomfortable	good ride, ob, shovel to dump
4,01	loading overburden	20	28.30	12.03	0.39	below caution zone	ok	not uncomfortable	average road, average ride
4,02	loading overburden	8	24.46	12.05	0.52	in caution zone	ok	little uncomfortable	poor road, poor maintenance on roads, average road
2,08	overburden & coal	8	16.19	13.27	0.67	in caution zone	fair	fairly uncomfortable	rejects washery to ob dump
2,24	loading overburden	11	14.25	14.10	0.52	in caution zone	fair	little uncomfortable	avg. ride, overburden, bit rough in spots
	Geometric mean	***17***	***54.5***	***9.88***	***0.41***				
	Minimum value	***8***	***14.3***	***7.23***	***0.27***				
	Maximum value	***24***	***184.3***	***14.10***	***0.67***				
Excavator									
3,04	loading overburden	24	1526.88	3.99	0.22	below caution zone	ok	not uncomfortable	good conditions, average work

APPENDIX 2

STUDY OF VIBRATION EXPOSURE IN MINING VEHICLES

Information for volunteers in the study

We invite you to participate in this study of Whole-Body Vibration (WBV) exposure in the coal industry. It is being funded by the Joint Coal Board Health and Safety Trust and is being conducted by present and former researchers from Worksafe Australia. It is under the surveillance of the University of Sydney Ethics Committee.

The study aims to do several things:

Measure and analyse WBV exposures measurements for coal workers in a range of vehicle types, under operational conditions, in both underground and open-cut coal mines and surface facilities

Survey back pain and other symptoms in operators and passengers together with the vibration measurements

Survey operators' working experience, opinions on the design of cabs and seats, and their comfort ratings of the ride

Assess vibration damping in vehicle seating

Record factors which might contribute to rough rides in mining

Compile a report of WBV exposure in mining work, and its possible effects on workers

Write a handbook on practical ways to reduce harmful vibrations in mining

We need your help in the following areas:

* ***measuring the whole-body vibration (WBV) exposures of drivers or passengers while driving or riding***

To achieve this we shall be placing small transducers on the seat where the operator or passenger is sitting, and on the frame of the vehicle. These will be attached to a data recorder mounted on, or within, the vehicle being tested. Recordings will be made for up to one hour at a time. After this time the data will be downloaded onto a computer. One set of measurements will be taken at a time but measurements may be repeated.

* ***surveying back pain and other symptoms in operators and passengers after the vibration measurements are recorded***

After we measure the vibration on the vehicle we will be asking you a series of questions on any 'aches and pains' which you might have. This will require a few minutes of your time.

* ***information on volunteers***

Some personal information on each volunteer is needed so that the study has a 'profile' of the workforce surveyed. These include:

* how old you are
* how tall you are
* how much you weigh
* if you smoke
* your working experience

This information will be gathered from each individual volunteer at the beginning or end of the work period.

* ***recording operators' and passengers' comfort ratings of the ride***

We shall ask you to give us your opinion of the ride we have just measured.

It is especially important that you do your normal work in the way you usually do it.

* ***opinions on road and other conditions***

Your opinions will be sought on road and other conditions as well as your ratings of the ride, your opinion on the cab and seat design.

* ***information on vehicles***

We need to know something about the vehicle being measured so that we can determine sources of vibration and ways of reducing it. Information such as the type, model, age, condition and maintenance, type of tyres, suspension etc will be collected from a range of mining personnel.

Confidentiality of results

All results obtained are confidential and will be used only for research. Identification of individual volunteers within the project is not possible except where the individual specifically requests information on their own ride(s). Information about overall results (without individuals identified) from each mine will be made available in individual mine reports. A major report on all sites will be written for the Joint Coal Board Health and Safety Trust.

Consent form (one signed copy to held by researcher, one to be held by the participant)

The study team is bound by the Declaration of Helsinki, an international agreement on the conduct of research involving people. Therefore your written consent is required and you are free to withdraw from the study at any time.

I ________________________________(please print your name) have read and understood the information sheet for volunteers about the study of 'Vibration exposure in mining vehicles' and hereby agree to participate in it.

I understand that I may withdraw from the study at any time.

Signed: ______________________________

Date: ______________________________

Any persons with concerns or complaints about the conduct of the research project can contact the Secretary of the Human Ethics Committee, University of Sydney on 02-9351 4811.

If you wish to discuss your involvement in the Project with one of the research team, we would be happy to arrange an opportunity for you to do so.

We can be contacted on:

Barbara McPhee	tel:	02-9808 2556
	fax:	02-9809-4194
Airdrie Long	tel:	02-9411 4248
	fax:	02-9411 4249
Gary Foster	tel:	02-9577 9270
	fax:	02-9577 9300

Thank you for your help

Barbara McPhee
Airdrie Long
Gary Foster

The Vibration Research Team

Participant's symptoms and work history

(To be administered by the researcher)

Date................................ Time: : hrs
Shift: : to : hrs
Type of shift usually worked: ....
Actual hours worked today: : to : hrs
Vehicle ID (make, model, no):...
Vibration recording ID:...
Trip length:............................(minutes)
Vehicle activity...

Activity	**Approximate time**

Participant's work and smoking history

How many years have you worked in the mining industry?

................years

What work have you done since you left school? Please detail below.

Other work	Years/months

Do you smoke? Yes No
Have you ever smoked? Yes No

Participant's symptoms and their relationship with work

With respect to the questions you have just answered on discomfort do you believe any of these symptoms are related to what you do at work?

yes no

If yes, can you tell me what activities set off your pain, ache or discomfort?

Symptom	Activity

ABOUT YOUR JOB

7 What is your job title? ☐ 34-56

8 How many years and months have you been doing your **present type of work** at this site?

Years ☐ + Months ☐ — If less than one month, how many weeks? ☐ 57-58 59-60 61

9 Have you worked elsewhere doing a similar type of work? 62

No 1 ☐ Yes 2 ☐

9.1 If yes, what is the total length of time you worked elsewhere, doing a similar type of work before starting at this site? 63

1 ☐ Less than 1 year
2 ☐ 1-2 years
3 ☐ 3-4 years
4 ☐ 5-9 years
5 ☐ 10 years or more

Note: Fill in next page before completing Q9.1

10 On average, how many hours a week do you work (including overtime but excluding main meal break)? 64-65

Hours ☐

HSE Health & Safety Executive

1-4 Ref ☐☐☐☐ 5 Rec 1 6/8 Site ☐☐☐ 9/12 SIC Activity ☐☐☐☐

MUSCULOSKELETAL DISORDERS

Dear Sir / Madam,

This questionnaire has been prepared by the Health and Safety Executive which is the UK organisation responsible for health and safety at work.

With the co-operation of your employer and trade unions we are conducting a survey to find out the extent to which muscle and joint aches and pains are experienced by employees in your occupation.

We are interested in mild and severe problems affecting muscles, ligaments, nerves, tendons, joints and bones suffered both at work and away from work. This could mean sprains, strains, inflammations, irritations and dislocation. For the purpose of this survey we are not interested in any injuries to the skin.

We would like you to complete this questionnaire about your health. All answers will be treated as **strictly confidential** and individual answers will not be made known to anyone other than the survey team.

The more questionnaires that are completed, the greater will be the accuracy and usefulness of the findings, the better to help us improve health and safety at work. Thank you for your help.

Epidemiology and Medical Statistics Unit (EMSU), Magdalen House, Trinity Road, Bootle, Merseyside L20 3QZ.

HOW TO ANSWER THE QUESTIONNAIRE

Please complete this questionnaire by answering ALL questions as fully as possible. Some of the questions require a written answer, for others you need only tick a box. ☑

Please do not write in the margin.

PERSONAL DETAILS

1 Date of birth — Day ☐☐ Month ☐☐ Year ☐☐ 13-18

2 Sex — Male 1 ☐ Female 2 ☐ 19

3 Today's date — Day ☐☐ Month ☐☐ Year ☐☐ 20-25

4 What is your weight? 26-27

stones ☐ + pounds ☐ or kg ☐ 28-29

5 What is your height? 30

feet ☐ + inches ☐ or cm ☐ 31-32

6 Are you right or left handed? 33

right 1 ☐ left 2 ☐ able to use both hands equally 3 ☐

2

MUSCULOSKELETAL DISORDERS

1-4 Ref ☐☐☐☐ 5 Rec [2]

Please answer all questions numbered **6** to **32** by using the tick boxes ☑ - *one tick for each question*

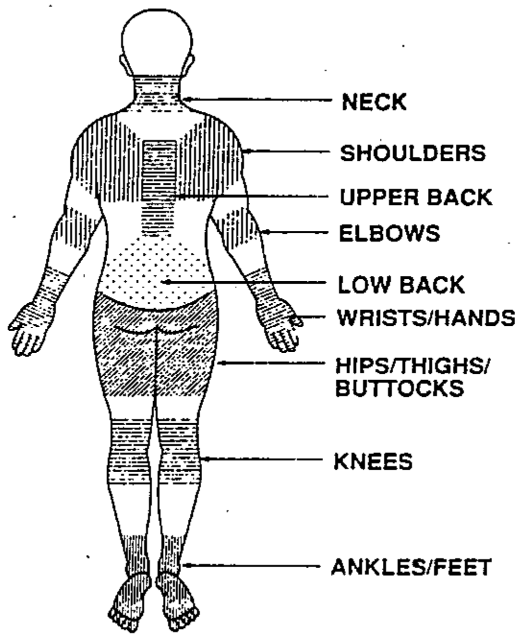
Please note that this part of the questionnaire should be answered, even if you have never had trouble in any part of your body.

Have you at any time during the **last 12 months** had **trouble (such as ache, pain, discomfort, numbness)** in:	Have you had **trouble** during the last 7 days:	During the **last 12 months** have you been **prevented** from carrying out normal activities (eg job, housework, hobbies) because of this trouble:
6 *Neck* No 1 ☐ Yes 2 ☐	7 *Neck* No 1 ☐ Yes 2 ☐	8 *Neck* No 1 ☐ Yes 2 ☐
9 *Shoulders* No 1 ☐ Yes 2 ☐ in the right shoulder 3 ☐ in the left shoulder 4 ☐ in both shoulders	10 *Shoulders* No 1 ☐ Yes 2 ☐ in the right shoulder 3 ☐ in the left shoulder 4 ☐ in both shoulders	11 *Shoulders (both/either)* No 1 ☐ Yes 2 ☐
12 *Elbows* No 1 ☐ Yes 2 ☐ in the right elbow 3 ☐ in the left elbow 4 ☐ in both elbows	13 *Elbows* No 1 ☐ Yes 2 ☐ in the right elbow 3 ☐ in the left elbow 4 ☐ in both elbows	14 *Elbows (both/either)* No 1 ☐ Yes 2 ☐
15 *Wrist/hands* No 1 ☐ Yes 2 ☐ in the right wrist/hand 3 ☐ in the left wrist/hand 4 ☐ in both wrists/hands	16 *Wrist/hands* No 1 ☐ Yes 2 ☐ in the right wrist/hand 3 ☐ in the left wrist/hand 4 ☐ in both wrists/hands	17 *Wrist/hands (both/either)* No 1 ☐ Yes 2 ☐
18 *Upper back* No 1 ☐ Yes 2 ☐	19 *Upper back* No 1 ☐ Yes 2 ☐	20 *Upper back* No 1 ☐ Yes 2 ☐
21 *Lower back (small of back)* No 1 ☐ Yes 2 ☐	22 *Lower back* No 1 ☐ Yes 2 ☐	23 *Lower back* No 1 ☐ Yes 2 ☐
24 *One or both hips/thighs/buttocks* No 1 ☐ Yes 2 ☐	25 *Hips/thighs/buttocks* No 1 ☐ Yes 2 ☐	26 *Hips/thighs/buttocks* No 1 ☐ Yes 2 ☐
27 *One or both knees* No 1 ☐ Yes 2 ☐	28 *Knees* No 1 ☐ Yes 2 ☐	29 *Knees* No 1 ☐ Yes 2 ☐
30 *One or both ankles/feet* No 1 ☐ Yes 2 ☐	31 *Ankles/feet* No 1 ☐ Yes 2 ☐	32 *Ankles/feet* No 1 ☐ Yes 2 ☐

REMEMBER - Please check you have answered questions 6 to 32

THANK YOU FOR COMPLETING THIS QUESTIONNAIRE

5



This picture shows how the body has been divided. Please answer the three questions shown opposite for each body area.
Body sections are not sharply defined and certain parts overlap. You should decide for yourself which part (if any) is or has been affected.

6

Quality of ride

To be administered to the driver or passenger for each trip measured
N.B. Questions written *italics* must be answered by the driver. Answers to all other questions may be supplied by anyone

Date.................................. Time: : hrs
Shift: : to : hrs
Observer's initial: ....

Roads/surfaces

(Circle which applies)

1. *How would you rate the road conditions on this ride?*
   good average poor

2. *Types of road or surface problems*

   water potholes soft spots rocks

   timber other (specify)

   ....

3. *How do the road conditions for this ride compare with other days?*

   better the same worse

Observer comments:
....
....
....

Quality of this ride

4. *Do you like operating this vehicle?*

   Yes No Reservations

Why?...
....

5. *How would you rate smoothness of the ride you have just had?*

   Good Average Poor

6. *How would you rate the smoothness or roughness of this vehicle with other ____________(vehicles in same class)?*

Better Same Worse

7. *How would you rate this ride compared to all other rides you have ever experienced? Please mark on the line where you think the ride rates.*

☺ Best ever ____________________________________ Worst ever ☹

8. *How did this ride make you feel? (please circle response)*

- *not uncomfortable (0)* *not rough (00)*
- *a little uncomfortable (1)* *a little rough (11)*
- *fairly uncomfortable (2)* *fairly rough (22)*
- *uncomfortable (3)* *rough (33)*
- *very uncomfortable (4)* *very rough (44)*
- *extremely uncomfortable (5)* *extremely rough (55)*

9. *Generally how do you feel at the end of your normal working day compared with when you start your working day? (please circle response)*

- *more comfortable*
- *less comfortable*
- *about the same*
- *varies depending on the machine that is driven*
- *varies depending on the activity of the machine*
- *other*

Why?...
....
....
....

Assessment of the cab, seat and vehicle

(To be administered for each driver in each vehicle)
N.B. Questions written *italics* must be answered by the driver. Answers to all other questions may be supplied by anyone

Date....................................... Time: : hrs

Vehicle make, type and no. ....

Observer's initials: ....

Ergonomics aspects of the cab:

(Circle which applies)

1. *Do you rate the displays in the cab as:*

   good acceptable poor

2. *Do you rate the controls in the cab as:*

   good acceptable poor

3. *Visibility from cab -*

   good acceptable poor

4. *What is the quality of the lighting of roadways/work areas/rails?*

   good fair poor

Comments on features ticked above:

....

....

Vehicle seat

(Circle which applies)

5.
Type/description..
....

6. *Suitability for vehicle*

good fair poor

7. *Condition/maintenance*

good fair poor

Comments:...

....

Adjustment for the operator

(Circle which applies)

8. *Did you adjust the seat before you started operating the vehicle?*

yes

it is now adjusted correctly

could not adjust correctly

no

no need to adjust - already OK

doesn't bother

suitable adjustments are not available

9. *Any problems with the design (e.g. lumbar support, padding, shape)?*

no yes

Comments:...

....

Estimation of work exposures to WBV

9. *What is the approximate length of work time between breaks on this machine*

(minutes)

10. *What types of machines are you certified to drive at this mine?*

Open-cut

dozers scrapers loaders graders trucks

draglines shovels excavators man haul

fitters vehicles other (specify)

Underground

continuous miner shuttle car LHD

men and/or materials transport vehicle (specify which type, make or model)

other (specify) ....

11. *What proportion of time do you spend on each machine (roughly)?*

Proportion of time	Type of machine

Driver experience and speed requirements

(This information could be supplied by anyone considered appropriate)

12. *How many years experience have you had driving heavy plant and equipment?*

.... *years*

13. *In your experience what contributes to rough rides?*

....

14. *What slows you down when you are operating mining machinery?*

....

Vehicle Checklist

(To be filled out by the researcher or mine personnel)

Date: .... Observer's initials: ....

Mine:..

Person (incl. job title) supplying information:

....

....

General vehicle information

Vehicle ID (make, model, no):..

Vibration recording(s) ID:..

Type:.(e.g. LHD, transport, miner)

....

....

....

Year of manufacture ....

Major rebuilds

(circle which applies):

yes   no   unknown/uncertain

Hours logged for the machine ....hrs

Condition of the machine

(circle which applies):

good   average   poor

Maintenance schedule: ....

....

Modifications
(circle which applies)

yes   no   unknown/uncertain

Type of modifications

....

....

Suspension
(circle which applies)

body   cab   other

Suspension type

mechanical   air   hydraulic   other

Comments:

....

....

Vehicle seat

Type/description..

....

(Circle which applies)

rigid (no padding, no suspension)

semi-rigid (rigid with padding)

suspension with padding

air mechanical

Is the seat

dished flat

Tyres/tracks/wheels

(Circle which applies)

air filled foam filled solid tracks other

Comments

....

....

....

Cab:

(Circle which applies)

driver facing

forward sideways

APPENDIX 3

A FLEXIBLE SYSTEM FOR MEASUREMENT AND ANALYSIS OF HUMAN VIBRATION DATA ACCORDING TO AUSTRALIAN AND BRITISH STANDARDS

GARY FOSTER[1], MICHAEL HARRAP[2], AIRDRIE LONG[3] & GERARD FAY[3]

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1. ABSTRACT

A study of whole-body vibration exposures, assessment methods and controls is being carried out in open-cut and underground coal mines by Worksafe Australia. The measurement of vibration exposure in the harsh mining environment presents some problems. In addition, the current Australian Standard (AS 2670) for whole-body vibration assessment has limitations when applied to the mining industry. The British Standard (BS 6841) adopts a different assessment method which may address these limitations. An integrated, compact, high capacity, intrinsically safe vibration measurement and analysis system has been developed to overcome measurement and analysis problems. The system is capable of measuring and analysing vibration data according to both standards. This paper describes the data collection and analysis system developed for the project and outlines the requirements of the British and Australian Standards for whole-body vibration.

2. INTRODUCTION

Worksafe Australia and the Acoustics and Vibration Centre, Australian Defence Force Academy, are conducting a research project which is investigating the exposure of underground and open-cut coal miners to whole-body vibration (WBV).

Back pain is a major problem among coal miners and there is some evidence that exposure to vibration is a contributing factor (Seidel and Heide 1986, Wikstrom, et al 1994). In particular the shocks or 'jolts and jars' experienced by mine workers are believed to be the main element of vibration responsible for the development of back and neck disorders (McPhee and Knowles 1992, Cross and Walters 1994). Miners are exposed to jolts and jars during some mining activities but mainly from vehicles travelling on rough roads.

The mining environment presents problems for the measurement and assessment of whole-body vibration. It can be wet, dusty and harsh with little space available for monitoring instrumentation. The potential for explosive atmospheres in underground coal mines also necessitates the use of intrinsically safe equipment. Vibration containing jolts and jars cannot be properly assessed using the current Australian Standard (AS 2670-1990) for whole-body vibration. The British Standard (BS 6841:1987), however, employs methods which may overcome these problems.

The Worksafe project will analyse vibration recordings according to both the Australian and British Standards in order to assess their suitability to evaluate WBV in mines. In addition, the dynamic characteristics of seating currently used in mining vehicles is being assessed by comparing floor and seat vibration levels.

Suitable instrumentation for the project was not commercially available so it was necessary to develop an integrated, intrinsically safe, compact, dust-proof, waterproof, robust and portable measurement system. A separate software package was also developed which was capable of analysing vibration signals according to both the Australian and British Standards. The methods employed in these standards are outlined below.

Published in the Proceedings of the 1995 Annual Conference of the Australian Institute of Occupational Hygienists

3. WHOLE-BODY VIBRATION STANDARDS

3.1 Australian and International Standards

The current Australian Standard for whole-body vibration (AS 2670.1 1990) is substantially the same as the International Standard (ISO 2631/1 - 1985) which is based on research and international consensus before 1970.

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). Two analysis methods are described in the Australian Standard. The first method, which provides a detailed analysis, compares the unweighted third-octave root mean square (r.m.s.) spectrum with a set of criteria curves for each axis. Boundaries are set for comfort ('reduced comfort boundary'), working efficiency ('fatigue-decreased proficiency boundary') and health ('exposure limit'). The second method frequency weights the signal then calculates the r.m.s. value to give a single 'weighted overall vibration approximation' value for each axis, according to Equation 1 below. This value is then compared with the limit for the most sensitive frequency band.

Equation 1

$$rms = \left[\frac{1}{T} \int_0^T a_w^2(t)dt \right]^{\frac{1}{2}}$$

where:

$a_w(t)$ = frequency - weighted acceleration in ms^{-2}

T = period, in seconds, during which vibration occurs

The major limitation with the Australian Standard and the International Standard is their inapplicability to vibration exposures which 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 which exceed this value.

The r.m.s. processing of the vibration signal does not give sufficient weighting to the high peaks. In an attempt to address this limitation, Griffin and Whitham (1980a,b) investigated the use of the root-mean-quad (r.m.q) as a method for assessing vibration exposures which contain shocks. The r.m.q. is exactly the same as the r.m.s. except that the function, (Equation 1), is raised to the 4th power and the 4th root of the result is taken. This mathematical function gives more weighting to the high peaks contained within the vibration signals. Griffin and Whitham found that r.m.q. averaging gave a better correlation with subjective responses than did the r.m.s. vibration value.

3.2 The British Standard

The current British Standard for WBV has adopted 4th power methods to evaluate vibration exposures containing crest factors exceeding six. The Standard also incorporates a time-dependency to the 4th power method by using a cumulative 'Vibration Dose Value' (VDV), instead of the average value used in the Australian Standard. An 'estimated vibration dose value' (eVDV), may be calculated from the r.m.s. value if the vibration is steady with a crest factor less than six.

The British Standard also considers whole-body vibration which results from contact with the backrest and floor. Rotational axes at the seat are also considered. This recognises all possible points of contact and vibration directions resulting in up to 12 axes to consider. However, it may not be necessary to measure all of these axes for a valid assessment. The frequency weightings which are applied to each of these axes are slightly different from those applied in the Australian Standard.

4. VIBRATION MEASUREMENT SYSTEM

The measurement system consists of six accelerometers, a purpose built data logger, a set of PC cards, (flash cards), a laptop computer and a magneto-optical disk drive.

The accelerometers and data logger are intrinsically safe. The datalogger has high capacity, is compact in size and is housed in a stainless steel enclosure enabling it to withstand the rough conditions found in mines. The set-up and start/stop functions are controlled from a keypad on the front of the unit. An LCD display indicates the level of signal from any of the input channels.

Six input channels are available for the x, y and z axes from two sets of triaxial accelerometers which will be generally located on the seat and floor of the vehicle. When required, the floor accelerometers may be used to measure vibration at the seat back contact point. The seat pad which contains the accelerometers is made from non-static polyurethane material. The floor accelerometers will be mounted on a metal plate which can be bolted or welded to the floor of each test vehicle.

Raw vibration signals are stored on three 20 Mbyte PC cards in the data logger giving a total of 60 Mbyte recording capacity. This allows for an 80-minute sample at a sampling rate of 1kHz. The sampling frequency and anti-alias cut-off frequency can be independently selected on the datalogger. The anti-alias filter is implemented as an 8th order Butterworth switched capacitor filter with appropriate noise limiting filters. For this application, the unit will be configured for a low-pass cut-off frequency of 160 Hz. This satisfies the requirements of both the British and Australian 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.

At the end of a sampling period, data is downloaded to a laptop computer via the removable flash cards. The magneto-optical drive is used for permanent data storage.

5. 'HVIBE' DATA ANALYSIS PROGRAM

Data collected will be analysed using the 'HVIBE' software which has been 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 both AS 2670 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.

The analysis capabilities of the program are as follows:

AS 2670 : Root mean square (r.m.s.) and peak signal levels; crest factor; third-octave spectra; data filtering using the appropriate whole-body frequency-weighting filters.

BS 6841 : Vibration dose value (VDV) and estimated vibration dose value (eVDV); data filtering using the specified whole-body frequency-weighting filters.

Other Analysis: Seat transmissibility; 'SEAT' value (Griffin 1990); narrowband r.m.s. and r.m.q. spectra.

Many of the human vibration calculations described by AS 2670 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 2048 point fast fourier transform (FFT). At the nominal data sampling rate of 1kHz, this leads to 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 two standards. It is also expected that the r.m.s. and r.m.q. spectra will be particularly useful when comparing eVDVs and true VDVs. The latter comparison will be included in the initial studies to be made using this software.

6. CONCLUSION

The whole-body vibration measurement and analysis system is designed to overcome the difficulties in measuring vibration in the harsh mining environment. It assesses whole-body vibration according to both the British and Australian Standards.

The flexibility of the system and the fact that it is custom built allows for modification of the software at a later stage to facilitate experimentation with alternative methods of vibration analysis.

Acknowledgments: The project is funded through the Joint Coal Board's Health and Safety Trust and conducted by a team from the Ergonomics and Occupational Hygiene Units in collaboration with staff from the Acoustics and Vibration Centre, Australian Defence Force Academy. In particular, we would like to thank Dr Hugh Williamson and Mr Murat Tahtali from the Acoustics and Vibration Centre, Australian Defence Force Academy, UNSW for their expertise, advice and assistance.

7. REFERENCES

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

BS 6841 : 1987, *Guide to measurement and evaluation of human exposure to whole-body mechanical vibration and repeated shock.* British Standards Institute, London.

CROSS J. & WALTERS M. 1994, Vibration and jarring as a cause of back injury in the NSW coal mining industry, *Safety Science,* 17:269-274.

GRIFFIN M.J. 1990, *Handbook of Human Vibration,* Academic Press Limited

GRIFFIN M.J. and WHITHAM E.M. 1980a, Discomfort produced by impulsive whole-body vibration, *Journal of Acoustical Society of America,* 68:1277-1284

GRIFFIN M.J. and WHITHAM E.M. 1980b, Time-dependency of whole-body vibration discomfort, *Journal of Acoustical Society of America,* 68:1522-1523

ISO 2631/1 - 1985, *Guide to the evaluation of human exposure to whole-body vibration Part 1: General requirements,* International Standards Organisation, Geneva

McPHEE B and KNOWLES J. 1992, Ergonomics in underground coal mining in NSW. *Proceedings of the 28th Annual Conference of the Ergonomics Society of Australia.* Melbourne, 252-257.

SEIDEL H. and HEIDE R.1986, Long-term effects of whole-body vibration: a critical survey of the literature, *Int Arch Occup Environ Health,* 58:1-26

WIKSTRÖM B.O. KJELLBERG G. A. and LANDSTRÖM U. 1994, Health effects of long-term occupational exposure to whole-body vibration: a review. *Int J Indust Ergonomics* 14:273-292.

Measuring Whole-Body Vibration Exposure in Mining

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ABSTRACT

An investigation is being carried out into Whole-Body Vibration (WBV) exposures in coal mines and the methods of assessing these exposures. The current Australian and International Standards for WBV assessment have limitations when applied to the mining industry. The British Standard adopts a different assessment method which may address these limitations.

This paper describes the methods given in the Australian and International Standards and compares them with the newer methods advocated in the British Standard.

The mining environment presents unique problems for the measurement of vibration. It has been necessary to develop an integrated, intrinsically safe vibration measurement and analysis system for the project. This is a flexible package which is capable of assessing whole-body vibration according to the Australian and British Standards.

The findings of the study will be applicable to all industries in which WBV occurs, for example, agriculture and construction, not just the mining industry.

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. Low back pain is believed to arise from the degeneration of the vertebral endplates and of the lumbar discs (Wikström, Kjellberg and Landström 1994). Muscle fatigue and stiffness have also been reported. Injuries believed to arise from exposure to vibration have led to lost work days through increased absenteeism, early retirement, work inefficiencies and increased compensation costs (Seidal & Heide 1986). Nevertheless to date, there are no conclusive data to link exposures with specific injuries nor to form a dose-response relationship (Wikström, Kjellberg and Landström 1994). However, subjectively, WBV causes discomfort and pain (Griffin 1993a). Workers from a range of industries are exposed to vibration, including construction and demolition, forestry, agriculture, transport and mining. Mine workers are exposed to both steady state vibration and vibration containing shocks. These shocks are commonly called jolts and jars.

The main sources of vibration for mine workers are engine vibration, machine activity and poor road conditions (McPhee and Knowles 1992). Jolts and jars are caused by rough roads and some machine activity (eg. dumping and scraping). The immediate effects of jolts and jars are often no more than discomfort or fatigue, but increasingly, they are reported as the source or aggravation of injuries. Jolts and jars are experienced by passengers and drivers alike in both underground and open cut coal mining and are believed to be the main element of vibration responsible for the development of back and neck disorders in mining personnel (Deacon 1990, McPhee and Knowles 1992, Cross 1993, Cross and Walters 1994).

The full extent of whole-body vibration exposure in mining in Australia is not known but the limited number of studies (Oh & Middlin 1991a,b; Cross 1993) that have been done indicate that some workers are being exposed to levels above that recommended in the current Australian Standard (AS 2670-1990).

In order to prevent or minimise the deleterious effects of exposure to WBV various national and international Standards have attempted to advise practitioners on 'safe' exposure levels. The Australian Standard (AS 2670.1 1990) is substantially the same as the International Standard (ISO 2631 1985) which is based on research conducted over 25 years ago. However, it is now questionable as to whether this Standard can be accepted as a reasonable basis for determining the safety of WBV exposures. Also, only steady-state vibration can be assessed by these Standards. On the other hand the British Standard (6841-1987) is more up-to-date and provides a method for evaluating vibration containing shocks.

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Researchers working in the area of WBV exposure and its detrimental effects on health are hampered by additional problems. These include a lack of adequate and specific exposure data, insufficient information on the mechanisms of injury and lack of any agreed standards in measuring and recording the type, frequency and severity of musculoskeletal symptoms in those exposed (McPhee 1995).

Added to this are the difficulties of measuring exposure. In mining, especially underground mining the problems associated with collection of sufficient, representative samples of work exposure are increased by the need for intrinsically safe equipment which is small in size and robust enough to withstand fairly rigorous handling in confined spaces and difficult environments.

To gain more insight into WBV exposures, their possible effects and controls in the mining industry, Worksafe is conducting a research project to survey WBV exposure in coal mine workers under operational conditions. To assess the suitability of the Australian and British Standards to evaluate whole-body vibration exposures this study will compare exposure data with subjective comfort ratings.

WHOLE-BODY VIBRATION

Whole-body vibration is mechanical vibration transmitted to the body as a whole through contact with a vibrating surface. In the workplace WBV is typically transmitted to the body via the buttocks, feet and back (when seated).

Vibration is generally composed of two components - a steady-state component (eg engine vibrations); and a shock or impulsive component commonly referred to as jolts and jars, as experienced when driving over a pot hole. The crest factor is a measure of the impulsiveness of the signal and is the ratio of the peak value to the root mean square (r.m.s.) value.

Vibration can be transmitted in any direction to the body. To strictly define the vibration vector six orthogonal axes are required (three translational and three rotational axes). Conventionally, the three translational axes are: 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) and the three rotational axes are: r_x rotation around the x axis (roll), r_y rotation around the y axis (pitch), r_z rotation around the z axis (yaw). These axes are defined relative to the subject. Ideally, vibration should be measured at each contact point between the body and the vibrating surface. For a seated subject this would be at the seat, the backrest and the floor (feet). Rotational axes are only important when the contact point for transmission is close to the centre of rotation otherwise the translational axes adequately describe the vibration. In practice only the x, y, and z axes are used and often only the z axis at the seat is measured.

The human body can be considered as a set of mechanical elements that resonate at different frequencies. These elements when combined result in the body being most sensitive to vibration for frequencies up to 100 Hz. The body is also sensitive to the direction of vibration. The most sensitive direction is the vertical axis (foot to head) in the frequency range 4-8 Hz. The vibration signal is weighted to take into account the human frequency sensitivity.

Vibration is generally assessed by measuring the acceleration in metres per second squared (ms^{-2}) but may also be expressed in terms of decibels according to the following formula:

$$L_a = 20\log_{10}\left(\frac{a}{a_0}\right)\ dB$$

where:

L_a = acceleration level
a = measured acceleration in ms^{-2} r.m.s.
a_0 = reference level of 10^{-6} ms^{-2}

The frequencies are restricted to about 0.5 to 100 Hz depending on the method and the direction.

WHOLE-BODY VIBRATION STANDARDS

In Australia the general method used to evaluate WBV exposure is the Australian Standard, 'Evaluation of human exposure to whole-body vibration - Part 1: General requirements', AS 2670.1 1990. It is substantially the same as ISO 2631/1 -1985 which was based on research and international consensus before 1970. Two methods are described in these Standards. The first method, which provides a detailed analysis, compares the unweighted third-octave root mean square (r.m.s.) spectrum with a set of criteria curves for each axis. The permissible exposure time is established by the highest third octave band with respect to the various limit boundaries. The second method, 'the weighted overall vibration approximation', frequency weights the signal then calculates the root mean square to give a single overall weighted vibration value for each axis, according to the formula:

$$rms = \left[\frac{1}{T} \int_0^T a_w^2(t)\, dt \right]^{\frac{1}{2}}$$

where:

$a_w(t)$ = frequency - weighted acceleration in ms^{-2}

T = period, in seconds, during which vibration occurs

This weighted value is then compared with the limit for the axis in the most sensitive frequency band.

The Australian Standard states that the approximation method can give a figure up to 13dB greater than the third-octave method because all frequencies contribute to the single overall value. This leads to an over conservative assessment on the effects of vibration for broad band signals.

The r.m.s. vibration levels and the daily duration of the vibration are compared against one of three boundary conditions. The boundaries are defined as:

a) the preservation of comfort ("reduced comfort boundary");
b) the preservation of working efficiency ("fatigue-decreased proficiency boundary");
c) the preservation of health and safety ("exposure limit"). (AS2670.1 1990)

As the average vibration increases the allowable exposure time decreases. The time dependency used in the Australian Standard provides vibration exposure limits for periods of 1 minute to 24 hours.

With reference to the exposure limit the Standard states: "The exposure limit recommended 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. (Such limit levels have been explored for male human subjects in laboratory research.)" The exposure limit is 6dB (2 times) the fatigue-decreased proficiency limit. The reduced comfort boundary is 10dB (3.15 times) below the fatigue-decreased proficiency boundary. However, the method used to determine the relationship between these boundaries and their time dependency is not documented and does not reflect subjective responses to vibration. The reduced comfort boundary is set at a level which does not take into account its subjective nature. For example, a luxury car occupant will expect a higher level of comfort than a bulldozer driver.

The Australian and International Standards only consider vibration in the three translational axes centred at the heart. They do not consider the vibration at the backrest, the floor (for a seated subject) or rotational vibration. The combined effect of vibration in the three translational axis maybe greater than the effect in any single axis. A value for this combined acceleration may be calculated from the following formula as given in AS 2670.1:

$$a = \sqrt{(1.4a_{xw})^2 + (1.4a_{yw})^2 + (a_{zw})^2}$$

where:

a = vector sum of the overall weighted vibration values

a_{xw}, a_{yw}, a_{zw} = the overall weighted vibration values for their respective axes

The vector sum is compared with the limit in the 4-8Hz range of the z-axis.

Most research to date has assessed vibration against the International Standard or the Australian Standard despite their short comings. The major limitation with these Standards is their inability to assess vibration exposures which exceed a crest factor of 6 (the crest factor is the ratio between the maximum peak value and the r.m.s. value). High crest factors are subjectively felt as jolts and jars. Jolts and jars are found to be disturbing by mine workers (McPhee and Knowles 1992) and it is important to assess this component of vibration as it is thought to be a major cause of injury in mining vehicles. Griffin and Whitham (1980a, b) have investigated the use of root-mean-quad (r.m.q) as a method for assessing vibration exposures which contain shocks. The r.m.q. is exactly the same as the r.m.s. except the function is raised to the 4th power and the 4th root is taken of the result. This mathematical function gives more weighting to the high peaks contained within the vibration signals. They found r.m.q. averaging gave better correlation with subjective responses than did the r.m.s. method.

The current British Standard for WBV, BS 6841: 1987 "Guide to measurement and evaluation of human exposure to whole-body mechanical vibration and repeated shock" has adopted 4th power methods to evaluate vibration exposure with crest factors greater than six. The British Standard implies the use of r.m.s. methods for crest factors less than six. The Standard incorporates a time dependency to the 4th power method by using a cumulative "Vibration Dose Value (VDV)" instead of an average value. Hoddinott (1986 as cited in Griffin 1990 p85) found better correlation between VDV, rather than r.m.s. methods, for subjective responses to vibration exposure which includes jolts and jars. The VDV is calculated according to the following formula:

$$VDV = [\int_0^T a_w^4(t)dt]^{\frac{1}{4}}$$

where:

$a_w(t) =$ frequency – weighted acceleration in ms^{-2}

T = total period, in seconds, during which vibration may occur

The British Standard gives a 'tentative action level' for the vibration dose value of $15ms^{-1.75}$ in any one day. In defining this action level, BS 6841 states that, "It is known that vibration magnitudes and durations which produce vibration dose values in the region of $15ms^{-1.75}$ will usually cause severe discomfort. It is reasonable to assume that increased exposure to vibration will be accompanied by increased risk of injury."

It should be noted that the value of $15ms^{-1.75}$ is a 'tentative action level' and not a limit (Griffin 1993b).

An 'estimated vibration dose value', eVDV, may be calculated from the r.m.s. value if the vibration is steady with a crest factor less than six. The eVDV will underestimate the true VDV when the vibration crest factor is greater than about six and slightly overestimate the vibration exposure if the crest factor is below three. The eVDV is easier to calculate than the 'true' VDV.

$$eVDV = [(1.4 \times a)^4 \times b]^{\frac{1}{4}}$$

where:

a = measured weighted rms value in ms^{-2}

b = duration of the vibration in s

The British Standard also considers whole-body vibration which results from contact with the backrest and floor. Rotational axes at the seat are also considered. This recognises all possible points of contact and vibration directions resulting up to 12 axes to consider. However, it may not be necessary to measure all of these axes for a valid assessment. Frequency weightings are applied to each of these axes and are slightly different from those applied in the Australian Standard.

As in the Australian Standard, the British Standard gives a method for the calculation of an acceleration value for the combined effect of vibration in each translational axis resulting in a 'total vibration dose value'. The total VDV is the fourth root of the sum of the fourth power of each VDV in each axis (BS 6841 : 1987 Appendix A).

To date little has been published on research using the British Standard assessment method making comparison of results difficult. Griffin (1986) reported field comparisons of the weighted r.m.s. method from the International Standard with the British Standard for road vehicles, a tractor and a military tank. He concluded that the British Standard provided a more realistic assessment of the vibration exposure.

THE STUDY

The Worksafe study is investigating whole-body vibration exposure of mine workers under operational conditions in open-cut and underground mines. The measurements of WBV exposure will be obtained for representative durations on a cross section of mining vehicles. The vibration exposures will be analysed according to the methods set out in both the Australian and British Standards. Subject ratings of the vibration exposures will be compared with the actual vibration measurements. By taking measurements at the floor and the seat the damping characteristics of the seats presently in use in mine vehicles can be evaluated.

Instrumentation

Coal mines have hazardous areas containing explosive atmospheres, generally methane. To use electrical equipment in coal mines it needs to be approved as intrinsically safe. Intrinsic safety means that no spark or thermal effect can be produced by the equipment to cause ignition of an explosive atmosphere. Battery powered equipment requires careful design to satisfy intrinsic safety standards.

The instrumentation needed to carry out the study has been developed in collaboration with the Acoustics and Vibration Centre (ADFA, Canberra). The equipment includes two sets of triaxial accelerometers, high capacity datalogger and a software program capable of analysing and assessing vibration exposures in accordance with both Australian and British Standards.

The two triaxial accelerometers will measure the three translational axes at the seat and the floor. The datalogger and transducers are intrinsically safe, compact, robust, dust proof, and water resistant to survive in the mining environment.

OUTCOMES

There are four major outcomes planned from this study:

- a survey of exposure to whole-body vibration of coal mine workers operating a range of mining vehicles under operational conditions in both open-cut and underground mines and a comparison of these exposures with subjective ratings of ride quality and symptoms of back pain;
- development of an integrated, compact, high capacity, intrinsically safe vibration measurement and analysis system;
- analysis of vibration exposure data according to both the Australian and British Standards; and
- production of industry guidelines for the measurement and control of vibration in coal mines;

This system will allow the recorded vibration to be analysed to both Australian and British Standards by non-experts. It can be used for vibration exposure measurements in all industries not just mining.

The industry guidelines will be produced as a manual. It will be a practical guide to reduce the vibration exposure in the coal mining industry. Much of the information contained in this manual will be applicable to a range of industries where WBV is a problem (for example, construction and demolition, forestry, agriculture, transport and other mining activities).

CONCLUSION

The Australian and British Standards differ in their approach to whole-body vibration analysis. The British Standard, using fourth power methods, may be more relevant to the measurement and assessment of whole-body vibration in the coal mining industry. This study will gather more field data to help resolve the problems of whole-body vibration measurement and assessment.

ACKNOWLEDGMENTS

The project is funded through the Joint Coal Board's Health and Safety Trust and conducted by a team from the Ergonomics and Occupational Hygiene Units of Worksafe Australia in collaboration with staff from the Acoustics and Vibration Centre, Australian Defence Force Academy.

Published in the Proceedings of the 1995 Annual Conference of the Ergonomic Society of Australia

In particular, we would like to thank Dr Hugh Williamson, Dr Michael Harrap and Mr Murat Tahtali from the Acoustics and Vibration Centre, Australian Defence Force Academy, UNSW for their expertise, advice and assistance.

Disclaimer: *The conclusions reached and scientific views presented in this paper are those of the authors and do not necessarily reflect those of Worksafe Australia.*

REFERENCES

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

BS 6841 : 1987, *Guide to measurement and evaluation of human exposure to whole-body mechanical vibration and repeated shock.* (British Standards Institute, London.)

CROSS, J., 1993, *Whole Body Vibration in Underground Mining, Department of Safety Science,* University of NSW for the Department of Mineral Resources.

CROSS, J. and WALTERS, M. 1994 Vibration and jarring as a cause of back injury in the NSW coal mining industry, *Safety Science,* **17**, 269-274.

DEACON, A.J, 1990, *Report on Open-Cut Seating for Mobile Equipment Operators.* (Tarong Coal on behalf of the Queensland Coal Association, March).

GRIFFIN, M.J., 1986, Evaluation of vibration with respect to human response. *SAE Paper 860047.* Society of Automotive Engineers International Congress and Exposition, Detriot, 24-28 February 1986.

GRIFFIN, M.J., 1990, *Handbook of Human Vibration,* Academic Press Limited

GRIFFIN, M., 1993a, *Vibration and Health, Proceedings of a Seminar on Human Vibrations. The Effect of Vibrations on People at Work,* Worksafe Australia, Acoustics and Vibration Centre (ADFA), and La Trobe University, Sydney, Canberra and Melbourne.

GRIFFIN, M., 1993b, *Ride and Comfort in Vehicles, Proceedings of a Seminar on Human Vibrations. The Effect of Vibrations on People at Work,* Worksafe Australia, Acoustics and Vibration Centre (ADFA), and La Trobe University, Sydney, Canberra and Melbourne.

GRIFFIN, M.J. and WHITHAM E.M. 1980a, Discomfort produced by impulsive whole-body vibration, *Journal of Acoustical Society of America,* **68,** 1277-1284

GRIFFIN, M.J. and WHITHAM E.M. 1980b, Time-dependency of whole-body vibration discomfort, *Journal of Acoustical Society of America,* **68,** 1522-1523

HODDINOTT, J.C., 1986, Investigation of the effect of duration on alternative methods of assessing human response to impulsive motion, *United Kingdom Group Meeting on Human Response to Vibration,* Loughborough University of Technology, 22-23 September 1986

ISO 2631/1 - 1985, *Guide to the evaluation of human exposure to whole-body vibration Part 1: General requirements.* (International Standards Organisation, Geneva)

Published in the Proceedings of the 1995 Annual Conference of the Ergonomic Society of Australia

McPHEE, B., 1995 Exposure to Whole-Body Vibration (WBV) and Back Disorders in Mineworkers *Proceedings of the 31st Annual Conference of the Ergonomics Society Australia, Adelaide(in preparation)*

McPHEE, B. and KNOWLES J. 1992, Ergonomics in underground coal mining in NSW. *Proceedings of the 28th Annual Conference of the Ergonomics Society of Australia.* Melbourne, 252-257.

OH, X. and MIDDLIN, A. 1991a, *Reduction of Personnel Vibration Hazards in Underground Coal Mines*, (National Energy Research, Development and Demonstration Program, Grant Report No. 1037).

OH, X. and MIDDLIN, A. 1991b, *Seating for Open-cut Moble Equipment Operators*, (Australian Coal Association Research Program, Grant Report No. 1339)

SEIDEL, H. and HEIDE, R. 1986, Long-term effects of whole-body vibration: a critical survey of the literature, *Int Arch Occup Environ Health*, **58,** 1-26

WIKSTRÖM, B.O. KJELLBERG, G. A. and LANDSTRÖM, U. 1994, Health effects of long-term occupational exposure to whole-body vibration: a review. *Int J Indust Ergonomics* **14,** 273-292.

Published in the Proceedings of the 1995 Annual Conference of the Ergonomic Society of Australia

Review of Exposure to Whole-Body Vibration (WBV) and Back Disorders in Mineworkers

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ABSTRACT

The scientific literature increasingly points to links between Whole-body Vibration (WBV) exposure and health disorders such as low back pain (LBP). In Australia a range of industries require 'off road' driving thereby subjecting employees to unknown levels of WBV. In mining there is an increasing awareness about the need to control such exposures and the need for more research on the topic. Issues needing to be addressed are actual WBV exposures and their causative factors such as the condition of roads; the engine and vehicle activity; vehicles, cab and seat design; and driver skills. As well, the link between exposures and health problems needs to be clarified.

1. INTRODUCTION

The putative effects on humans of exposure to Whole-Body Vibration (WBV), at best may be discomfort and interference with activities; at worst may be injury or disease *(Griffin 1993)*. However, comparatively little is known about the specific effects of exposure to vibration, particularly WBV, on the musculoskeletal system.

In Australia there are a number of industries and occupations which require workers to drive 'off road' vehicles and machinery. These include mining, farming and agriculture, forestry, construction, minerals exploration and utilities. The intensity and duration of exposures to WBV appear to vary but there is no information to confirm this or whether these exposures lead to ill-health or injuries. The need to reduce the risks for back pain and other sprains and strains is being recognised by employers and others; the reduction of WBV exposure is now viewed as one way to prevent or, at least reduce, the severity of these disorders.

2. RISK FACTORS FOR BACK PAIN

In the developed world, work-related back disorders are the commonest causes of workers' compensation claims, sick leave and early retirement *(Kelsey and Hardy 1975; Frymoyer et al 1983; Kumar and Davis 1983; Westgaard and Åaras 1984)*. Back disorders are usually accompanied by back pain and no truly effective medical or surgical treatment exists for a large number of cases.

Back disorders are believed to arise from damage to the spine and surrounding structures brought about by an accumulation of strains placed on the back over time and some occupations have been associated with earlier, more frequent or more severe symptoms (*Wickström 1978; Riihimäki et al 1989)*. These disorders are most commonly seen in middle aged and older people (> 35 years) *(Andersson 1981)* although it is not unusual for symptoms to be reported by teenagers and young adults. In some cases acute injuries, resulting from severe trauma, such as car accidents, precipitate symptoms in young people with little evidence of prior damage. However, in most people the precipitating event is unlikely to be the 'cause' of the disorder - it is simply 'the last straw'.

A number of different work-related and individual factors are considered to be risk factors for back disorders but there is no clear understanding of the relative contribution of these factors. As well there is no general explanation of *how* back disorders occur, that is, what actually goes wrong in the back which gives rise to symptoms. However, epidemiological studies have

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indicated that the following factors in physical work increase the risk of back disorders and pain:

- heavy dynamic physical work (e.g. manual handling)
- static work postures (including sedentary work)
- frequent bending and twisting of the trunk
- lifting and forceful movements
- repetitive work
- vibration *(Andersson 1981).*

While there has been a range of research carried out in the areas of physical loads and postures and their relationship to back pain, much less is known about the effects on the musculoskeletal system of exposure to WBV.

3. MUSCULOSKELETAL DISORDERS ARISING FROM EXPOSURE TO WBV

Research to date reveals a lack of dose-response correlation between WBV exposure and symptoms of musculoskeletal disorders such as LBP. This reflects more on the complexity of the research rather than a lack of interest by investigators. It has proved very difficult to obtain real exposure and follow-up data. Many of the investigations deal with *either* the effects of short or long term exposure on health; *or* the measurement of exposure at work or in the laboratory. Both are difficult areas: the former because of either the variability of measures for clinical outcomes, or the lack of information on the link between biomechanical, physiological or psychological changes and exposures. The latter is difficult because of the problems associated with gathering representative WBV exposure data.

The most frequently reported adverse effect from all sources of WBV is LBP and sciatica thought to arise from premature degeneration of the joints and end plates of the spinal vertebrae and herniated lumbar disc *(Wickström 1978; Wilder et 1982; Frymoyer et al 1983; Kjellberg and Wikström 1985; Kjellberg, Wikström and Dumberg 1985; Seidel, Bluethner and Hinz 1986; Dupuis and Zerlett 1987; Hulshof and Van Zanten 1987; Kjellberg and Wikström 1987; Boshuizen, Hulshof and Bongers 1990; Dupuis, Hartung and Haverkamp 1991; Pelmear, Roos and Maehle 1992, Seidel 1993; Wikström, Kjellberg and Landström 1994).* Paraesthesia of the limbs also has been reported *(Dupuis and Zerlett 1987).* Laboratory studies have noted degeneration of the lumbar vertebrae after intense long-term exposure to WBV *(Seidel and Heide 1986).*

Dupuis and Zerlett (1987) noted that reports of back pain were age-related, i.e. reports of LBP increased with age, as might be expected in the general population *(Wickström 1978; Andersson 1981).* However, there is evidence that back pain is occurring earlier than expected for workers exposed to WBV (*Boshuizen, Bongers and Hulshof 1992*). In the Netherlands, Germany and the USA studies of people exposed to vibration at work indicate that, *when compared with controls,* premature spinal degeneration and/or low back pain was more prevalent in crane operators *(Bongers et al 1988a,b; Boshuizen et al 1990a,b; Burdorf and Zondervan 1990);* helicopter pilots *(Bongers et al 1990; Boshuizen, Bongers and Hulshof 1990b);* subway train operators *(Johanning 1991);* tractor drivers *(Boshuizen et al 1990 a,b; Boshuizen, Bongers and Hulshof 1992);* and forklift drivers *(Brendstrup and Biering-Sørensen 1987).*

Prolonged sitting, poor working postures and inadequate ergonomic conditions (including poor seat and cab design) also are believed to contribute to back pain and are usually found in association with WBV exposure *(Kelsey and Hardy 1975; Troup 1978; Wickström 1978; Bongers et al 1988a, 1990; Riihimäki et al 1989; Burdorf and Zondervan 1990; Johanning*

Published in the Proceedings of the 1995 Annual Conference of the Ergonomic Society of Australia

1991; Boshuizen, Bongers and Hulshof 1992). As well, many driving jobs involve manual handling *(Wickström 1978; Riihimäki et al 1989).* Therefore it is not possible at this stage to indicate the specific contribution WBV exposures make to low back pain (LBP), and other musculoskeletal symptoms, separate from these important factors.

Injuries believed to arise, at least partially, from exposure to WBV have led to lost work days through increased absenteeism, early retirement, work inefficiencies and increased compensation costs *(Seidal and Heide 1986; Bongers et al 1988b; Boshuizen, Bongers and Hulshof 1990b;). Deacon (1990)* reported that the NSW Joint Coal Board figures indicated that vibration and shock is responsible for 30% of all back injuries in open-cut coal mines. *Cross and Walters (1994)* examined NSW mineworkers' compensation data relating to reported 'causes' of back pain. They found that no conclusion could be drawn from these data with regard to the relationship between overall vibration exposure and claims for back injury. However, approximately 11% of neck and back injuries were reported to be due to vehicle jarring. The contributory effects of vibration, as one of several risk factors, to the onset of back and neck pain could not be determined from the Workers' Compensation statistics.

There is virtually no information on ways by which workers' exposure to WBV might be attenuated such as the impact on exposure of improved road maintenance, correct cab and seat design, carefully selected seat cushioning and well designed seat suspension. These aspects are now considered to be important but, to date, no intervention studies appear to have addressed them.

4. EXPOSURE TO WBV IN MINING

Mineworkers are exposed to WBV while using transport and other mining equipment. While some work has been done on WBV exposure in coal mineworkers in Australia *(Oh and Middlin 1991a,b; Cross 1993, Cross and Walters 1994)*, Canada *(Village 1989; Village Morrison and Leong 1989)* and the USA *(Hutton and Brubaker 1982; Love et al 1992; Gagliardi and Utt 1993)* the full extent of WBV exposure in mining in Australia is not known. However, there is evidence that some exposure levels are above that recommended in the current Australian Standard (AS 2670-1990) for many operators and perhaps passengers *(Oh and Middlin 1991a,b; Cross 1993, 1994)*.

A previous study of open-cut mines found that many vehicles in use including scrapers, haulage trucks, dozers and graders were unacceptable when assessed against current Australian Standards *(Oh and Middlin 1991a)*.

Anecdotal evidence suggests that drivers of bulldozers and dump trucks in open-cut mines are exposed to excessive WBV according to the Australian Standard. For workers in underground mines the duration of exposure to WBV may be less but the magnitude is likely to be higher than in open-cut mines due to the poor conditions and nature of the vehicles used. A study *(Village 1989)* of underground load-haul-dump vehicles (LHDs), found that 20 of 22 tested vehicles exceeded the ISO 2631 six hour limit in the z direction (vertical axis through the body).

In mining, WBV is considered as having two different components i.e. a continuous level (or steady state); and jolts and jars. The main sources of vibration for operators of mining equipment are engine vibration, machine activity (dumping, loading etc) and road conditions. The jolts and jars which occur while a vehicle is in motion are usually referred to as 'rough rides'. The immediate effects of 'rough rides' for many mineworkers may not be more than discomfort or fatigue. However, increasingly, they are being reported as the source or aggravation of injuries *(McPhee and Knowles 1992; Cross and Walters 1994)*. In underground and open cut coal mines 'rough rides' are experienced by both passengers and

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drivers. They are believed to be the major source of vibration responsible for the development of back and neck disorders in mine workers.

A number of other factors including vehicle suspension, cab and seat design, visibility and driver skills are all believed to either amplify or attenuate the exposures *(McPhee and Knowles 1992; McPhee 1994, p13).*

While passengers in mine transport vehicles often are seated for shorter periods than drivers, rough rides for them may still be harmful: passengers cannot see or anticipate rough patches; they often face sideways and have no way of bracing or reducing the impact of jolts and jars; much of the seating is poorly designed; and some transport vehicles do not have suspension.

5. VIBRATION STANDARDS

The current Australian Standard AS2670.1-1990 *Evaluation of Human Exposure to Whole-Body Vibration* is essentially the same as the International Standard ISO2631-1985. This Standard assesses the WBV exposure against three criteria:

1. the preservation of health or safety ('exposure limit')
2. the preservation of working efficiency ('fatigue decreased deficiency boundary')
3. the preservation of comfort ('reduced comfort boundary').

The limits consider the permissible duration of the exposure at different frequencies.

A major limitation of the Australian Standard is the inability to assess vibration exposures which are subjectively felt as jolts and jars. It is now considered important to assess this component of WBV as it is thought to be a major cause of injury.

However, the British Standard BS 6840:1987, *Guide to measurement and evaluation of human exposure to whole body mechanical vibration and repeated shock* can assess vibration exposures which include jolts and jars. The "vibration dose value" is more applicable to mining because it is a measure of *total* exposure rather than the *average* exposure. The vibration dose procedure yields a better correlation with subjective responses of the ride than does the Australian Standard. However, there is still much research needed before a proper dose - response relationship can be established for WBV. Published literature to date indicates that the British Standard has not been used to assess vibration in the mining industry.

6. CONTROL OF VEHICLE VIBRATION

To reduce vibration exposure while driving the following factors need to be addressed:

- poor road conditions
- lack of adequate suspension in vehicles
- lack of appropriate seat suspension
- poor cab design, layout and position
- poor seat design
- poor visibility and
- inadequate driver skills and awareness *(McPhee and Knowles 1992).*

These problems exist in a range of industries but especially in underground and open cut mining. They are gaining recognition as the probable source of at least some of the back and other musculoskeletal disorders experienced by mineworkers. While there appears to have been very little research into, or systematic review of these factors, the NSW Coal Mining Inspectorate, mine managers and most manufacturers of equipment now recognise the need for better seating and vehicle suspension (*Department of Mineral Resources NSW 1995*).

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6.1 Seat suspensions

Oh and Middlin (1991a,b) undertook WBV measurement in both open-cut and underground coal mines in NSW and Queensland. These data were used to develop a seat prototype suspension mechanism to reduce the detrimental effects of vibration on open-cut mine machinery operators. While the underground version is some way off, the open-cut version is currently being trialed in NSW mines.

From experimental data *Cross (1993)* found that the acceleration of the seat is a strong function of the roadway surface, the speed of the vehicle and the seat design. Cross also indicated that the vibration measurements should evaluate the vibration over the period that the vehicle is in motion, otherwise the vibration is easily dominated by the work cycle rather than the intrinsic vehicle vibration.

The U.S. Bureau of Mines *(Gagliardi and Utt 1993)* compared mechanical and air suspension seats in laboratory tests. At the vibration levels tested, the air suspension seat, pressurised above 503.3 kPa provided better vibration attenuation than the mechanical suspension.

6.2 Road construction and maintenance

The Australian Road Research Board (1993) has produced a handbook on the construction and maintenance of unsealed roads. This contains useful information for all industries. In order to assist underground mining personnel with the correct development and maintenance of roads a report has been written which outlines ways in which problems such as water and vehicle damage to roads can be reduced *(Coffey and Partners 1994)*.

7. CONCLUSION

As information from current and future research becomes available it may be easier to quantify WBV exposures for workers in a number of Australian industries. However, in the meantime it is critical that ways of controlling exposure are investigated and the findings publicised.

ACKNOWLEDGEMENTS
The project mentioned above is funded by the Joint Coal Board's Health and Safety Trust and is conducted by a team from the Ergonomics and Occupational Hygiene Units at Worksafe Australia in collaboration with staff from the Acoustics and Vibration Centre, Australian Defence Force Academy, Canberra.

REFERENCES

ANDERSSON, G.B.J. 1981 Epidemiologic aspects on low-back pain in industry, *Spine*, **6**, 53-60.

AUSTRALIAN ROAD RESEARCH BOARD, 1993, *Unsealed Road Manual - Guidelines for Good Practice*, (Commonwealth Office of Local Government, Department of Defence - Army and the Australian Roads Research Board, Canberra).

BONGERS, P.M., BOSHUIZEN, H.C., HULSHOF, C.T.J. and KOEMEESTER, A.P., 1988a, Back disorders in crane operators exposed to whole-body vibration, *International Archives of Occupational and Environmental Health*, **60**, 129-137

Published in the Proceedings of the 1995 Annual Conference of the Ergonomic Society of Australia

BONGERS, P.M., BOSHUIZEN, H.C., HULSHOF, C.T.J. and KOEMEESTER, A.P., 1988b, Long-term sickness absence due to back disorders in crane operators exposed to whole-body vibration, *International Archives of Occupational and Environmental Health*, **61**. 59-64

BONGERS, P.M., HULSHOF, C.T.J., DIJKSTRA, L., BOSHUIZEN, H.C., GROENHOUT, H.J.M. and VALKEN, E., 1990, Back pain and exposure to whole body vibration in helicopter pilots, *Ergonomics*, **33**, 1007-1026

BOSHUIZEN, H.C., BONGERS, P.M. and HULSHOF, C.T.J., 1990a, Self-reported back pain in tractor drivers exposed to whole-body vibration, *International Archives of Occupational and Environmental Health*, **62**, 109-115

BOSHUIZEN, H.C., BONGERS, P.M. and HULSHOF, C.T.J., 1990b, Back disorders and occupational exposure to whole-body vibration, *International Journal of Industrial Ergonomics*, **6**, 55-59.

BOSHUIZEN, H.C., HULSHOF, C.T.J. and BONGERS, P.M., 1990, Long-term sick leave and disability pensioning due to back disorders of tractor drivers exposed to whole-body vibration, *International Archives of Occupational and Environmental Health*, **62**, 117-122

BOSHUIZEN, H.C., BONGERS, P.M. and HULSHOF, C.T.J, 1992, Self-reported back pain in fork-lift truck and freight-container tractor drivers exposed to whole-body vibration, *Spine*, **17**, 59-65

BRENDSTRUP, T. and BIERING-SØRENSEN, F., 1987, Effect of fork-lift driving on low-back trouble, *Scandinavian Journal of Work Environment and Health*, **13**, 445-452

BURDORF, A. and ZONDERVAN, H., 1990, An epidemiological study of low-back pain in crane operators, *Ergonomics*, **33**, 981-987

COFFEY and PARTNERS INT. P/L, 1994, *Underground Roads Manual. Construction and Maintenance. Report No 2197/6-AA*, (C3026 AMIRA, Melbourne).

CROSS, J., 1993, *Whole Body Vibration in Underground Mining*, (Department of Safety Science, University of NSW for the Department of Mineral Resources).

CROSS, J. and WALTERS, M., 1994, Vibration and jarring as a cause of back injury in the NSW coal mining industry, *Safety Science*, **17**, 269-274.

DEACON, A.J, 1990, *Report on Open-Cut Seating for Mobile Equipment Operators*. (Tarong Coal on behalf of the Queensland Coal Association, March).

DEPARTMENT OF MINERAL RESOURCES NSW, 1995, *Coal Mining Inspectorate Guideline for Free Steered Vehicles, MDG No:1 , (NSW DMR).*

DUPUIS, H., and ZERLETT G., 1987, Whole-body vibration and disorders of the spine. *International Archives of Occupational and Environmental Health*, **59**, 232-336.

DUPUIS, H., HARTUNG, E. and HAVERKAMP. M., 1991, Acute effects of transient vertical whole-body vibration, *International Archives of Occupational and Environmental Health*, **63**, 261-265

FRYMOYER, J., POPE, M., CLEMENTS, J., WILDER D., MacPHERSON, B., ASHIKAGA, T., 1983, Risk factors in low back pain, *Journal of Bone and Joint Surgery*, **65-A**, 213-218.

GAGLIARDI, J.C., UTT, W.K., 1993, *Vibration testing of off-road vehicle seats,* (US Bureau of Mines. Pittsburgh, PA).

GRIFFIN, M., 1993, *Vibration and Health, Proceedings of a Seminar on Human Vibrations. The Effect of Vibrations on People at Work,* (Worksafe Australia, Acoustics and Vibration Centre (ADFA), and La Trobe University, Sydney, Canberra and Melbourne).

HULSHOF, C. and VAN ZANTEN, V., 1987, Whole-body vibration and low-back pain, *International Archives of Occupational and Environmental Health,* **59**, 205-220

HUTTON, S.G. and BRUBAKER, R., 1982, Vibration effects on mine workers, *CIM Bulletin, February,* 85-93

JOHANNING, E., 1991, Back disorders and health problems among subway train operators exposed to whole-body vibration, *Scandinavian Journal of Work Environment and Health,* **17**, 414-9

KELSEY, J., and HARDY, J., 1975, Driving of motor vehicles as a risk factor for acute herniated lumbar disc, *American Journal of Epidemiology,* **102**, 63-73.

KJELLBERG, A. and WIKSTRÖM, B.O., 1985, Whole-body vibration: exposure time and acute effects - a review, *Ergonomics,* **28**, 535-544

KJELLBERG, A., WIKSTRÖM, B.O. and DIMBERG, U., 1985, Whole-body vibration: exposure time and acute effects - experimental assessment of discomfort, *Ergonomics,* **28**, 545-554

KJELLBERG, A. and WIKSTRÖM, B.O., 1987, Acute effects of whole-body vibration, *Scandinavian Journal of Work Environment and Health,* **13**, 243-246

KUMAR, S., and DAVIS, P.R., 1983, Spinal loading in static and dynamic postures: EMG and intra-abdominal pressure study. *Ergonomics,* **26**, 913-922.

LOVE, A.C., UNGER, R.L., BOBICK, T.G. and FOWKES, R.S., 1992, *A Summary of Current Bureau Research into the Effects of Whole-Body Vibration and Shock on Operators of Underground Mobile Equipment* (US Bureau of Mines. Pittsburgh, PA).

McPHEE, B., 1994 *Ergonomics for the Control of Sprains and Strains in Mining.* (Joint Coal Board and Worksafe Australia, Sydney, Australia).

McPHEE, B. and KNOWLES, J., 1992, Ergonomics in underground coal mining in NSW. *Proceedings of the Annual Conference of the Ergonomics Society of Australia.* Melbourne, 252-257.

OH, X., and MIDDLIN, A., 1991a, *Reduction of Personnel Vibration Hazards in Underground Coal Mines,* (National Energy Research, Development and Demonstration Program, Grant Report No. 1037 March 1991).

OH, X., and MIDDLIN, A., 1991b, *Seating for Open-cut Mobile Equipment Operators,* (Australian Coal Association Research Program, Grant Report No. 1339, August 1991).

PELMEAR, P.L., ROOS, J.O. and MAEHLE, W.M., 1992, Occupationally-induced scleroderma, *Journal of Occupational Medicine,* **1**, 20-25

RIIHIMÄKI, H., TOLA, S., VIDEMAN, T. and HÄNNINEN, K., 1989, Low-back pain and occupation. A cross-sectional questionnaire study of men in machine operating, dynamic physical work, and sedentary work, *Spine*, **14**, 204-209

SEIDEL, H. and HEIDE, R., 1986, Long-term effects of whole-body vibration: a critical survey of the literature, *International Archives of Occupational and Environmental Health*, **58**, 1-26

SEIDEL, H., BLUETHNER, R. and HINZ, B., 1986, Effects of sinusoidal whole-body vibration on the lumbar spine: the stress-strain relationship, *International Archives of Occupational and Environmental Health*, **57**, 207-223

SEIDEL, H., 1993, Selected health risks caused by long-term whole-body vibration exposure. *American Journal of Industrial Medicine*, **23**, 589-604.

TROUP, J.D.G., 1975, Driver's back pain and its prevention. *Applied Ergonomics*, **9**, 207-214.

VILLAGE, J., 1989, Ergonomic and environmental assessment of haulage trucks for design improvements, *Proceedings of the Annual Conference of the Human Factors Association of Canada.*

VILLAGE, J., MORRISON, J.B. and LEONG, D.K.N., 1989, Whole-body vibration in underground load-haul-dump vehicles, *Ergonomics*, **32**, 1167-1183

WESTGAARD, R., and ÅARAS, A., 1984, Postural strain as a causal factor in the development of musculoskeletal illness, *Applied Ergonomics*, **15**, 162-174.

WICKSTRÖM, G., 1978, Effect of work on degenerative back disease, *Scandinavian Journal of Work Environment and Health*, Suppl 1, 1-12

WIKSTRÖM, B.O., KJELLBERG, G. A. and LANDSTRÖM, U., 1994, Health effects of long-term occupational exposure to whole-body vibration: a review. *International Journal of Industrial Ergonomics*, **14**, 273-292.

WILDER, D.G., WOODWORTH, B.B., FRYMOYER, J.W. and POPE, M.H., 1982, Vibration and the human spine, *Spine*, **7**, 243-254.

Published in the Proceedings of the 1995 Annual Conference of the Ergonomic Society of Australia

A comparison of rides on different vehicles using three current Standards for Whole-body Vibration (WBV) exposures

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Keywords: Whole-body Vibration (WBV), Standards, exposures, mining vehicles.

ABSTRACT

Whole-body Vibration (WBV) Standards are changing. The current Australian Standard (AS), based on the previous International Standard, appears inadequate in the assessment of risks for injury to drivers from WBV especially if exposures include jolts and jars. The British (BS) and the new International Standards (IS) adopt different assessment methods which may address these limitations.

In a study of WBV exposures in coal mining vibration, results for an average ride of each of three vehicle types commonly used in open-cut mines were analysed according to the three different Standards and the results compared.

The roughest rides were experienced in the manhaul vehicle and bulldozer with a high proportion of jolts and jars. The dump truck recorded much lower vibration levels.

In terms of permissible exposure times, the current AS is the least stringent. Almost all vehicle rides would satisfy the exposure and fatigue criteria for an 8 hour shift if the one-third octave method of assessment is used. The recommended maximum exposure levels are greatly reduced under BS criteria with the manhaul and bulldozer reduced to five hours and one hour respectively.

The new IS combines aspects of the previous IS and the BS and provides guidelines on 'caution zones' for excessive vibration levels. Using this Standard the manhaul and dozer reached the caution zone in 12 and 31 minutes respectively, while the dump truck was acceptable for 12 hours.

It is concluded that the newer Standards appear to be much more stringent than the current AS and may be more appropriate for assessing risks for injury.

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1. INTRODUCTION

There is limited relevant scientific information on the effects of WVB on the human body. Most exposure studies relate to the z-axis and were conducted in laboratories (Griffin, 1990). The contribution of vibration in the x- and y-axes to back pain and other symptoms is acknowledge but not quantified and it is not possible at the moment to specify, with any precision, the type or probability of injury caused by overall vibration exposure. However, anecdotal and statistical evidence and biomechanical research indicate that jarring in vehicles is the direct precipitator of some vibration related back problems (McPhee 1995).

The current Australian Standard for WBV exposure (1990) is based on an International Standard adopted in 1985. It has been recognised that this Standard does not properly assess all the risks of exposures especially if they include shocks or jolts and jars. In terms of permissible exposure times, the AS is less stringent than the BS and the IS (Long *et al*, 1995).

The British Standard (1987) addresses the issue of jolts and jars by incorporating a vibration dose value (VDV) which is based on 4^{th} power methods. In 1997 a new International Standard was adopted which combines aspects of the previous IS and the BS and provides guidelines on 'caution zones' for excessive vibration levels. It also incorporates the VDV for exposures which include high peaks. However, none of the current standards addresses the effects of intermittent exposures to vibration or the influence of work breaks.

For this analysis two drivers and one passenger in three different vehicles commonly used in open-cut mines were selected to illustrate the differences highlighted by the three Standards.

As part of the study individuals' opinions of rides were sought in order to determine whether or not operators' and passengers' ratings of rides corresponded to the assessments provided by the various Standards. Data for this paper is a part of larger study currently being conducted in open-cut and underground coal mines in NSW.

2. METHODS

The instrumentation and software for collection and analysis of the WBV data were developed specifically for this project (Foster et al 1995). Measurement of WBV 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 of each vehicle.

Three volunteer subjects from two open-cut mines were selected. One was a dump truck operator, one a bulldozer operator and the third was a passenger in a man-transport four wheel-drive road vehicle. Measurements were made on vehicles undertaking routine work under normal operational conditions. Data on WBV were collected on each one of the three rides and were subject to analysis using all three Standards.

As well an evaluation of each ride was sought from the individuals and was compared with the objective results. Two types of ride assessment were used. The first was derived from the British Standards Institution with a six point scale ranging from 'not uncomfortable' to 'extremely uncomfortable'. Operators were asked to describe in these terms how they felt at the end of the recorded ride. The rating was linked with readings (RMS) and any relationship was noted.

The second was a simple rating scale. 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 which were labelled left to right as good, OK, fair and poor.

2.4 Whole-body Vibration Standards

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. This boundary may not be relevant to the mining industry.

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

- *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.

In practice, it is common to use the Fatigue Decreased Proficiency boundary as well as the Exposure boundary for guidance on worker exposure.

The Australian Standard is only suitable for evaluating vibration exposures that are fairly continuous without jolts and jars.

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 VDV is more sensitive to vibration exposures that include jolts and jars that produce crest factors of 6 and above. The VDV uses fourth power methods to calculate an accumulated vibration dose for the exposure period.

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. The Standard also states...."It is reasonable to assume that increased exposure to vibration will be accompanied by increased risk of injury".

New International Standard. *ISO 2631-1.2. 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 RMS* value to evaluate exposure. The Standard uses a 'caution zone' for classifying vibration exposures that lie between specified limits depending on the exposure duration. Exposures above this caution zone are 'likely to cause injury'.

The new International Standard introduces a vibration dose value (VDV) for vibration exposures with crest factors above 9. These Standards have been discussed in more detail in previous papers (Long et al, 1995; McPhee et al 1998).

3. RESULTS

3.1 Comparison of different Standards

Vehicle	Activity	Australian Standard permissible limits		British Standard (time to reach VDV action level)	New International Standard permissible limits: Caution Zone		Likely Health Risk	
		Fatigue	**Health**		**RMS method**	**VDV method**	**RMS method**	**VDV method**
Dump truck	loading & dumping overburden	19 hours	24 hours	>24 hours (z axis)	7 hours	n/a	12 hrs	n/a
Track dozer	ripping & pushing hard rock	7 hours	19 hours	5 hours (x, y & z axes)	n/a	31min	n/a	8 hours

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Manhaul vehicle	transport of passengers around mine	6 hours	17 hours	1 hour (z axis)	n/a	12min	n/a	3 hours

Table 1 Comparison of acceptable exposure duration as assessed by different standards

Australian Standard	**British Standard**	**International Standard**
Highest RMS acceleration value for 1/3 octave frequency band, worst axis. Three different criteria boundaries – comfort, fatigue and health. Fatigue boundary generally used for permissible exposure times.	Vibration Dose Value (sensitive to peaks). Action level is 15 m/sec $^{1.75}$ *Combined axes where necessary*	*(1)Constant vibration use:* **Overall RMS acceleration level** *(2) Vibration exceeding crest factor of 9 (i.e. containing shocks) use:* **Vibration Dose Value** *Combined axes where necessary*

Table 2 Assessed Parameter for different Standards

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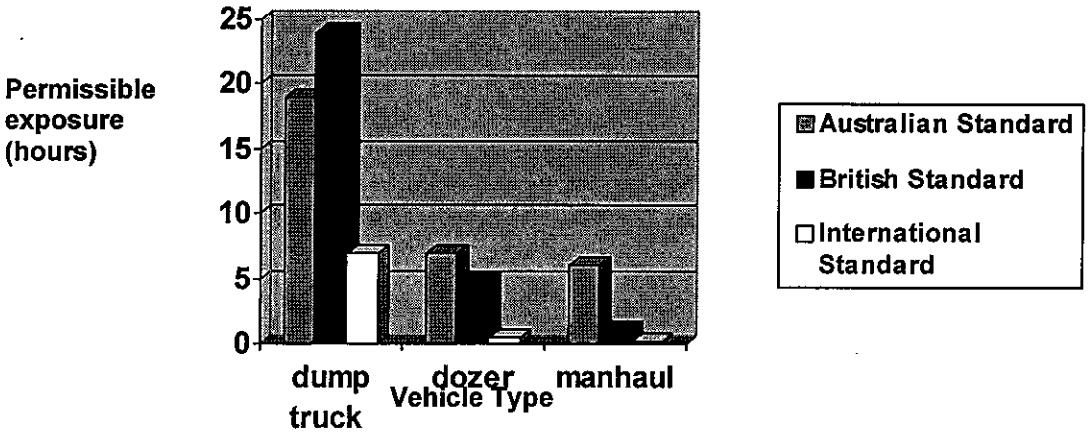

Figure 1. Comparison of permissible exposure limits using different Standards

3.2 Vehicle activities and how the Standards are applied

Dump trucks haul either coal or overburden within the mine. Most travelling is done on main mine roads that are generally well maintained. The ride is typically not rough but some jolting may occur during loading of large overburden rocks. The work is continuous for either an 8-hour or 12 hour shift. Most vibration exposure is in the z-axis (up and down).

Track dozers are used for a variety of tasks around the mine including, spreading overburden, coal heap organisation, ripping and pushing coal or overburden and road making. The ride is generally rough especially when ripping hard rock resulting in high levels of shocks to the dozer operator. Equally high vibration levels are experienced in x, y and z axes so it is necessary to combine these contributions for exposure assessment. Dozer operation is fairly continuous for either eight or 12-hour shifts.

Manhaul vehicles are used generally to transport mine workers from the muster and crib rooms to their work site. Trips lengths generally vary between 5-10 minutes, four or more times per shift. While they would not be used for eight-hour periods they could still cause injury due to the severe jolts and jars experienced especially by passengers on rough roads. This is indicated by the very high VDV values. Vibration exposure is usually in the z axis direction.

3.3 Operator's ratings of ride

Passenger's and operators opinions on road/work area conditions, smoothness or roughness of ride, and on ride comfort indicated that they generally classified each of the three rides as acceptable and average. The comparative findings are listed below in Table 3.

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Vehicle	Activity	Individual's rating of ride simple	BSI comfort	Individual's comments
Dump truck	Loading and dumping overburden	OK	a little uncomfortable	good road, average ride
Track dozer	ripping and pushing coal	good	not uncomfortable	good ride
Man haul	passenger run from muster area to pit	OK	a little uncomfortable	average passenger ride

Table 3 Ratings of ride by operators and passenger

4. DISCUSSION

The three vibration Standards use different assessment methods and exposure criteria and therefore yield quite different outcomes. The Australian Standard is least stringent because it assesses only the RMS acceleration value for the highest 1/3 frequency band, for the worst axis. Under the fatigue criteria of this Standard, exposures to operators of the dump trucks, dozers and manhauls would be acceptable. The Australian Standard is not suitable for rides which contain jolts and jars or shocks which produce crest factors (peak level/RMS level) of greater than 6. Of the three examples, only the dump truck qualifies for assessment under the Australian Standard because dozers and manhauls exceeded the crest factor limit. In other words, the Australian Standard underestimates the risk of vibration exposures which contain shocks.

Permissible exposure times are greatly reduced if the International or British Standards are used for assessment. The International Standard uses a weighted, RMS acceleration measure that aggregates the effect of several frequencies and also allows for the summation of vibration contributions from all axes when these are significant e.g. dozer. The resulting 'caution zone' exposure limit is lower than the equivalent 'fatigue' criteria of the Australian Standard. For example, the acceptable exposure duration for the dump truck is 19 hours under the Australian Standard but is reduced to 7 hours under the International Standard.

The British and International Standards introduce 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. Typical manhaul passenger and, to a lesser extent, dozer rides are rough and produce high peaks or shocks. When the VDV is used the acceptable exposure times are greatly reduced. For example, the permissible limit for the manhaul is reduced from six hours in the Australian Standard to one hour for the British Standard and down to12 minutes if the International Standard is used. The International Standard is more stringent than the British Standard because it uses a lower VDV threshold for its exposure criteria.

With respect to the individuals' ratings of comfort there appeared to be no correlation between these and the measured vibration on these rides on either scale. Individuals underrated the roughness of these rides which is consistent with findings from the main study. However, the overall results indicate that the simple scale better reflects the roughness of the ride.
The reasons for the lack of any apparent relationship between the individual's comfort ratings and the measured vibration levels are unclear. It may be related to previous exposures and habituation to rougher than normal rides; 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.

5. CONCLUSIONS

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 access the important components of rough rides, that is jolts and jars, and as a result reduces the allowable exposures to these.

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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 better-designed equipment. Nevertheless, it is likely that reduced operating times and other controls in will be needed in the interim in vehicles undertaking activities that result in jolts and jolts.

The question arises: are the methods used in the new IS valid for the assessment of jolts and jars? The new Standard appears to go some way in assessing the type of vibration that may lead to the slow onset of injury.

One problem is that injuries often manifest themselves in a one-off severe jolt in an otherwise smooth ride such as that caused by a pot hole in a good road. These incidents are known to lead to low back and neck injury and are recognised by operators as damaging. However, a dose-response relationship has not 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 peak limit.

While complaints of back and neck pain arising from vehicle rides in mining are common operators and passengers generally appear not to be good assessors of rides which could be leading to long term damage. The contribution of prolonged lower levels of vibration to the development of symptoms is unknown at this point. Drivers on dump trucks complain about low grade symptoms at the end of the working day presumably from prolonged sitting. It also may be that constant exposure, without the breaks that are possible on other vehicles, are contributing to a significant extent.

Rough vehicle rides also occur in other industries in Australia such as construction, exploration and surveying, forestry, farming, agriculture and demolition. It is likely that exposures in these industries will be similar to those in mining so the new Standard also will have implications for these industries.

First published in Proceedings of the 1998 Annual Conference of the Ergonomic Society of Australia

6. ACKNOWLEDGEMENTS

This Project is funded by the Joint Coal Board's Health and Safety Trust and the National Occupational Health and Safety Commission (Worksafe). The equipment has been developed in collaboration with staff from the Acoustics and Vibration Centre, Australian Defence Force Academy, Canberra and AR Technologies.

7. REFERENCES

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

BS 6841 : 1987, *Guide to measurement and evaluation of human exposure to whole-body mechanical vibration and repeated shock.* British Standards Institute, London.

ISO 2631/1 - 1997, *Guide to the evaluation of human exposure to whole-body vibration Part 1: General requirements.* (International Standards Organisation, Geneva)

Foster G., Harrap M, Long A. and Fay G., (1995). A flexible system for measurement and analysis of human vibration data according to Australian and British Standards. *Proceedings of the Australian Institute of Occupational Hygiene Annual Conference*, Adelaide, 152-158.

Griffin, M.J., (1990). *Handbook of Human Vibration*, Academic Press Limited, London.

Long, A., Foster G., Fay G. and McPhee B., (1995). Measuring Whole-Body Vibration Exposure in Mining. *Proceedings of the 31st Annual Conference of the Ergonomics Society of Australia*, Adelaide, 29-36.

McPhee B., (1995). Review of Exposure to Whole-Body Vibration (WBV) and Back Disorders in Mineworkers. *Proceedings of the 31st Annual Conference of the Ergonomics Society of Australia,* Adelaide, 37-44.

McPhee. B., (Foster G. and Long A.), (1998). Whole-body Vibration Standards. Ergonomics Australia, Ergonomics Society of Australia, Canberra, April, 13-15.

Assessment of whole-body vibration exposure using Australian and International Standards - a case study

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INTRODUCTION

The workshop aims to provide some information on current Standards in Whole-body Vibration (WBV) and how this can be used to guide employers, employees and equipment manufacturers towards safer rides in vehicles. The following issues will be addressed along with a case study, which is written up in the following pages.

- What we know and do not know about exposure to WBV from the current scientific literature,
- Work factors that could contribute to WBV exposure,
- The link between WBV and back pain and other musculoskeletal disorders,
- The proposed mechanisms of injury resulting from WBV,
- The contribution of ergonomics to the reduction of exposure to damaging WBV in vehicles,
- Other possible strategies for reducing WBV exposures in vehicles at work,
- Methods for recording and analysis of WBV data - why is it so difficult? and,
- Comparison of the new International Standard with the current Australian Standard on WBV. See the case study below.

CASE STUDY: a load haul dump vehicle in an underground coal mine

In this example, a load haul dump vehicle is being used underground to build a ramp of gravel to enable high roof meshing. The ground surface was particularly rough causing intermittent jolts and jars (shocks) to the driver. Both the Australian Standard and the International Standard offer alternative methods of assessment. The prescribed assessment method is not well defined in either Standard and a range of outcomes is possible as shown in Table 1. The following case study outlines the analysis using both Standards.

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Table 1. Comparison of exposure duration guidelines using Australian[1] and International Standards[2] for a Load Haul Dump vehicle operating in an underground coal mine.

Australian Standard[1]
AS 2670.1 - 1990

Method	Time to reach FDP* boundary
One–third octave	8hr
Overall RMS** single axis	2.5hr
Overall RMS combined axes	1hr.
-	-
-	-

International Standard[2]
ISO 2631-1,1997

Method	Time to reach Caution Zone
-	-
Overall RMS single axis	3hr
Overall RMS combined axes	1.5hr
VDV*** single axis	26 min
VDV combined axes	17min

* Fatigue decreased proficiency
** Root mean square
*** Vibration dose value

(a) Assessment by Australian Standard, AS 2670.1 – 1990[1]

The Australian Standard allows two methods of assessment.

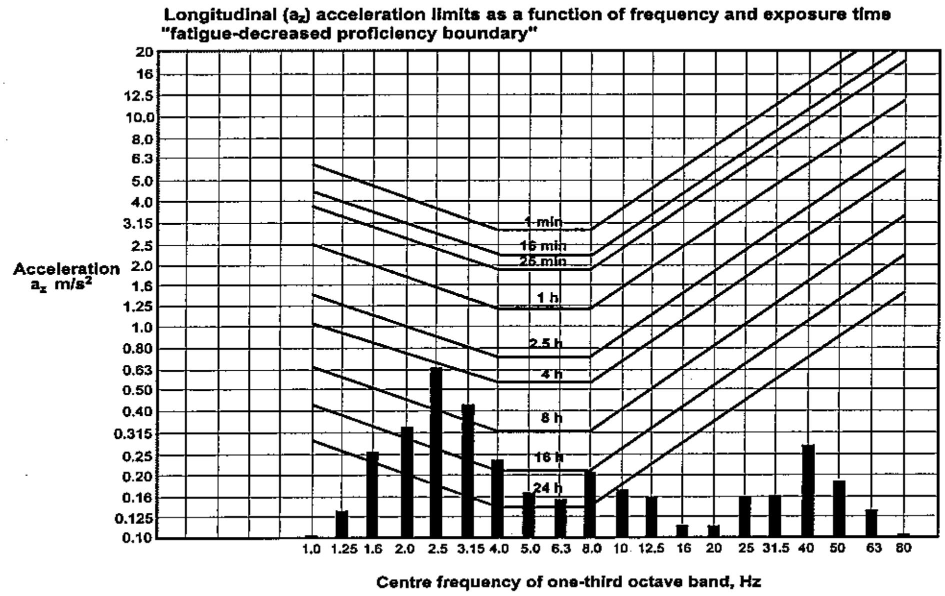
One-third octave method.

This is the preferred method according to the Standard.

STEP 1 Measure RMS acceleration levels in one-third octave frequency bands for each axis of vibration. The Standard recommends that the measurement be made over a period of at least one minute.

STEP 2 Compare the worst axis with the criteria curves given in AS 2670.1. In this case the highest exposure is in the z-axis. The following figure shows the third-octave spectrum of acceleration in the z-axis superimposed on the criteria curves for the z-axis fatigue-decreased proficiency boundary.

Figure 1.



STEP 3 Identify the lowest boundary (exposure limit) exceeded for each frequency band. The lowest time limit is taken as the permissible exposure period for this activity.

For this activity, the lowest boundary exceeded is 8 hours (at 2.5Hz). This value is generally accepted as the limit for exposure duration.

Comments

1. This method is not suitable for vibration exposures that include shocks or jolts and jars. The Standard[1] states, 'when the crest factor is greater than about 6, the recommended vibration evaluation method may underestimate the effect of the motion'.

2. This method bases the assessment on a single frequency for only one axis of vibration and assumes no cumulative contribution from the other frequencies.

3. 'Exposure limits' are obtained by multiplying the acceleration values by 2 and comparing them with the same criteria curves. The 'reduced comfort boundary' is found by dividing the acceleration values by 3.15 and comparing them to the criteria curves.

4. In practice, the one-third octave method is commonly used with the 'fatigue-decreased proficiency' boundary in determining exposure duration limits.

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Weighted overall vibration method.

The second method accepted under the Australian Standard is the 'weighted overall vibration approximation'. The Standard notes (4.2.4 Broad-band vibration –notes page 8[1]) that in cases where the one-third octave analysis is 'difficult or inconvenient…. a single number representing the overall vibration signal for the frequency range 1 to 80 Hz may be weighted with an electronic network'. Many lower cost instruments are capable of producing this weighted vibration value.

The weighting curves are given in the Standard and are similar in shape to the criteria curves shown in Figure 1 above, with the most sensitive region being in the 4-8Hz range for the z-axis and between 1-2 Hz for the x and y axes.

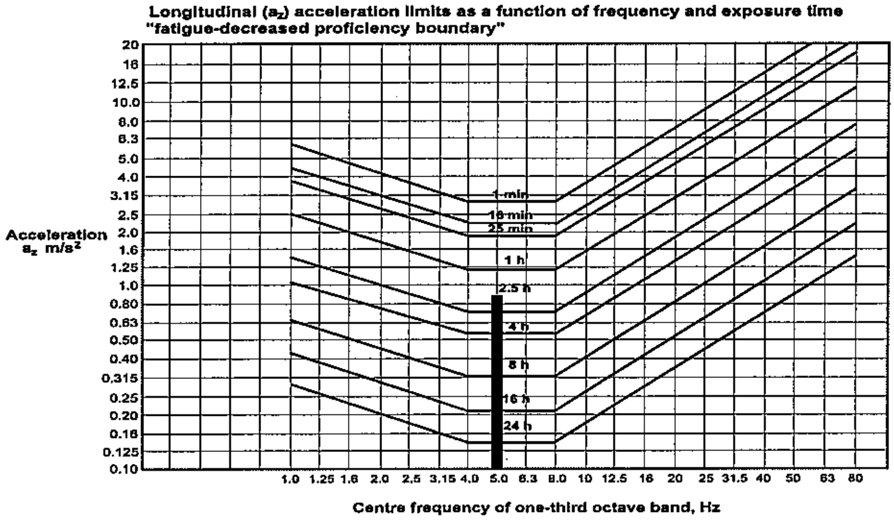
STEP 1. Select appropriate whole-body vibration weighting network on instrument. Obtain average reading of vibration exposure for z, x and y-axes.

For this example, the z-axis produces the highest weighted RMS vibration level of 0.89 m/s^2. Other axes give values of 0.51 m/s^2 for the x-axis and 0.44 m/s^2 for the y-axis.

STEP 2. Compare the reading obtained in STEP 1 for the worst axis with the most sensitive frequency band of the criteria curves used in the one-third octave method. The most sensitive region for the z-axis criteria curves is between 4 and 8 Hz. The boundary exceeded will give an indication of the limit to exposure duration.

For this example the value of 0.89 m/s^2 (z-axis) crosses the 2.5 h boundary.

Figure 2.



Comments

1. The Standard states that this approximation method can give a value up to 13 dB* greater than the one-third octave method because all frequencies contribute to the overall value. It also states that this could lead to an over-conservative assessment of the effects of vibration for broad band signals.

2. In practice we have found that this method tends to be more realistic in terms of worker fatigue than the one-third octave method.

3. If this method is used the fatigue-decreased proficiency boundary limit is reduced from 8h to 2.5h compared with the one-third octave method.

4. The Standard also states, 'In such cases where the evaluation according to the weighted overall acceleration method results in inadmissible levels, the detailed method using one-third octave band frequency analysis is the recommended method of choice'.

5. In cases where the axes contribute equally to the total vibration exposure, a method of combining these contributions is given.

   A value for this combined acceleration may be calculated from the following formula as given in AS 2670.1:

$$a = \sqrt{(1.4a_{xw})^2 + (1.4a_{yw})^2 + (a_{zw})^2}$$

where:

a = vector sum of the overall weighted vibration values

a_{xw}, a_{yw}, a_{zw} = the overall weighted vibration values for their respective axes

The vector sum is compared with the limit in the 4-8Hz range of the z-axis.

Note: The 1.4 multiplication factor adjusts the x and y axis values so that they can be applied to the z-axis criteria.

This is not applicable in this case example because most vibration is being transferred to the body of the operator via the z-axis (see STEP 1 above).

The combined result for this example is 1.29 m/s^2. If this value is used, the exposure duration would be reduced to only 1hour.

* Acceleration level (L_a) m/sec^2 $= 20 \text{ Log}_{10} \frac{a}{a^o}$ where $a^o = 10^{-6}$ m/sec^2

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(b) Assessment by New International Standard ISO 2631-1, 1997[2]

The new International Standard uses the overall, weighted, RMS acceleration in its assessment of steady state (without shocks) vibration. There are two distinct guidance levels, a 'caution zone' and a 'likely health risk zone' as shown in Figure 3. The frequency weightings applied differ slightly to those applied in the Australian Standard.

In this example, the time to reach the caution zone used for comparison with the time to reach the Fatigue Decreased Proficiency boundary of the Australian Standard.

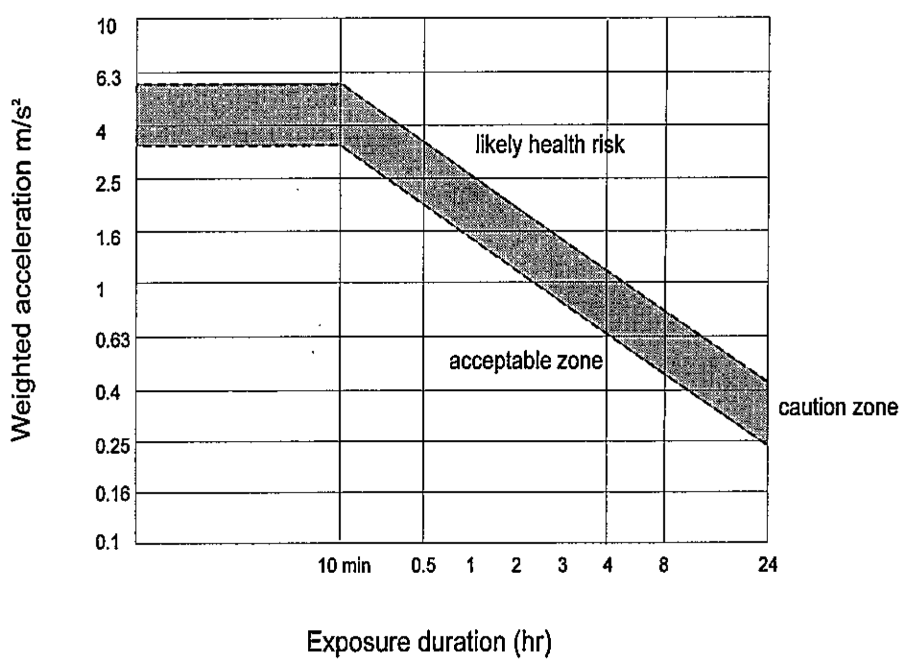
STEP 1. Measure the weighted overall RMS acceleration level in x, y and z-axes.

In the example, these were:
x-axis 0.58m/sec^2
y-axis 0.58m/sec^2
z-axis 0.77m/sec^2

STEP 2. Highest exposure occurs in the z-axis. The value of 0.77m/sec^2 is compared with the criteria curves shown in Figure 3.

In the example: **caution zone is reached in 3 hours exposure**
likely health risk zone in 8 hours exposure

Figure 3. International Standard (ISO 2631-1, 1997): Health guidance caution zones



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STEP 3. *Combined RMS*

As in the Australian Standard, there is provision for the combination of contributions from each axis when these are roughly equal.

With combined axes: caution zone is reached in 1.5 hours
likely health risk zone reached in 3 hours

Notes:

The ISO Standard also incorporates a "Vibration Dose Value", (VDV) in assessing vibration exposures that include shocks or high peak levels. The VDV uses 'fourth power' methods that are more sensitive to high peak levels than the RMS or 'second power' methods.

An alternate method, the 'Running RMS', may also be used for this type of vibration. The Running RMS evaluation method takes into account occasional shocks and transient vibration by use of a short integration time period of 1 second. The vibration magnitude is defined as a Maximum Transient Vibration Value (MTVV).

STEP 4. Measure the VDV or Running RMS where vibration exposure includes shocks or jolts and jars. In this case the ride is particularly rough and includes shocks. The calculated, full shift (8hrs) VDV for the z-axis was 6.9 $m/sec^{-1.75}$.

When the criteria are applied the caution zone is reached in 26 minutes and the likely health risk zone in 6.8 hours.

STEP 5 *Combined VDV*

If the VDV is combined for all axes the caution zone is reached in only 17 minutes and the likely health risk zone in 4.6 hours.

Comments

1. The Standard and exposure criteria are generally vague. This may be intentional because the effects of whole-body vibration on different subjects are not clear-cut. Caution and likely health risk zones are meant to provide guidance only.

2. Combining the contributions from each axis makes a large difference to the exposure criteria. The Standard simply states, 'When vibration in two or more axes is comparable, the use of the vector sum is sometimes used to estimate health risk', (Clause 7.2.2 Note 14)[2].

3. Applying the VDV also makes a significant difference to the exposure criteria. The Standard provides a test for the application of the VDV. Unfortunately, in practice, we have found that the test does not discriminate very well between continuous vibration and shock type vibration.

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4. The VDV exposure duration criteria should only be used as a general guide to rides that have a high shock content. In any particular ride a potentially injurious jolt may occur within the first few seconds of the ride. This makes the idea of a *permissible duration* for this type of vibration exposure redundant. A limit on the size or amplitude of the jolt may be a more useful exposure criterion in this case.

5. The VDV is weighted in the same way as the RMS vibration i.e. most sensitive between 4 – 8 Hz in the z-axis. These frequencies were established in laboratory tests using steady state vibration and may not apply to shocks. Higher shock frequencies could also contribute significantly to back injury.

6. A peak limit may be more appropriate to protect against shock type vibration.

Conclusion

At the moment the Australian Standard, AS 2670.1, is legally accepted for assessment of *steady state* whole-body vibration. It is recognised in the Standard that shock type vibration exposure may be underestimated using the methods prescribed.

The one-third octave method is the least conservative of the assessment methods prescribed in the Australian Standard. In coal mining, we have found that most vehicle rides are considered acceptable using this method.

The overall weighted RMS acceleration level, which takes into account all frequencies, is more conservative and gives similar results for both Australian and International Standard in the case example. We have found that this method yields results that agree with subjective opinions of operators in terms of fatigue.

The ISO Standard also recommends the use of the VDV and running RMS methods to assess shock type vibration. We have found that the VDV is a good *indicator* of the amount of shock vibration in a ride. However, exposure duration recommendations based on VDV are often unrealistically short and do not account for the fact that injury could occur from a shock (i.e. vehicle hitting a pot hole) occurring in the first few seconds or minutes of the ride.

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References

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

2. ISO 2631-1.2 - 1997, *International Standard. Mechanical vibration and shock - Evaluation of human exposure to whole-body vibration*. International Standards Office, Geneva.

3. Foster G., Harrap M, Long A. and Fay G. (1995) A flexible system for measurement and analysis of human vibration data according to Australian and British Standards. *Proceedings of the Australian Institute of Occupational Hygiene Annual Conference*, 152.

4. Long, A., Foster G., Fay G. and McPhee B. (1995) Measuring Whole-Body Vibration Exposure in Mining. *Proceedings of the 31st Annual Conference of the Ergonomics Society of Australia*, 29-36.

5. McPhee B. Review of Exposure to Whole-Body Vibration (WBV) and Back Disorders in Mineworkers. (1995) *Proceedings of the 31st Annual Conference of the Ergonomics Society of Australia*, 37-44.

6. McPhee, B., Foster, G. and Long, A., (1998). A Comparison of Rides on Different Vehicles Using three current Standards for Whole-body Vibration (WBV) exposures. *Proceedings of the 34th Annual Conference of the Ergonomics Society of Australia*, 46-53.

Published in Proceedings of the 1999 Annual Conference of the Ergonomic Society of Australia