Overview of the occupational exposure limits for hand-arm and whole-body vibration

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ABSTRACT

The introduction in 2002 of the Directive of the European Parliament, 2002/44/EC, established exposure limits for hand-arm and whole-body vibration in the occupational work environment. The requirements of this Directive have led to legislation and regulations in the member countries. The subsequent efforts by the regulatory authorities have increased the awareness of the potential injury from excessive exposure. Advances in instrumentation have increased the understanding of the actual exposures in the workplace. The introduction of the EU Machinery Directive requiring declaration of vibration levels in machinery specifications has led to data measured under controlled standard conditions. At this time Safe Work Australia is considering the need for occupational vibration exposure limits. This paper will discuss the vibration exposure limits, provide an overview of the EU requirements and consider the lessons that can be learnt.

INTRODUCTION

Vibration in the workplace is created by the operation of tools, plant and machinery. Some vibration can be beneficial in that it provides advice to the operator that the item is working. However, like other workplace exposures, as the level of vibration transmission to the operator increases it can cause annoyance, disturbance and at higher exposures there is a risk of injury. Similar to noise in the workplace, there is both the effect of continuous vibration and of sudden impulsive shock, which is often referred to as 'jolts and jars'. Human vibration in the workplace is categorised in two ways:

- Hand-arm vibration (HAV) where the transmission is from the tool via the hand, into the arm and then the body; and
- Whole-body vibration (WBV) where the transmission is from the item via the feet or the bottom and into the body.

There are currently no exposure limits for vibration in the workplace in Australia. The Model Work Health and Safety Regulations [Safe Work Australia, 2011a] define the exposure standards for noise (Regulation 56) and a Code of Practice deals with noise in the workplace [Safe Work Australia, 2011b]. The model regulations make reference to taking care with exposure to human vibration under a number of sections including manual handling, electrical installations etc and it is similarly mentioned in some codes of practice, such as for construction. But there is currently no regulation limiting HAV or WBV exposure to a particular value in Australian workplaces.

The importance of establishing exposure limits for human vibration in the workplace was recognised by the European Union and in 2002 a directive was issued by the European Parliament on the minimum health and safety requirements regarding the exposure of workers to the risks arising from physical agents (vibration) [EC 2002]. The agreement on this directive meant that the European countries were obliged to introduce legislation and regulations defining vibration exposure limits in the workplace. The UK adopted regulations with exposure limits in 2005 [UK 2005].

The similarity between the regulatory framework for work health and safety legislation in the UK and the Australian context indicates that the experiences from the UK following implementation of the EU directive limits for HAV and WBV in the workplace can provide valuable guidance. This paper summarises some of the findings from a study undertaken for Safe Work Australia on the implementation of the EU vibration directive and provides some data to highlight the sort of exposures that are being experienced in current Australian workplaces.

EFFECTS OF EXPOSURE TO VIBRATION

Hand-arm vibration

The most commonly reported effects of exposure to excessive HAV are vascular and the obvious signs are known as 'vibration white finger'. Periodical spasms in the small blood vessels in the fingers cause constriction of the blood supply to the fingertips and results in the fingers turning white in the first instance. In severe cases the fingers may ultimately turn blue. The first link with occupational vibration exposure of this effect was made by Alice Hamilton in 1918 following her study on the hands of stone cutters. In a follow up study by Taylor et al [1984] on stonecutters in the same quarries an 80% prevalence of vibration white finger was found. The authors commented that over the 60 years there had been no change in the design of the air hammers and that the measured values were *"outside the recommended limits"*.

Non-vascular effects of HAV include disorders to bone and joints, peripheral neurological, muscles as well as the whole body and central nervous system. These can include carpal tunnel syndrome and reflex sympathetic vasoconstriction of cochlea blood vessels which can effect hearing (as listed in the Code of Practice on noise [Safe Work Australia, 2011b] The most common symptoms of injury from HAV include tingling and numbness in the fingers; not being able to feel things properly; loss of strength in the hands; and the fingers going white (blanching) and becoming red and painful on recovery (particularly in the cold and wet, and probably only in the tips at first). The effects include: pain, distress and sleep disturbance; inability to do fine work (e.g. assembling small components) or everyday tasks (e.g. fastening buttons); reduced ability to work in cold or damp conditions (i.e. most outdoor work) which would trigger painful finger blanching attacks; and reduced grip strength which might affect the ability to do work safely. [HSE, 2011a]

Whole-body vibration

Back pain is the most commonly reported effect of excess WBV. Therein lies the problem for definitely attributing an injury to the level of WBV and thence defining safe exposure limits. Back pain can be caused by many factors which may include WBV singly or in combination.

The risk factors in the workplace that may contribute to back pain include: poor design of controls, making it difficult for the driver to operate the machine or vehicle easily or to see properly without twisting or stretching; incorrect adjustment by the driver of the seat position and hand and foot controls, so that it is necessary to continually twist, bend, lean and stretch to operate the machine; sitting for long periods without being able to change position; poor driver posture; repeated manual handling and lifting of loads by the driver; excessive exposure to whole-body vibration, particularly to shocks and jolts; and repeatedly climbing into or jumping down from a high cab or one which is difficult to get in and out of [HSE,2011b].

The study 'Vibrisks" supported by the EC [2006] included research projects on WBV. Summary comments highlighted the problem with dose response relationships as it was found that with higher cumulative WBV exposures the Italian and Dutch results showed increased risk of lower back pain while the Swedish and UK results did not. More recent analysis by Bovenzi [2010] found a better relationship between lower back pain and the metric VDV rather than the r.m.s. An example of the effects of WBV and shock on lower back and neck pain is the study by Milosavljevic et al [2012] on farm workers using quad bikes. Repeated shocks on the body can be experienced by those in vehicles travelling at speed over rough terrain and this is commonly referred to as 'jolts and jars'. There is clear evidence that spinal damage can be caused by severe shocks such as those encountered by crew in a fast vessel going across the waves in a high sea state [Price, 2010].

OPTIONS FOR MITIGATING VIBRATION EXPOSURE

Hand-arm vibration

The most effective mitigation measure for HAV is to reduce the source of the vibration either by changing the operation of the tool or incorporating vibration damping in the design of the tool. Since the introduction of the EU Machinery Directive in 1989 (updated in 1998 and 2006), there has been a requirement for the declaration of vibration values for tools placed on the EU market or put into service in the EU. These 'declaration values' are measured under specified test conditions and so the declared values cannot be directly applied in all workplaces. Some studies have shown that the declared values do not even provide an accurate rank ordering of the items when used in the workplace [Heaton and Hewitt, 2011]. However the implementation of the machinery directive [E C2006], coupled with the advice to industry on the benefits of choosing low vibration output tools, has led to greater emphasis by the manufacturers on the engineering design of tools to minimise vibration and maintain their market advantage [Brereton, 2011].

Changing the operation of the tool is another mitigation measure and can range from reducing the time of use through to reviewing the entire process. Changes such as removing the operator from direct contact with the tool or introducing a rig to provide support can reduce the transmission into the hand-arm. Other means for minimising the effects of HAV exposure include keeping the hands warm to limit the vascular damage and minimising grip force while maintaining control of the tool. Gloves are a common mitigation measure but there are concerns about their effectiveness and research studies are in progress to evaluate the role of gloves as a mitigation measure. Their use does however keep the hands warm and may also encourage a reduced grip force.

Whole-body vibration

The most effective mitigation measure for WBV is to reduce the source of the vibration either by changing the operation of the mobile plant or incorporating vibration damping in the seat or standing platform.

The changes in operation can range from remote control vehicles, where the operator is fully removed from the cabin, through to better control of the surfaces and training of the drivers. The importance of keeping the driving surface smooth and of training drivers not to use unnecessary speed was highlighted in the handbook for mining "Bad Vibrations" [McPhee et al, 2009].

Reducing the transmission of vibration to the driver involves design of the vehicle suspension and of the seat. There have been significant advances in the design of seats for workplace vehicles but it is essential that these are properly adjusted for the driver and the type of travel surface.

LIMITS FOR EXPOSURE

Exposure action and limit values in the EU vibration directive are shown in Table 1 for both HAV and WBV. The daily exposure value in terms of m/s^2A(8) is the r.m.s. (total value) of the frequency-weighted acceleration values normalised to an eight-hour reference period A(8). The VDV is the vibration dose value based on 4th power of the acceleration signal and the units are $m/s^{1.75}$. The option for the metric for the WBV as VDV is based on research that showed a 4th power relationship between vibration magnitude and discomfort [for example Mansfield, 2005] and effect [for example Bovenzi, 2010]. The VDV has an important role by providing a better indication of those rides with a high proportion of shock or "jolts and jars". However the UK regulations [2005] have adopted only the rms metric for WBV exposure limits and have not included VDV limits in their regulations.

Employers are obliged to minimise the risks of exposure to vibration but once the "action value" is exceeded they must minimise the exposure and introduce health surveillance. Exceedance of the "limit value" requires immediate action to reduce the exposure below the limit value.

Table 1 Exposure action values and limit values from EU Vibration Directive.

Vibration	Exposure Action Value	Exposure Limit Value
Hand-arm vibration	2.5 m/s^2(A8)	5 m/s^2(A8)
Whole-body vibration	0.5 m/s^2(A8)	1.15 m/s^2(A8)
	9.1 $m/s^{1.75}$ VDV	21 $m/s^{1.75}$ VDV

It is interesting to compare the exposure limits in the EU vibration directive with the health guidance zones from Annex B of AS 2670.1 [2001] reproduced in Figure 1 and which is a direct reproduction of the ISO standard2631.1 on Evaluation of human exposure to whole- body vibration [ISO, 1997]. In view of the lack of regulations, this is the only guidance that is currently applicable in Australia. The two equations referred to in this Figure relate to two different ways for assessing the time dependence, one based on square root (B1 on figure) and the other on the fourth root (B2 on figure). These do overlap in the main area of concern for WBV namely over the exposure period of 4 to 8 hours where the health guidance caution zone ranges from 0.43 m/s^2 to 0.86 m/s^2 .

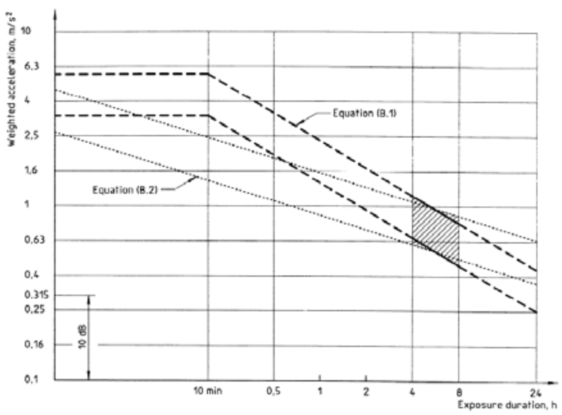

Figure 1 Whole body vibration health guidance caution zones [from AS 2670.1, 2001]

VIBRATION EXPOSURE IN AUSTRALIAN WORKPLACES

To date there has been no comprehensive quantitative study of exposure to vibration across workplaces in Australia. The study undertaken for Safe Work Australia on "National Hazard Exposure Worker Surveillance (NHEWS) – Exposure to vibration and the provision of vibration control measures in Australian workplaces" [Safe Work Australia, 2010] was undertaken via computer assisted telephone interviews with 4500 workers across 17 Australian industries. While keeping in mind that this was only a self reporting study the findings do lead to concern about the extent of vibration exposure in Australia. The overall findings were that 43% reported exposure to HAV, 38% to WBV and 17% to both HAV and WBV. It should also be noted that this survey did not include responses from the mining industry. Both the mining and the construction industries are growth industries in Australia where it is known there is a high risk of excessive vibration exposure.

In terms of HAV, the range of tools used in Australian workplaces is similar to those used internationally so there is a basis for similar concerns about excessive exposure. For example Table 2 gives a sample of some exposures measured in Australian workplaces by one of the authors (Foster). This shows the use of the needle gun could lead to exposure well above the EU exposure limit value. It can also be seen that the jack hammer, which is widely used in the construction industry, led to a high HAV exposure. Following the introduction in the European Parliament of the Machinery and the Vibration Directive [EC 2010, EC 2002] there has been considerable emphasis on European manufacturers to incorporate better design in the tool and more recent models have led to considerably lower exposure. For example, Atlas Copco [2006] has been awarded a UK award for its Cobra jack hammers, which incorporate isolation and meet "the requirements of increasingly stringent health and safety legislation". An engraver may not be considered as producing high HAV. But accurate use requires a tight controlled grip of the tool and this is reflected in the high HAV exposure.

Table 2 Examples of some HAV exposures [Foster].

Tool	Vibration level (m/s^2)	Time to Action Level	Time to Exposure Limit	Estimated Daily Exposure Time	Average Daily Exposure Level (m/s^2)
Jack hammer	9.9	30 min	2 hr	1 hr	3.5
Angle grinder	2.5	8.5 hr	>24 hr	4 hr	1.7
Engraver	6.2	1.5 hr	5 hr	30 min	1.6
Needle gun	17.9	9 min	37 min	1 hr	6.3

Figure 2 presents WBV data obtained by Foster at an Australian mining site. The items are ordered in Figure 2a in terms of the r.m.s. value and the caution zones are from the Australian Standard. Figure 2b presents the data for the same items but in terms of the VDV measured data. It can be seen that not only has the rank ordering changed but more items are above the action level for this metric, which has a greater sensitivity to jolts and jars.

The variability from the actual operation of a vehicle is shown in Figure 3. This Figure shows the differing vibration levels in the three axes measured for a number of dozers and dump trucks (x is in the forward direction, y to the side and z vertical). The jolts and jars from the operation of dozers and graders are highlighted by the use of the VDV measure.

Mining is one industry for which there has been concern for some time. The Joint Coal Board supported the production of the handbook "Bad Vibrations" [McPhee et al] which was first published in 2001 and revised in 2009. The various state government departments responsible for safety and health do provide some advice on reducing vibration exposure in the workplace.

The initiatives from Safe Work Australia to support studies such as the NHEWS [2011] on vibration and the more recent literature review, indicate that there are concerns about the extent of vibration in Australian workplaces. The information to date on the extent of potentially injurious exposure is limited to those industries that have resources and the knowledge from overseas operations. A quantitative study of exposures across industries will give a better indication of the extent of risk for the Australian workforce.

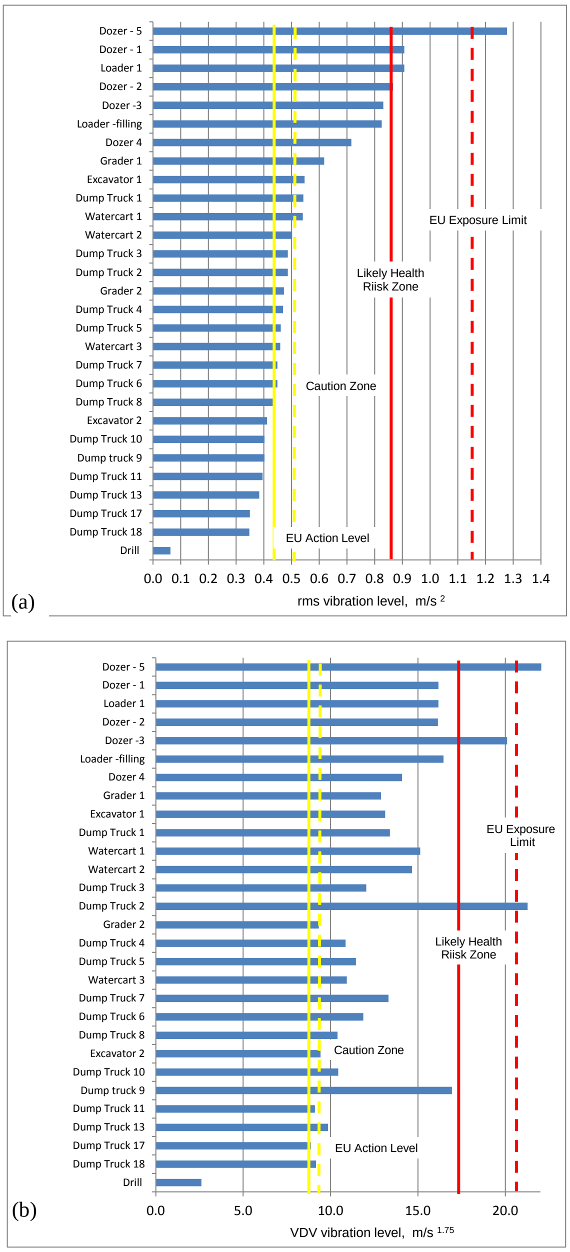

Figure 2 Whole body vibration levels, in terms of rms (a) and VDV (b), for a range of mobile plant used on mining and construction sites.

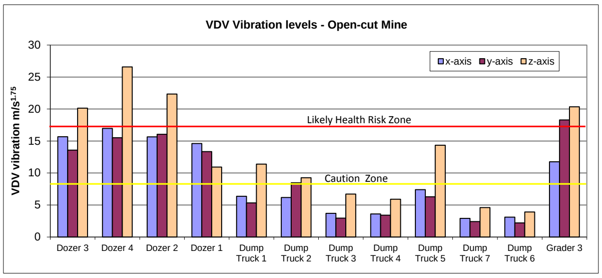

Figure 3 Whole body vibration levels, in terms of VDV, for a range of mobile plant used on mining and construction sites.

CONCLUSION

Australia currently has no regulations for exposure limits for either HAV or WBV in the workplace. Even from the limited information available there is demonstrated risk of injury from excessive exposure to vibration in Australian workplaces. The implementation of the EU machinery and vibration directives in European countries has led to manufacturers and suppliers paying greater attention to the vibration levels of their tools and plant. Adoption of similar codes of practice and regulatory limits would lead to greater protection of the Australia workforce from excessive exposure to vibration.

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