Toward a meaningful way to measure whole body vibration in motor cycle riders exposed to rough surfaces

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ABSTRACT

Motor cycles are used in the many occupations in Australia such as agriculture, courier services, postal delivery and police and results in exposure to whole-body vibration. Whole-body vibration exposure can be measured on the motorcycle seat, however, it can be expected that riders will sometimes lift themselves clear of the seat. The measurement on the seat only is therefore likely to be inaccurate. The aim of this study was to discover the relationship between seat-measured exposure and actual exposure. Vibration was measured simultaneously on the seat and on the rider for a range of terrain types. The results revealed that when riding on the seat that vibration dose values within about 10% of each other can be obtained by measuring vibration at the seat and on the rider. The results indicated that lifting clear of the seat increases seat vibration and decreases rider vibration. When lifting clear of the seat, the differences noted are large and indicate that the alternative method of measurement, on the rider, would be more meaningful. The small sample sizes in this study means that it is only indicative. However, it points toward the development of more meaningful analysis of whole body vibration caused by motorcycle riding.

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INTRODUCTION

Motorcycles are used in the many occupations in Australia. These include agriculture, courier services, postal delivery, police, etc. Vibration in motorcycle riding presents an interesting case regarding assessment of whole body vibration. Motorcycle riding is mainly a seated activity in these occupations. The Australian Standard covering whole-body vibration is Australian Standard 2670.1-2001, Evaluation of Human Exposure to Whole Body Vibration. Whole-body vibration exposure for a motorcycle rider can be measured on the motorcycle seat, which is the normal location for whole body analysis of a seated position. However, for off road, rough road or occasional severe bumps such as speed bumps and kerbs it can be expected that riders will sometimes lift themselves clear of the seat. The measurement on the seat is therefore likely to be inaccurate in that it would overestimate the vibration exposure for two reasons: 1. lifting off the seat will cause the motorcycle seat to vibrate more thus increasing the measured values; and 2. when the rider lifts clear of the seat the rider's spine is not directly exposed to the vibration of the seat. The aim of this study was to discover the relationship between seat-measured exposure and actual exposure.

Published research concerning vibration and motorcycle riding has focused on hand-arm vibration with the exception of one recent study on whole body vibration (Chen and others 2009). These studies have been in the postal delivery setting (e.g. Tominaga 1994; Tominaga 1995; and Yokomori and others 1986; Matsumoto and others 1986), agriculture (e.g. Anttonen and others 1995) and police (Mirbod and others 1997). None of these report on whole body vibration. Chen and colleagues (2009) studied whole body vibration on scooter style motorcycles. However, they rode only on paved roads and deliberately avoided or slowed down if encountering potholes manhole covers, humps or uneven surfaces. Among other vibration examples Lewis and Griffin (1998) report a measured vibration dose value for a mountain bike. Lewis and Griffin note that "..the posture of the rider and forces applied to the body at the seat may make this an inappropriate application of this standard" (1998, p. 923). Generally, whole body vibration studies on motorcycle riding do not seem to be very prominent among published research.

The study of whole body vibration in a range of other equipment such as tractors and construction machinery is better reported. Table 1shows a list of vibration dose values from: Mansfield 2001; Cann and others (2003); Chen and others (2009) and Lewis and Griffin (1998). The table shows the sampling time and measured vibration dose value (VDV). The VDV value listed itself can be confusing as it needs to be considered together with the sampling period which varies according to the test methods. To make comparisons, a one hour VDV has been listed. The various equipment and conditions can then be compared on a level footing.

Table 1 Vibration dose values of various equipment

Equipment/condition	Source[1]	Sample time (min)	VDV (m/s1.75)	1hr VDV (m/s1.75)
Bicycle off road on rough tracks	1	1	16.45	45.8
Wheel loader	2	20	31.7	41.7
Power boat (14m) in sea at state 3, 35-40 knots	1	1	11.81	32.9
Military tank, commander's seat cross country at 30 km/rh	1	1	9.79	27.2
Off-road dump truck	2	20	17.2	22.6
Four-wheel drive ambulance at 40km/hr	1	1	7.83	21.8
Car on unmade surface at 20 km/hr	1	1	7.43	20.7
Scraper	2	20	14.9	19.6
Scooter type motorcycle on paved rural road at max 55km/hr	4	8hrs	28.1	16.7
Forklift truck on mixed hard surfaces	1	1	5.92	16.5
Skid steer – mini	2	20	11.6	15.3
Inflatable power boat (8m) in seat at state 3, 40 knots	1	1	4.99	13.9
Backhoe	2	20	9.81	12.9
Skid steer – regular	2	20	9.64	12.7

Table 1 Continued

Equipment/condition	Source[1]	Sample time (min)	VDV ($m/s^{1.75}$)	1hr VDV ($m/s^{1.75}$)
Bulldozer – large	2	20	9.01	11.9
Ride-on power trowel	2	20	8.81	11.6
Crawler loader	2	20	8.71	11.5
Bulldozer – small	2	20	8.56	11.3
Vibratory compactor	2	20	8.16	10.7
Compactor	2	20	7.86	10.3
Grader	2	20	7.25	9.5
Bus in city with speed humps	1	1	2.79	7.8
Excavator	2	20	5.76	7.6
Variable reach forklift	2	20	5.73	7.5
Dockside crane – loading operations	1	1	2.46	6.8
Car on bumpy potholed road at 15km/hr	3	0.5	2.0	6.6
Foklift	2	20	3.35	4.4
Car on highway at 100km/hr	3	0.5	1.16	3.8
Mobile crane	2	20	0.92	1.2

[1]Reference 1 = Lewis and Griffin 1998; Reference 2 = Cann et al. 2003; Reference 3 = Masfield 2001; Reference 4 = Chen et al. 2009

METHODS

Vibration measurements were made with two Larson Davis HVM 100 monitors and PCB Model 356B40 ICP triaxial accelerometers housed in a rubber seat pad. The operator sits on the seat pad which is orientated to measure vibration in the vertical direction (z-axis), the horizontal side to side direction (y-axis) and horizontal forward to backward direction (x-axis).

The instruments were calibrated to the rated sensitivity of the accelerometer.

Measurements were made simultaneously on the seat and directly on the rider. One ICP triaxial vibration sensor was placed on the motorcycle seat. The measurement and analysis were carried out according to methods described in Australian Standard AS 2670-2001. A seat-pad accelerometer was connected to the rider in the vertical position so that the x-axis became the z-axis on the accelerometer seat pad. This is an unconventional technique and a method of attachment had to be devised. It was not practical to fix the accelerometer directly to the rider. The rider wore a miner's belt threaded through the belt-loops. The pad was lodged in the rear strap of the belt, and then taped to the belt and to the pants. The accelerometer was therefore firmly fixed to the rider's pants. However, there was the potential for movement between the pants and the rider. The data recorders were in a pannier and the rider's shirt pocket.

Given the arrangement of accelerometers, the x-axis of the rider accelerometer was compared with the z-axis of the seat accelerometer. These would be directly comparable if the accelerometers were positioned exactly at right angles. This was only approximately the case as the riders posture would vary according to riding conditions, stature and posture. For the above reasons there is likely to be some difference between the vibration recorded by the two instruments.

To gain some knowledge about the vibration recorded by the two positions, a number of trials were performed with the rider remaining in the seat. This enabled an assessment of whether the two accelerometers were recording similar values. After this was performed, the rider repeated a range of conditions, lifting out of the seat when striking bumps.

The motorcycle used was a 110cc agricultural motorcycle. According to the motorcycle's odometer reading it had travelled 1658km. Tyre pressures were set at 32psi at a service station. The rider was a 51 year old male with 11 years experience. The rider's self-reported height and weight were 157cm and 64kg.

Examination of various terrain conditions was made using the dual-accelerometer arrangement:

- Smooth surface (underground car park);
- "Square" shaped kerb;
- "Roll top" kerb;
- Rough unmade rutted soil.

In each case measurements were made while the rider either:

- Remained in seat; or
- Lifted out of the seat when encountering a jolt.

Vibration levels were assessed with the Basic Evaluation Method of AS 2670.1-2001 using the root mean square (RMS) acceleration levels and the Additional Evaluation Method using the vibration dose value (VDV) method. The vibration dose value is a fourth power method that is sensitive to jolts and jars. The RMS acceleration applies to more continuous vibration exposures that do not include a high proportion of jolts and jars. The VDV has been shown to correlate with perception of discomfort when exposed to vibration including shocks (Mansfield and others 2000).

AS 2670-2001 (Clause 6.3.3) $\frac{VDV}{a_w T^{1/4}} = 1.75$

Where VDV = vibration dose value for duration of the measurement.

a_w = average weighted r.m.s acceleration level.

T = duration of measurement in seconds.

The informative section of AS 2670.1-2001 provides guidance on vibration exposure duration that could lead to adverse health effects mainly concerning back pain and damage to the spine. A 'caution zone' is set out for classifying vibration exposures that lie between specified vibration limits depending on the exposure duration. The VDV caution zone is between a VDV value of 8.5 and 17 $m/s^{1.75}$.

However there is no universal agreement about the indicator levels. For instance, AS 2670.1-2001 indicates that the methodologies of the previous standards were protective and suggests that the data based on alternative measures (such as VDV) be collected to obtain information on the dose-effects relationship. These relationships are not well known. "Unfortunately, no-one appears to have carried out an epidemiological study where the prevalence of high acceleration events was considered" (Sandover 1998, p. 931). The limits themselves are contained within informative annexes to the Standard. The Standard is therefore a guide to the measurement of vibration exposure but not a guide to the limits that would apply.

RESULTS

Comparison of seat vibration and rider vibration when riding on the seat

With the rider remaining on the seat, vibration was measured simultaneously on the seat and on the rider for a range of terrain types. Speeds were all low as would be the case when negotiating rough surfaces. The connection of the accelerometer to the rider was as good as could be achieved under the circumstances but was acknowledged to be less than perfect. For this reason an examination was made of the comparative vibration dose values when the rider remained on the seat.

Table 2 shows the results of simultaneous measuring of vibration dose value on the rider and on the seat when riding on the seat. The rider/seat VDV ratio indicates the magnitude of the VDV measured at the rider compared to the magnitude of the VDV measured on the seat. The values are normalised to one hour. This is to place varying measurement times on an equal footing, for comparison with the one hour VDV values shown in the introduction for other types of equipment, and gives a sense of the VDV that could be experienced in an extended period of very rough conditions.

Under ideal conditions riding in the smooth underground car park there was very low vibration and a very close match between the VDV measured on the rider and that measured on the seat with the figures being only 1% different. The vibration dose values (for a one hour activity) for the other activities are in the range of 19-26 $m/s^{1.75}$, thus being comparable to activities such as off-road car driving, a dump truck, etc as measured other vibration research and shown in Table 1

The average figures for the comparison of the vibration measured at the rider versus that at the seat for all rides were as follows indicating that the two methods were measuring close to the same values (with 100% being perfect)::

- Traditional kerb: 88%
- Rough soil offroad: 100%
- Roll-top kerb: 103%
- Smooth ride: 101%

The methodology of attaching an accelerometer to the rider is not a standard one. It is also acknowledged that the fixing of the accelerometer was not perfect although it was quite firmly attached to a belt and clothing. These points noted, while potential movement of the accelerometer independent of the rider probably occurs to some degree it does not appear to be a significant issue as the vibration measured by the two accelerometers is similar. Further, given that spinal injury is the major concern, it makes sense to measure vibration as close as possible parallel to the spine rather than perpendicular to the seat. For these reasons, and bearing in mind some caution owing to the customised and experimental nature of the measurements, there seems to be good reason to examine the rider vibration data when off-seat.

Table 2 Difference between vibration measurement on the rider and on the seat when riding on the seat

Ride descriptions	Length (min)	Seat VDV ($m/s^{1.75}$)	Seat 1hr VDV ($m/s^{1.75}$)	Seat rms ($m/s^{1.75}$)	Rider VDV ($m/s^{1.75}$)	Rider 1h VDV ($m/s^{1.75}$)	Rider rms	Rider/ Seat VDV
Smooth surface (one trial)	2	1.82	4.3	0.40	1.84	4.3	0.33	101%
Repeated ride over “roll top” gutter 6/minute								
Trial1	1	6.56	18.3	1.01	6.99	19.5	1.27	107%
Trial2	1	7.28	20.3	1.17	7.18	20.0	1.35	99%
Trial3	1	6.9	19.2	1.15	7.16	19.9	1.38	104%
Average	1	6.93	19.3	1.11	7.11	19.8	1.33	103%
Repeated ride over square kerb 9 times over two minutes (one trial)	2	11.4	26.7	1.21	10	23.4	1.38	88%
Rough soil								
Trial1	1	8.53	23.7	1.4	9.68	26.9	1.76	113%
Trial2	1	10.5	29.2	1.59	10.1	28.1	1.90	96%
Trial3	1	8.57	23.9	1.09	7.86	21.9	1.59	92%
Average	1	9.34	26.0	1.36	9.4	26.2	1.75	100%

RIDING VIBRATION WHEN LIFTING CLEAR OF THE SEAT OVER BUMPS

As discussed, riders adapt to rough conditions by lifting clear of the seat. Table 3 shows the results of trials where the rider lifted clear of the seat over bumps. The measurements shown were made on the rider and on the seat.

It can be seen that the motorcycle itself vibrates significantly more when the rider is clear of the seat yielding 1hr VDV values in the range 30-50 $m/s^{1.75}$. The VDV for the seat are much greater than those for the seat as shown in Table 2 when the rider stayed on the seat. The reason would be that damping effect provided by the rider was now not present.

When lifting clear of the seat, the measurements of vibration of the rider show results that are much lower than the simultaneous measurement of vibration of the seat. These values are for 1hr VDV in the range 12-16 $m/s^{1.75}$. The comparisons are based on repeated rides over the same terrain and show the off-seat VDV was between 24% and 47% of the measured VDV at the seat as illustrated in Table 3 and Figure 1.

Table 3 Specific task/terrain vibration riding out of the seat over bumps

Ride descriptions	Length (min)	Seat VDV (m/s1.75)	Seat 1hr VDV (m/s1.75)	Seat rms (m/s1.75)	Rider VDV (m/s1.75)	Rider 1hr VDV (m/s1.75)	Rider rms (m/s2)	Rider/Seat VDV %
Repeated ride over continuous “roll top” gutter 5/minute								
Trial1	1	11.9	33.1	1.44	5.84	16.3	1.00	49%
Trial2	1	12.5	34.8	1.58	5.68	15.8	1.05	45%
Trial3	1	12.3	34.2	1.52	5.85	16.3	1.03	48%
Average	1	12.2	34.0	1.51	5.79	16.1	1.03	47%
Repeated ride over square kerb 9 times over two minutes	2	21.8	51.0	1.91	5.39	12.6	0.93	24%
Rough soil								
Trial1	1	9.87	27.5	1.62	4.26	11.9	0.96	43%
Trial2	1	14.9	41.5	2.01	5.20	14.5	1.23	34%
Trial3	1	15.7	43.7	2.43	5.48	15.3	1.3	35%
Average	1	14.1	37.5	2.02	4.98	13.9	1.17	35%

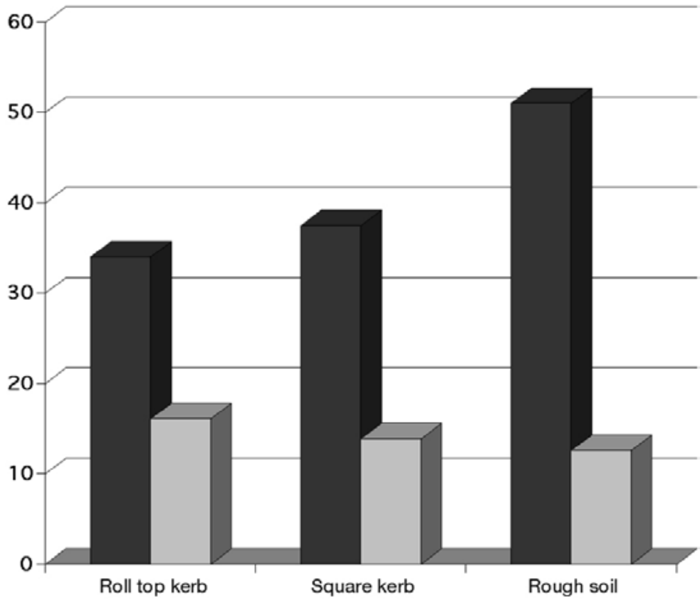

Figure 1 Comparison of z-axis vibration dose values (1hr VDV m/s$^{1.75}$) measured on the seat and the rider when lifting out of the seat over various surfaces

CONCLUSION

Off-road vehicle use is known to yield high vibration measurements. Whole body vibration research in motorcycle use has not been widely reported. One of the reasons for this may be the difficulty in obtaining realistic measurements. Attachment of an accelerometer to the seat will be reasonable in the case of seated riding. This would be applicable in most road-based use, however when encountering speed humps, kerbs, etc the rider may lift them self clear of the seat. In the case of off-road use this practice will be more common. The lifting of the rider could be expected to increase the vibration of the seat but decrease the vibration exposure of the rider. Thus measurement at the seat will probably be an overestimate of the actual exposure.

This exploratory study yielded two important indicative outcomes. Firstly, the results revealed that vibration dose values agreeing within about 10% by measuring vibration at the seat and on the rider can be obtained. Thus measurement of vibration on the person was indicated to be reasonable method. Secondly, using the direct measurement technique, the results indicated that lifting clear of the seat increases seat vibration and decreases rider vibration. The differences noted are large and indicate that the alternative method of measurement, being directly on the rider, would be more meaningful. The small sample sizes in this study means that it is only indicative. However, it points toward the development of more meaningful analysis of whole body vibration caused by motorcycle riding.

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