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Review of Data Measured

by

Reactec HAVwear

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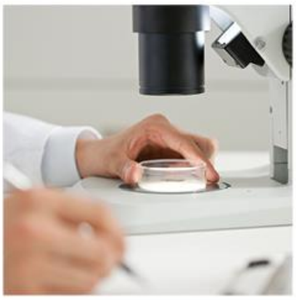

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REPORT TO CLIENT

Report of review of data from Reactec HAVwear

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EXECUTIVE SUMMARY

IOM Consulting was requested by Jacqui McLaughlin, CEO of Reactec Ltd., to conduct a review of data collected using the HAVwear system.

The aim of the review was to; compare the measurements made using the HAVwear system with the measurements made with conventional methodology; consider the actual level of vibration measured by each method; identify whether the HAVwear system provides reproducible results;and to identify whether the results produced by HAVwear are consistent.

The study was conducted in two parts; Phase 1 - an initial review of vibration magnitude data which had been obtained by Reactec. This provided an early understanding of the relation between HAVwear data and data obtained by conventional measurement methods. Phase 2 used the findings from Phase 1 to design a programme of vibration magnitude data to be collected by IOM from both HAVwear and conventional means on sites during normal use of the tools.

The main aim of the work was to consider whether the HAVwear system could be used as an appropriate Risk Assessment/Risk Management tool.

The data collected by the HAVwear system, during real use of various tools, is in general, comparable with the range of vibration magnitudes achieved by conventional means. Taking account of the variation which may occur when measuring hand arm vibration, the data generated by the HAVwear system provides a useful source of information to inform a suitable and sufficient risk assessment.

Although the HAVwear system does not measure vibration ‘on tool’, in accordance with the requirements of BS EN ISO 5349-1: 2001, it does provide ranges of vibration magnitudes that are comparable to that produced by conventional measurement techniques, or as published by the tool manufacturers, appropriate for the purposes of use for risk assessment and risk management. The means of obtaining the information to inform risk assessments, using the HAVwear system offers a simple mechanism whereby assessment of exposure, and changes in exposure, can be readily monitored over extended periods of time.

The HAVwear information, gathered on a regular basis, does inform the development of risk reduction control measures and can be used to identify trends in risk reduction.

A glossary of the terms explaining the technical terms used when discussing Hand Arm Vibration and found in this report is provided in Appendix 4.

1 INTRODUCTION

IOM Consulting was requested by Jacqui McLaughlin, CEO of Reactec Ltd. to conduct a review of data collected using the HAVwear system.

Reactec have developed a wearable hand arm vibration monitoring system to assist in the prevention and control of the risk of hand arm vibration syndrome (HAVS). The HAVwear unit is worn on the wrist of the tool user and, through the use of the Reactec analytics reporting software, provides continuous monitoring with automated reporting, indicating exposure.

The HAVwear module has a screen indicating the vibration exposure and tool information. The module can be set to give an audible alert and vibrate at a given limit indicating the exposure level to the individual wearer. The Reactec system transmits all data to create Cloud-based reports in real time, identifying employees at risk from high exposure and the source of the vibration; this information can be used to support risk reduction activities.

The new wearable system builds on the previous Reactec HAVmeter model which uses Tool Tags fitted magnetically to each item of equipment. When the HAVmeter is attached to the Tool Tag, the information is transferred to the HAVmeter to record the usage of that particular tool. This system monitors the vibration directly from the tool; the new HAVwear unit measures the vibration experienced at the wearer's wrist.

The HAVwear module calculates and displays in real-time exposure points to inform the wearer of their exposure to vibration. Sound and vibration alerts also inform the wearer of incremental increases in exposure and action thresholds exceeded. Reports are generated which include individual worker exposure and related tool use.

The wearable device mounts to the operator's wrist and comprises a 3 – axis linear accelerometer sampling every few seconds over a range of frequencies, generating magnitude values for each axis. The corresponding frequency point magnitude values for each axis are combined to create an overall magnitude value for each point on the spectrum.

The data collated by the HAVwear module includes the trigger time from tool use, the exposure points calculated from the trigger time and static vibration data programmed into the tool tag (Tool Exposure Points). The vibration magnitude determines 'sensed vibration' and exposure points based on the wrist determined sensed vibration and the trigger time (Sensed Exposure Points).

The new HAVwear system does not measure the vibration on the tool, as with conventional measurement techniques. Questions have therefore been raised as to whether the data produced by the system is directly comparable with the conventional measurement methods for HAV and specifically, those considered to be in accordance with ISO 5349.

The purpose of this report is to study the suitability of the vibration magnitude data determined by the HAVwear module and whether the resulting Sensed Exposure Points data is appropriate as a Risk Assessment / Risk management tool.

This report first discusses the review of data which Reactec collected on a small number of tools, i.e. Phase 1. This is followed by a discussion of the data gathered by the HAVwear system concurrently with conventional measurement data gathered by IOM during the use of various types of hand tools within the work environment. This Phase 2 data provided comparative data values obtained using conventional measurement methods for HAV in accordance with ISO 5349 and data obtained through the HAVwear device.

2 AIMS AND OBJECTIVES

2.1 Aims

The aim of the review was to:

- Compare the measurements made using the HAVwear system with the measurements made with conventional methodology;
- Consider the actual level of vibration measured by each method;
- Identify whether the HAVwear system provides reproducible results;
- Identify whether the results produced by HAVwear are consistent.

2.1.1 Phase 1

An initial review of measurement data, obtained by Reactec, was carried out to provide an early understanding of the relation between HAVwear data and data obtained by conventional measurement methods.

These findings were subsequently used to identify and design further measurement and analyses requirements.

2.1.2 Phase 2

A second phase of the work, carried out under the control of IOM Ltd., involved the collection of measurement data, from both HAVwear and conventional means, on live sites, i.e. taking measurements and gathering data during real life activities, with individuals trained in the use of the equipment. The data gathering from the HAVwear system and the conventional measurement data were gathered simultaneously on each individual tool.

The aim of this phase of the work was to consider the use of the HAVwear system as a Risk Assessment/Risk Management tool and/or as a Risk Management tool, in addition to the direct comparison of the data collected by the two measurement methods.

2.2 Objectives

This work was designed to answer the following questions;

- Does the Reactec Analytics Platform, incorporating the HAVwear, provide information which is useful in the completion of a suitable and sufficient risk assessment of the risk of HAVS to the tool user?

- Does the sensed vibration data provided in the Reactec Analytics Platform reporting software and the calculation of Sensed Exposure Points from this reflect the probable vibration experienced during real tool use?

- Does the information produced support a risk assessment which is more realistic than the use of a trigger timer and manufacturers’ data or paper records and manufacturers’ data or historic ISO 5349 test data?

- Does the information on tool users and tool behaviour in the Reactec Analytics Platform support the development of controls to reduce the risk to employees from tool use?

3 PHASE 1

3.1 Method of Data Review

The information made available to IOM by Reactec included:

- Evaluation of 23 tool scenarios by the HAVwear system at a client's site using up to three vibration measuring methodologies simultaneously. The measurements obtained were presented as a comparison, conducted by Reactec, with the manufacturers' data and the variation between the three methods evaluated.
- Comparison of measurements using HAVwear and conventional methodology over varied time periods.
- Comparison of average tag vibration measurements with HAVwear measurements for three manufacturers.

Summary explanations of the statistical procedures undertaken by IOM are given in Appendix 1.

Study power is often an issue with statistical analysis of relatively small datasets. Power refers to the ability of a statistical test to detect a given effect size or association of interest in a dataset. Where there were fewer than 10 data points available for a given tool, it was considered that it may not be feasible to conduct a detailed review; this data was therefore excluded from any statistical analyses. With such small sample sizes, it is not likely that any differences in vibration magnitude readings between the devices would be detected statistically.

That said, over 80% of the test scenarios had at least 10 data points[1] and were compared through statistical analysis.

The following procedures were undertaken:

1. Cleaning of the data sent from Reactec, including consistency checks.

2. Check for outliers in each tool dataset; one record was deleted based on the comments provided by Reactec (One outlier was removed in the "Makita SDS DHR202 6mm bit" dataset due to a "Battery out" comment that coincided with a much lower Larson Davis (LD) vibration magnitude).

3. Performance of non-parametric stats using medians (Wilcoxon signed rank sum test) as most paired data were found not to be normally distributed for most tool tests (i.e. HAV and LD/Svantek and/or Bruel & Kjaer (B&K)). The median represents the 50th percentile in a dataset, or the middle value. An advantage of using the median instead of the mean (simple average), is that the median is not influenced by very small or large values, known as outliers.

[1] The number of trials for each tool ranged from 3 to 33.

4. Test for any vibration magnitude differences in: tools tested and substrates used, where the number of trials with HAVwear readings was ≥ 10.

5. Since Reactec had expressed an interest in differences specifically between HAVwear and the LD/Svantek data and not necessarily the B&K device (both LD & Svantek are presumed to be routinely used in making measurements), the focus of the statistical analysis was therefore on those measurements. As only one of these units was used for each tool test, it was not possible to compare measurements of LD and Svantek within the same tool.

6. Manufacturer's vibration magnitude data were also provided by Reactec for each tool. These data include a vibration value and an uncertainty (k) factor, indicating a potential range of vibration values, typically +/- 1.5 m/s^2. It is not known under which testing conditions the manufacturer's values were derived, although it may be assumed that they were obtained in accordance with the relevant part of ISO 28927. This series of standards present vibration test codes for various types of portable hand-held machines and specify a laboratory method for measuring hand-transmitted vibration emission at the handles of hand-held equipment. It is a type-test procedure for establishing the magnitude of vibration in the gripping areas when operated in laboratory conditions. It is intended that the results be used to compare different models of the same type of machine.

7. In turn, these standards are based on ISO 20643, which gives general specifications for the measurement of the vibration emission of hand-held and hand-guided machinery. It is applicable to hand-held power tools (e.g. chipping hammers, sanders), hand-guided powered machines (e.g. lawn mowers, single-axle tractors, vibratory rollers), and other types of powered machines fitted with handles, guiding beams or similar means of control, of all power sources (electrical, hydraulic, pneumatic, internal combustion engine, etc.). It is not applicable to fixed machinery in which the vibration is transmitted to the hands of the user through the workpiece, nor to vibration transmitted from steering wheels or control levers of mobile machinery where the operator's position is on the machine.

   As they can be assumed to have been generated under standardised conditions they are a useful reference point for comparing vibration emissions from different models of machine although it is widely acknowledged that they do not necessarily reflect 'real life' exposures; often only providing one point of reference. However, because they are often used for assessing likely workplace exposures, the degree of overlap between the HAVwear and these data was examined.

3.2 Findings

3.2.1 Summary of Initial Findings

For all tools combined, (Spearman) correlations between HAVwear values and each other unit were strong (≥0.62) and were statistically significant. Values of correlation coefficients can range between -1 (inverse association), through zero (no association), to 1 (perfect agreement), so these findings indicate a high degree of positive agreement between vibration magnitudes determined by the HAVwear and other devices.

For all tools combined, the HAVwear median vibration magnitude was significantly higher (37.5%) compared to the LD and Svantek readings pooled together. Comparing these results graphically via a boxplot, it appeared there were some high, or outlier, values in the LD/Svantek readings. As these values pertained to one tool (Makita HR2610 in concrete), readings were compared without these particular data to determine the impact of this one tool.

When comparing measurements from the different units for each tool (n=23, including one tool that was subdivided into three different tests as different sized drill bits were used), the HAVwear results were found to be statistically significantly higher in 9/23 tools (+16.5to 317.1%), lower in 6/23 tools (two are from the same tool) (-16.2 to -56.4%) and not different in 8/23 tools.

Reviewing measurements taken in different substrates, the HAVwear had higher measurements than the other units in timber and grass. The HAVwear result was lower in the one tool tested in ‘wood’. When this was grouped in with ‘timber’, the HAVwear results were still higher than the other devices.

There was little association between the difference (%) in HAVwear and LD/Svantek vibration magnitudes with trigger time (correlation coefficient = -0.08) with no statistical significance identified. As described above, potential values can fall between -1 and 1, so -0.08 is not indicative of any meaningful association.

3.3 Discussion

3.3.1 Correlation between HAVwear and other Measurement Instruments

For all tools combined, (Spearman) correlations between HAVwear results and each of the other measurement meters were strong, ranging from 0.62 with LD to 0.85 for Svantek.

These findings provide strong evidence for a positive association: values of vibration magnitudes of the HAVwear module tend to increase with greater readings of the other devices and especially with those of the Svantek device.

The difference in these correlations suggests that readings from the HAVwear module are more closely aligned with the Svantek readings. The scatterplot below illustrates the association between the median HAVwear readings for each tool with those of the LD/Svantek measurements (Figure 3.1).

Each median data point in Figure 3.1 is labelled with the substrate in which the test was performed. Since the data points from each substrate are mostly scattered on either side of the line, there is little indication from this graph that differences in vibration magnitudes between each instrument vary greatly by substrate.

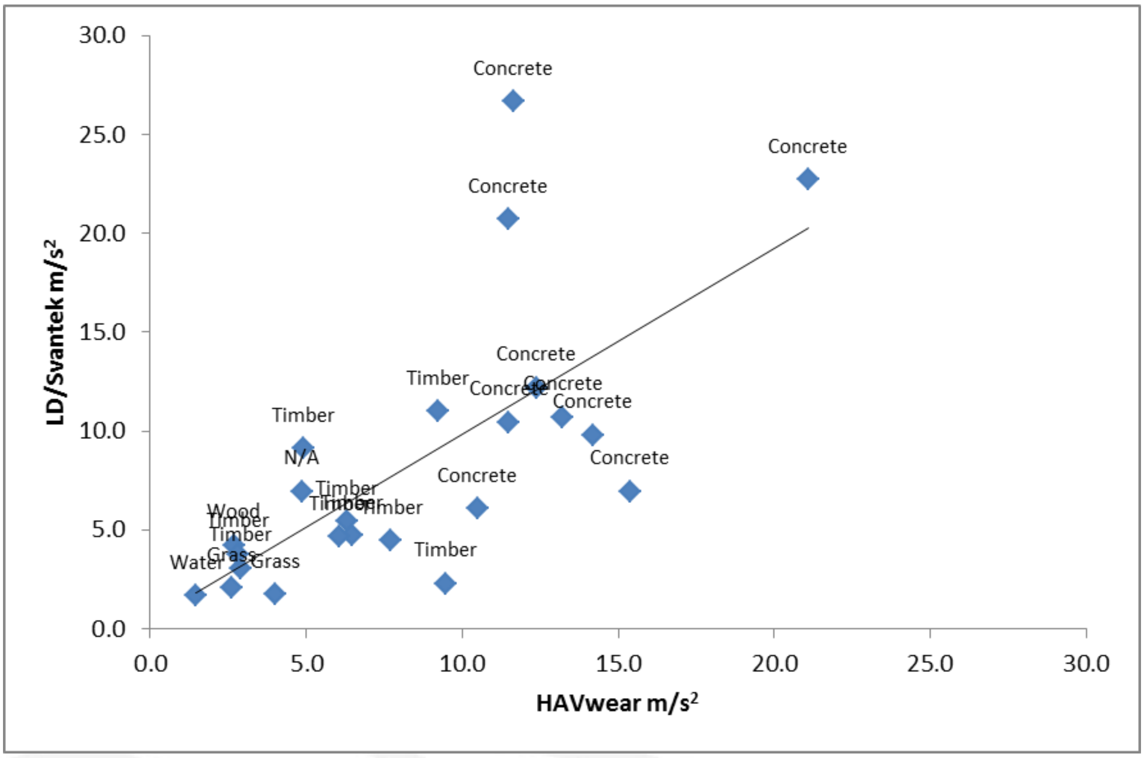


Figure 3.1 - The correlation between median HAVwear and LD/Svantek readings, with test substrate.

There are two data points in Figure 3.1 that represent higher median vibration magnitudes in the LD/Svantek device than in the HAVwear (test tools #12 and #13). Comments recorded during that test (Makita HR2610 in concrete) stated that the drill bit had broken and was replaced. The operator noted that the new bit caused higher vibration, resulting in a loosened grip. Whilst this might be representative of real world use, we omitted the results of this particular test to observe the influence of this specific tool scenario.

Figure 3.2 illustrates a scatterplot of the median vibration magnitudes without these two tests. Although the two graphs are similar, the trend line in Figure 3.2 is closer to the HAVwear axis, an indication of a tendency toward higher readings in the HAVwear (an even correlation would produce a trend line at a 45° angle).

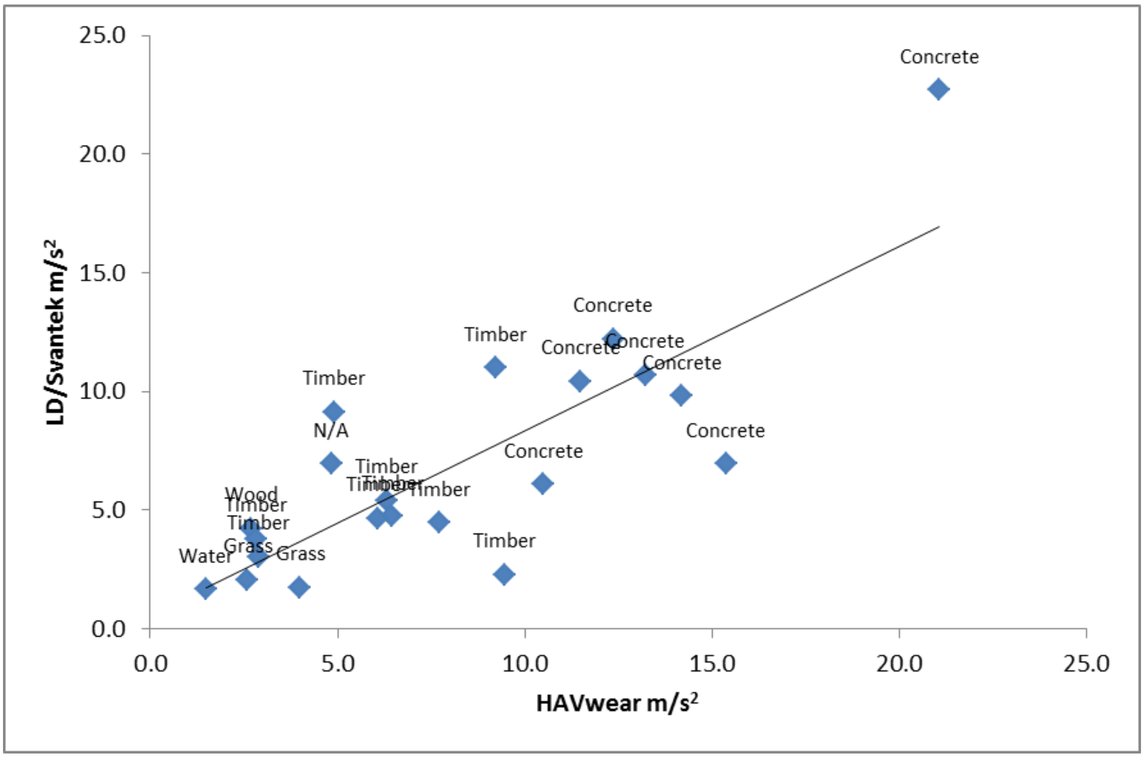


Figure 3.2 - The correlation between median HAVwear and LD/Svantek readings, with test substrate, omitting test tools #12 and #13.

Correlations are helpful to understand the strength and direction (i.e. positive or negative) of the relationship between two datasets, though it is noted that they do not provide information on absolute differences.

For all tools combined, the HAVwear median vibration magnitude (8.3 m/s²) was 37.5% higher than that of LD and Svantek combined (6.1 m/s²). The Interquartile Range (IQR) shows the values in the 25th to 75th percentile range, or the middle 50% of the data, and is helpful to accompany the median. The IQR for the HAVwear vibration magnitude of all tools combined is [4.6-11.5 m/s²], which is slightly higher compared to that of LD/Svantek at [3.4-11. 1 m/s²].

The boxplot presented below in Figure 3.3 provides a graphical representation of the median, IQRs and outlier values for HAVwear and the other devices. The median value is distinguished by the horizontal line in the middle of each box, representing the IQR.

As noted above, the median is 37.5% higher in the HAVwear and the IQRs in each plot are a very similar size. This informs us that there is very comparable variation in the middle 50% of values in each dataset, though vibration magnitude values tend to be higher in the HAVwear.

The vertical lines, or whiskers, extending from either side of the boxes include values within 1.5 times the IQR. Data points on the outside of this range are considered to be outliers. The LD/Svantek has more and a greater range of outliers than does the HAVwear.

This pattern indicates that the readings from the HAVwear device tend to be more consistent than those from the LD/Svantek.

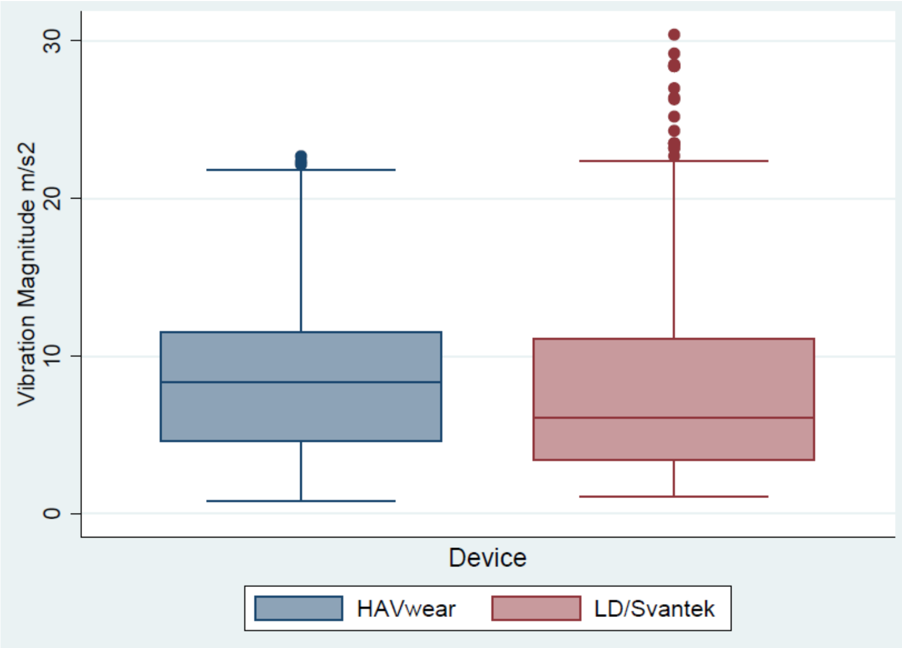


Figure 3.3 – A boxplot comparison of the HAVwear and LD/Svantek.

As noted in the correlation discussion above, the outlier values in the LD/Svantek may be partly attributed to readings from the Makita HR2610.

Figure 3.4 shows the distribution of readings from each device if these tools were omitted. Whilst there now appears to be a smaller range for the LD/Svantek results, there are still outliers outside the typical range for LD/Svantek.

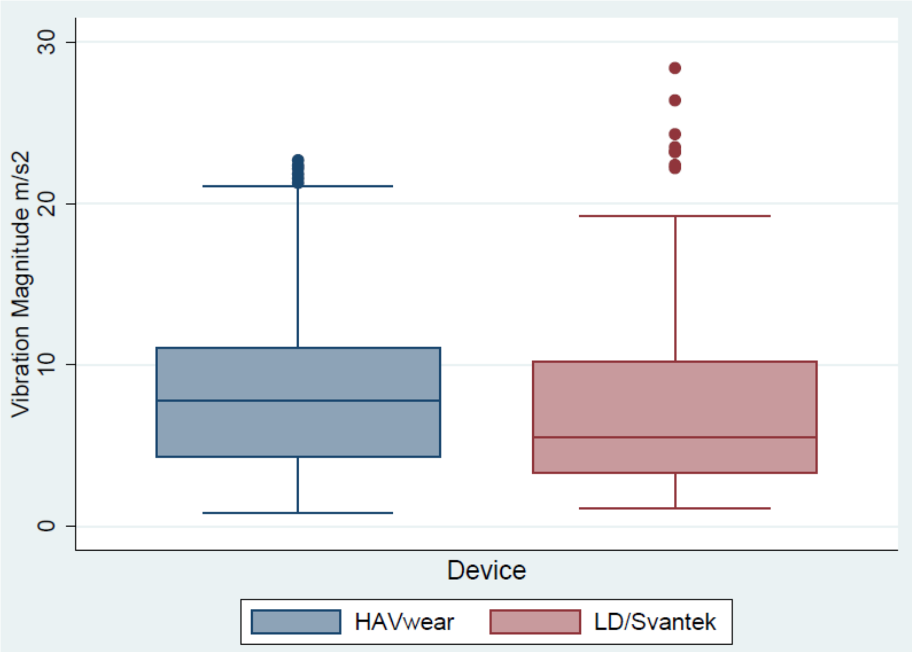


Figure 3.4 – A boxplot comparison of the HAVwear and LD/Svantek without the results from the Makita HR2610.

3.4 Comparison of HAVwear Data from Different Tools

Figure 3.5 displays the different median values for each tool in three different scenarios; (Appendix 2 presents a list of the tools tested). The first and third bars represent the median vibration magnitudes in the HAVwear and LD/Svantek devices. The error bars indicate the IQR, or the middle 50% of vibration magnitude values for a given tool.

The second bar displays the manufacturer's vibration magnitude value, as supplied by Reactec to IOM. The k value, or uncertainty factor, for the manufacturer's data is typically +/- 1.5 m/s^2 for a given tool, which represents a range of higher and lower values that might be expected with tool use. This factor was used to compare the manufacturer's data with the observed vibration magnitude readings from the HAVwear and LD/Svantek devices.

Comparing measurements from the different units for each tool (n=23, measurements from one tool were subdivided into three different tests as different sized drill bits were used), the median HAVwear was found to be significantly higher in 9/23 tools (+16.5% to +317.1%), lower in 6/23 tools (2 are the same tool) (-16.2% to -56.4%) and not different in 8/23 cases; (4/8 contained fewer than 10 data points and were not statistically compared).

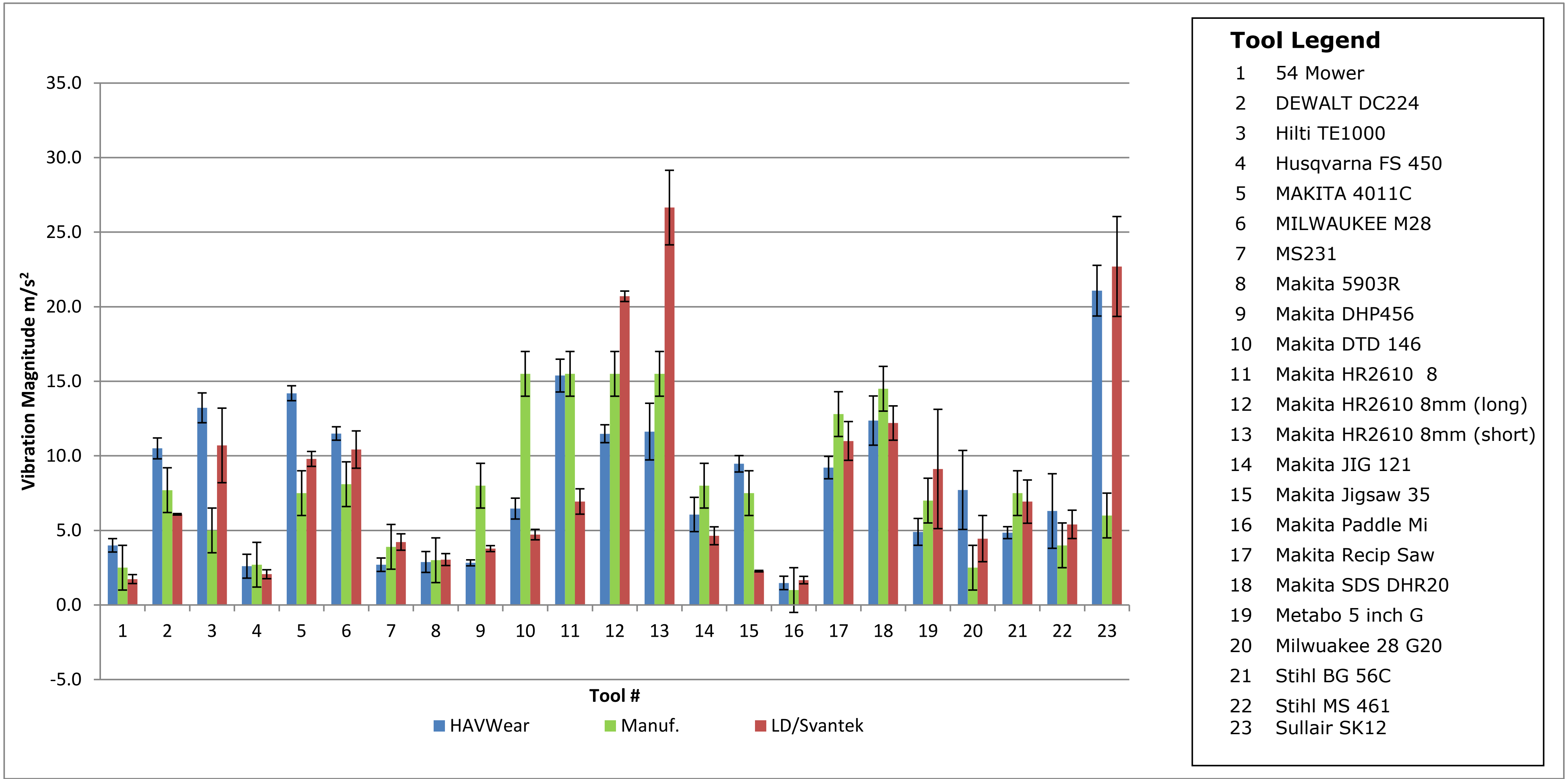


Figure 3.5 – The median vibration magnitudes measured by HAVwear and LD or Svantek alongside manufacturer values.

Compared to the LD/Svantek device, HAVwear readings were statistically greater in tools #3-6, 10, 14, 15, 20 and 22, whilst readings were lower in tools #7, 12, 13, 17, 19, 21. Figure 2.5 displays much higher median HAVwear readings in tools #1, 2 and 11, but the few data points available for these tools did not permit a statistical comparison.

The greatest negative difference in HAVwear readings is in tools #12 and #13, which are actually the same tool but with the use of different drill bits (Makita HR2610). One of the most positive differences in HAVwear readings is in tool #11, which is, again, the Makita HR2610, but with another drill bit in use. A statistical comparison of the vibration magnitudes between these tests with different drill bits shows no difference for HAVwear, but a significant difference for the LD device ($p<0.001$).

The availability of the manufacturer's data provides another reference point to assess the comparability of the HAVwear device to the industry standards. From Figure 2.5, it is evident that there is overlap in the ranges of HAVwear and the manufacturer's data in 11[2] of the tool scenarios. As a comparison, in the LD/Svantek, there was overlap in 13[3] of the tools. Comparing the experimental data with the manufacturer's values, the concordance of HAVwear readings is quite comparable to that of the LD/Svantek devices with the manufacturer's data.

3.5 Measurements Made on Different Substrates

Reviewing the measurements made by testing in different substrates, the HAVwear gave higher median measurements than the other units in timber (38.0%) and grass (95.3%) (Figure 3.6). The HAVwear median was found to be lower in the tests for the one wood tool (-36.0%). When these results were grouped in with the tests conducted in timber, the HAVwear readings remained higher than the other units. The median HAVwear reading was 30.0% lower for the blower, for which the substrate was air; there was no statistical difference identified for tools tested in concrete.

[2] Tool #: 1, 4, 7, 8, 11, 14-16, 18, 19, 22.
[3] Tool #: 1, 4, 6-8, 14, 16-22.

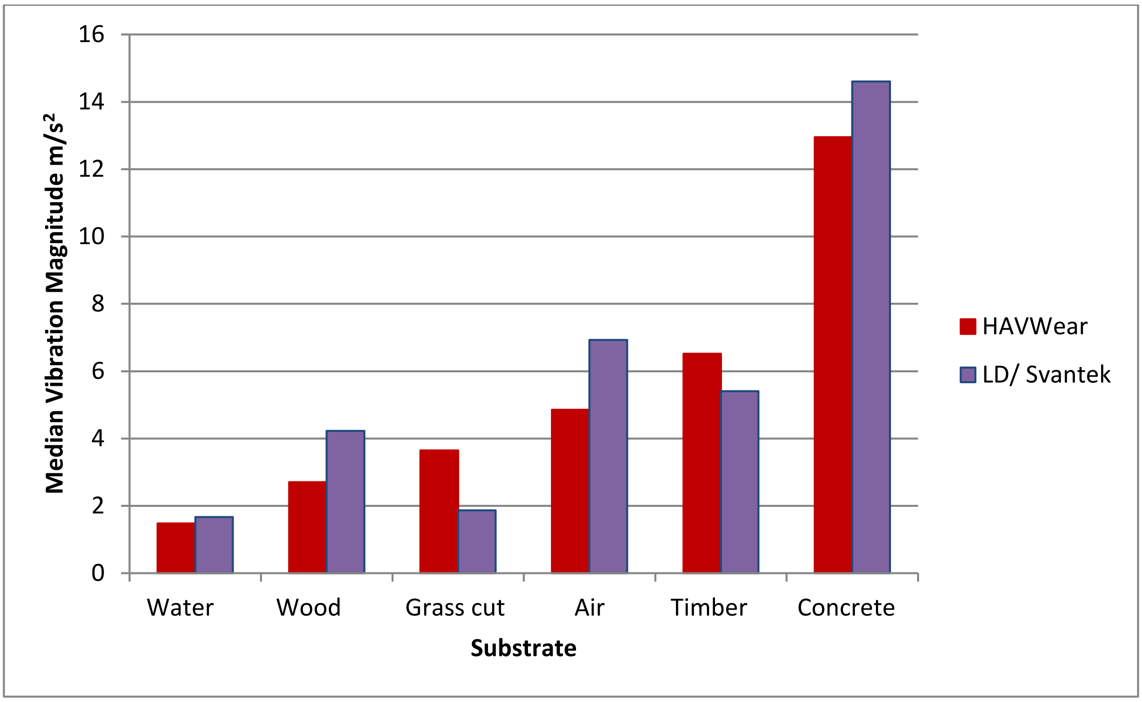


Figure 3.6 – Vibration magnitude measurements in different substrates.

3.6 Effect of Trigger Time

There was no statistical correlation between the difference (%) in HAVwear and LD/Svantek vibration magnitudes with trigger time. This finding is reassuring, as any underlying bias from trigger time to increase/decrease readings compared to standard industry methods may present a challenge for practical settings. It is however noted that the trigger times were mainly of one minute, with three trials less than 20 seconds and two lasting in excess of two minutes, though these outliers represent only 1% of all tests.

4 PHASE 2

4.1 Method of Data Collection

As an extension to the initial data analysis undertaken by IOM, additional vibration magnitude data were generated from tests of various tool types. The extra tool tests were meant to provide further insights on any differences between HAVwear and the other devices across a range of vibration magnitude levels.

The measurements were taken by an IOM Occupational Hygienist using the HAVwear and LD device. Various sites were visited where a range of power tools were being used in normal circumstances. This gave the opportunity to measure the vibration magnitudes during real life use of the tools and also to conduct a significant number of repeat measurements. A list of the tools measured is given in Appendix 3.

The sites where the measurements were taken included:

- Council forestry team at an arboretum: park maintenance.
- Council maintenance team: on-site maintenance and repair garage.
- Council road crew: road repair and road maintenance crews. Cutting and repairing paths and refilling channels in preparation for installation of street lighting.
- Company: general workshop activities, both internal and external.

A total of 40 tools with unique serial numbers were tested; with the user wearing the HAVwear unit and with the LD device attached to the tool. Different models of the same tool description, e.g., chainsaw, were aggregated for analysis, resulting in 16 different tool types for comparison.

In six instances, measurements were omitted where standardised testing conditions were not maintained, per recommendations by the tester. After deleting these records, data from 477 individual tests were used for analysis.

Each tool test included a reading from both the HAVwear and LD device, representing an average vibration magnitude over the full test duration, which was approximately one minute on average. Analysis was also performed to assess any differences in vibration magnitude readings by tool group and test duration.

4.2 Method of Data Review

The purpose of this analysis is to assess the comparability of Reactec's HAVwear unit and Larson Davis (LD) HVM100 device with respect to the vibration magnitude measurements (m/s^2) of 16 different tools.

Vibration magnitude measurements from the two devices were compared statistically using a combination of correlation analysis and t-tests/signed rank tests, as in the previous analysis.

4.3 Results & Analysis

4.3.1 Overview

Table 4.1 below presents summary data of the readings from the HAVwear and LD devices (n=477). Overall, the HAVwear device tended to produce slightly higher readings than that of the LD device (both the mean and median HAVwear readings were higher). This trend is consistent with the previous comparative analysis performed by IOM.

Table 4.1 - A summary of the HAVwear and LD readings (m/s^2).

	Mean	Standard Deviation	Min	25th Pctl	50th Pctl	75th Pctl	Max
HAVWear	9.7	5.5	0	6.2	8.2	11.8	29.6
LD	7.5	4.1	0.9	5.1	6.2	9.0	26.9

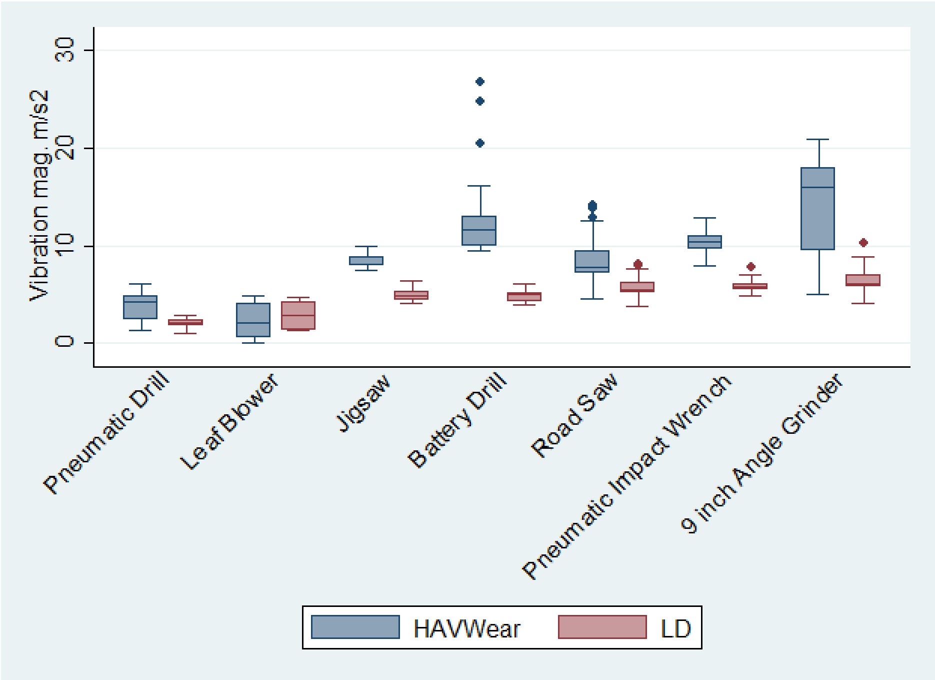
4.3.2 Individual Tools

Although the overall trend in vibration magnitude readings for the HAVwear tends to be greater, this finding was not consistent when examining each individual tool test.

Figure 4.1a below depicts boxplots of the tools with vibration magnitudes lower than the overall LD median (6.24 m/s^2) and Figure 4.1b presents those tools with higher magnitudes. As a reminder, the "box" component includes the data ranging from the 25^{th} percentile (pctl) to the 75^{th} pctl, also known as the Interquartile Range (IQR). The lines on either side of the box represent 1.5x the IQR, with those data points falling outside this range to be considered more extreme values (outliers).

According to the figures below, there are two tools for which the HAVwear readings appear to be substantially lower than those of the LD: the brush cutter and the pneumatic orbital sander; however , the data from the brush cutter was not considered to be statistically important.

(a)



(b)

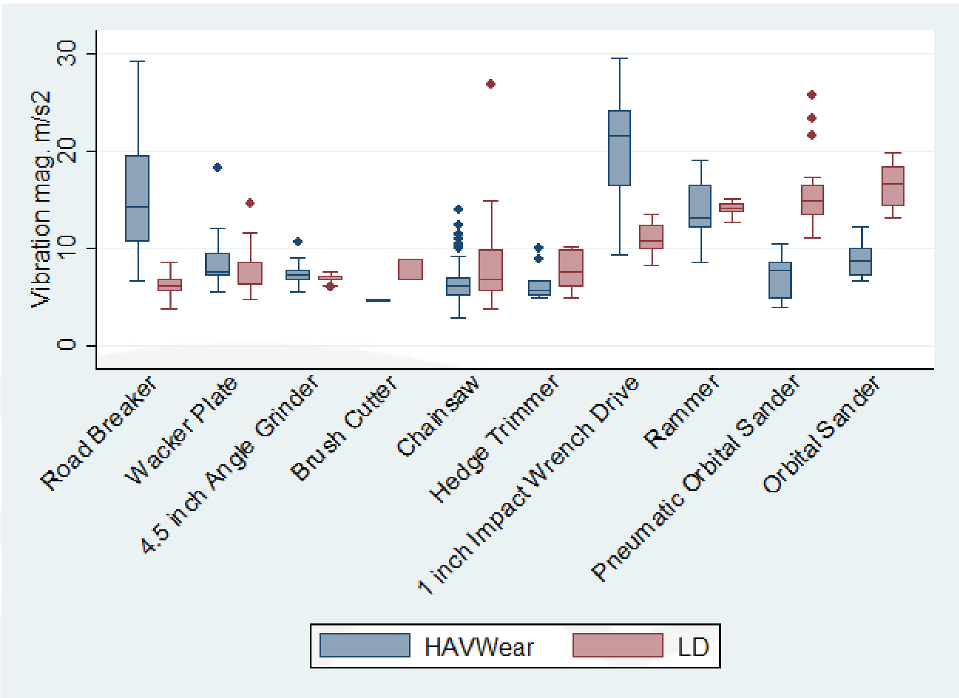


Figure 4.1 - The distribution of HAVwear and LD measurements for each tool where measurements are (a) lower and (b) higher than the overall LD median (6.24 m/s²).

To quantitatively assess the visual differences displayed in Figure 4.1, paired comparisons[4] of means or medians were undertaken. For simplicity, Table 4.2 below displays only mean values and differences between HAVwear and LD, though non-parametric statistical testing was also employed for the comparison of two tools[5].

The tool names are highlighted in orange where the HAVwear was significantly higher (8/16), blue where lower (2/16), green where the same (4/16), and white where insufficient data were available to test statistically (HAVwear lower in both cases).

In addition, Table 4.2 also shows the correlation or association between the measurements recorded by the two devices. This value indicates the strength of the relationship between the two instruments, ranging from -1 (exactly inverse) to +1 (perfect agreement).

The HAVWear and the LD meter are both measuring the vibration of the same tool during the same test, albeit with the HAVwear on the arm of the user and the LD's HVM100 on the tool. There is therefore an expectation for substantial positive association between the recorded values.

For over half of the tools (9/16), correlation coefficients were > ~0.5 and significant, with 2/16 other tools having positive value, but not significant; 2/16 did not have sufficient data (N/A). Three tools had negative, but not significant, values.

Table 4.2 - A comparison of the correlations and mean vibration magnitudes for each tool, with an indication of statistical significance.

Tool No.	Tool	n	Correlation	HAVwear mean vib (m/s^2)	LD mean vib (m/s^2)	Difference in means (HAV - LD)
1	1" Impact Wrench	18	0.57*	20.0	11.0	9.0***
2	4.5" Angle Grinder	20	-0.34	7.3	6.9	0.4
3	9" Angle Grinder	10	0.48	14.1	6.6	7.5***
4	Battery Drill	25	0.73***	13.2	4.8	8.4***
5	Brush Cutter	3	N/A	4.6	7.5	-2.9
6	Chainsaw	95	0.54***	6.3	7.8	-1.5***
7	Hedge Trimmer	12	-0.09	6.3	7.8	-1.5
8	Jigsaw	20	0.67**	8.4	4.9	3.5***
9	Leaf Blower	6	N/A	2.2	2.8	-0.6
10	Orbital Sander [1]	43	-0.07	7.9	16.0	-8.1***
11	Pneumatic Drill	40	0.84***	3.7	2.0	1.7***

[4] Log-transforming data to represent Normal approximations, where necessary.
[5] Battery drill and Wacker plate.

Table 4.2 cont.

Tool No.	Tool	n	Correlation	HAVwear mean vib (m/s²)	LD mean vib (m/s²)	Difference in means (HAV - LD)
12	Pneumatic Impact Wrench	20	0.34	10.4	5.9	4.5***
13	Rammer	20	0.48*	13.8	14.1	-0.3
14	Road Breaker	84	0.49***	15.4	6.2	9.2***
15	Road Saw	41	0.8***	8.6	5.7	2.9***
16	Wacker Plate	20	0.9***	8.7	7.4	1.3***

*p<0.05, **p<0.01, ***p<0.001

1 the results for the orbital sander have been combined.

The key concern raised in the analysis appears to be the orbital sander results. The vibration magnitude measured during the survey was higher than expected and higher than published manufacturers data would indicate as common. No specific causes of this high level could be identified from observations on the use of the tool during the measurement periods.

A download of field data, collated by Reactec from over 70 hours of trigger time was provided. This demonstrated that the HAVwear data was generally higher than the data used by the end user as the static tag value for the tools. This indicates that the HAVwear data would provide an indication of higher risk than the end users assumptions, in line with the higher vibration magnitude measured.

4.3.4 Duration of Test

As most of the tool tests were conducted for a period of one minute, it might be difficult to assess any differences in vibration recordings between the two devices over different test durations.

Figure 4.3 below shows a scatterplot of the differences in vibration magnitudes (HAVwear m/s^2 - LD m/s^2) across the average time recorded for each test by the HAVwear and LD device. Most of the tests lasted for 1 minute, thought it appears the HAVwear may read higher in some of the tests lasting less than one minute (circled in Figure 4.3).

In fact, 18/25 tests <1-minute-long were conducted with the 1" impact wrench. This is most likely to be a reflection of the short trigger time required when operating such a tool.

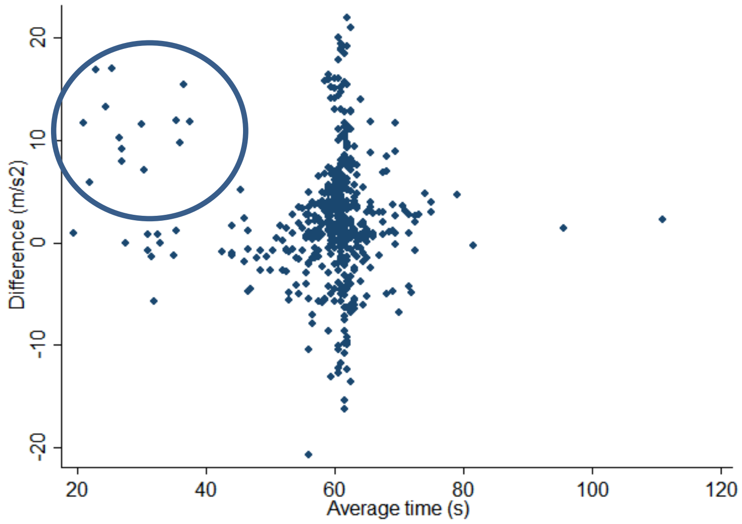


Figure 4.3 - A comparison of the difference in vibration magnitudes for each test (HAVwear - LD) by average time recorded by the two devices. The encircled data is from the 1” impact wrench tests.

In addition, a test was performed to determine the agreement of the time of each test recorded by the two devices, which appeared to be strongly correlated (rho=0.71; $p<0.001$). Figure 4.4, below, illustrates a scatterplot of the test time recorded by each device.

As demonstrated in Figure 4.4 below, most tests appear to have lasted one minute. However, there is some apparent discrepancy for the shorter tests, where the HAVwear readings are lower. Fifteen (or 50%) of the tests during which the time differences (LD - HAVwear) were more than 10 seconds related to the 1” Impact Wrench Drive. The discrepancy in trigger time noted with the impact wrench reflects the nature of the test carried out with this specific tool which due to method of use precludes a continuous 1minute trigger pull.

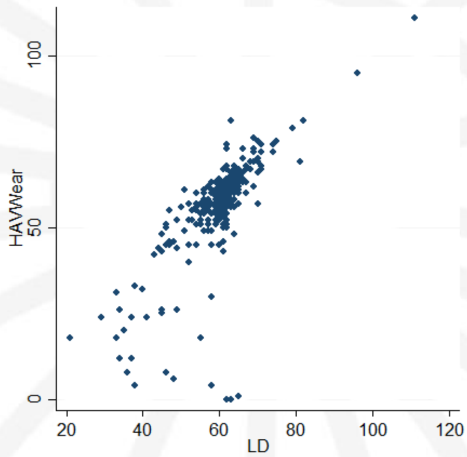


Figure 4.4 - A comparison of the time (s) recorded by each device for each test.

4.3.5 Grouped Tool Type

It was considered instructive to examine differences in the recorded vibration magnitudes among groups of similar tools were tested. Although each tool is relatively unique in its design, function, duration of use and vibration magnitude, we formed four broad groups for comparison, as presented in Table 4.

Table 4.3 – Groups of similar tools tested.

Tool Group	Tool
Impact	Road Breaker
	Wacker Plate
	Wrench Drive
	Impact Wrench
	Rammer
Cutting	Brush Cutter
	Hedge Trimmer
	Jigsaw
	Pneumatic Drill
	Battery Drill
	Road Saw
Grinding	Angle Grinder
	Chainsaw
	Orbital Sander
Other	Leaf Blower

As presented in Figure 4.5, the average vibration magnitudes for the HAVwear device appear to be greater than the LD device for cutting and impact tools, yet lower for tools used for grinding. Quantitatively comparing these data confirms statistically significant differences in the tool groups (except for other). The lower vibration magnitudes for the HAVwear in the grinding tools is largely due to one tool the orbital sander. There are also known difficulties in assessing vibration magnitudes from impact tools due to the often short duration of the action of the tool.

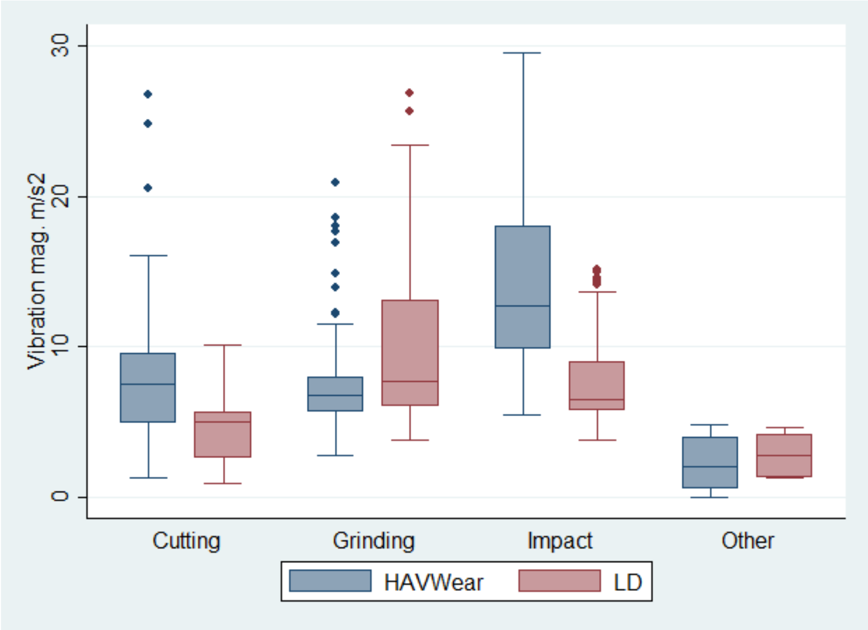


Figure 4.5 - A boxplot comparison of vibration magnitudes across similar tool groups.

4.3.6 Comparison with Published Data

Where possible data published by HSE giving a summary of vibration magnitudes of some common machines has been compared with the data collected by the HAVwear system and the conventional measurement technique. The data included in Table 4.4 below is given as a recommended initial value (75%ile) (m/s2). It is noted that with some limited information and differences in the tools and potentially in their use this is not a direct comparison; but does serve to give a basic comparison between the different assessment techniques.

Within the limitations of the comparisons which can be made it is evident that there is some overlap in the ranges of the HAVwear data and the published data. There are however some disparities, in particular with the impact wrench.

Table 4.4 - Comparison of Measured Vibration Magnitudes with HSE published data

Tool No.	Tool	HAVWear mean vib (m/s^2)	LD mean vib (m/s^2)	HSE Range Lower (10%) to Upper (90%) (m/s^2)	HSE Recommended initial value (75%ile) (m/s^2)
1	1" Impact Wrench	20.0	11.0	3 - 11	5 -10
2	4.5" Angle Grinder	7.3	6.9	2 - 5	4
3	9" Angle Grinder	14.1	6.6	3 -10	7
4	Battery Drill	13.2	4.8	6 - 13	5 - 10
	Brush Cutter	4.6	7.5	3 - 5	5
6	Chainsaw	6.3	7.8	3 - 7	7
7	Hedge Trimmer	6.3	7.8	3 - 14	7
8	Jigsaw	8.4	4.9	9 - 17	11
9	Leaf Blower	2.2	2.8	-	-
10	Orbital Sander	8.7	16.4	4 - 14	9 - 12
11	Pneumatic Drill	3.7	2.0	6 - 8	8
12	Pneumatic Impact Wrench	10.4	5.9	3 - 11	5 - 10
13	Pneumatic Orbital Sander	7.2	15.6	4 - 12	9

4.3.7 Discussion

After careful interpretation of the results from 16 different tool types tested with the HAVwear and LD device, there is only one tool type ([pneumatic] orbital sander) where the mean HAVwear readings are greater than -2.0 m/s^2, compared to the LD unit.

As there was no significant directional relationship at lower or higher average vibration magnitudes for this tool, it appears the HAVwear consistently reads lower for this tool. The discrepancy in readings for this specific tool might be attributed to the wearer compensating in some way that reduces the vibration magnitude recorded by the HAVwear device, relative to the LD unit.

Whilst the HAVwear device was also found to read statistically lower in the chainsaw, the absolute mean difference was only 1.5 m/s^2, which coincides with the manufacturer's uncertainty range for vibration magnitudes. Therefore, these average readings from the two instruments do not appear to be meaningfully different.

Ultimately, if the HAVwear device tends to read a higher vibration magnitude, the vibration hazard a worker is exposed to would be overestimated (a false positive).

However, in the case of the orbital sander, the HAVwear would provide an underestimate of a worker's vibration exposure (a false negative), which may be undesirable from a safety perspective.

In summary, with the exception of the orbital sander, the recorded HAVwear vibration magnitudes appeared at least as high as those recorded by the LD device.

5 SUMMARY OF FINDINGS

5.1 Phase 1 Findings

The following section summarises the findings from Phase 1 of the work. It should be noted that while statistical significance has been considered when drawing these conclusions, the data has been compiled from a specific set of tools and conditions which do not reflect findings from other tools and circumstances of use. Outliers and variations were noted in all data sets which could not always be explained due to the limited data in some data sets. Nevertheless, there were clear trends that emerged through the analysis.

There is an indication of a high degree of agreement between readings of the HAVwear and other devices.

The HAVwear results were found to be statistically significantly higher in 9/23 tools, lower in 6/23 tools and not different in 8/23 tools.

- Reviewing measurements taken in different substrates, the HAVwear had higher measurements than the conventional devices in timber and grass, but was found to be lower for those tested in air. The difference between the units was not significantly different for tools tested in concrete.

- There was little association between the difference (%) in HAVwear and LD/Svantek vibration magnitudes with trigger time.

- The findings provide strong evidence for a positive association of the values of vibration magnitudes measured by the HAVwear and by conventional devises; with a tendency for the HAVwear readings to increase with greater readings of the other devices, especially with those of the Svantek device.

- When these results were reviewed in relation to substrate the HAVwear readings remained higher than the other units.

- Indication that the readings from the HAVwear device tend to be more consistent than those from the conventional devices.

- Comparing the experimental data with the manufacturer's values, the agreement of the HAVwear readings is quite comparable to that of the LD/Svantek devices with the manufacturer's data.

- There was no statistical correlation between the difference (%) in HAVwear and conventional vibration magnitudes with trigger time.

5.2 Phase 2 Findings

The following section summarises the findings from the Phase 2 of the work.

Again it should be noted that while statistical significance has been considered when drawing these conclusions, the data has been compiled from a specific set of tools and conditions which do not reflect findings from other tools and circumstances of use. Outliers and variations were detected in the data sets which could not always be explained due to the limited data in some data sets. Nevertheless, there were clear trends that emerged through the analysis.

- The overall trend (>70%) in vibration magnitude data for the HAVwear tends to be greater than those measurements made by conventional methods. However, this finding was not consistent across each individual tool test, as one tool in particular showed lower vibration magnitude readings from the HAVwear.

- Where measurements are taken concurrently over a one-minute period the results from the HAVwear and the conventional method are consistent.

- When aggregating results of each tool group, there were differences in the HAVwear and LD vibration magnitudes across impact, cutting and grinding tools.

- The average vibration magnitudes for the HAVwear device appear to be greater than the LD device for cutting and impact tools, yet lower for tools used for grinding. However, the lower vibration magnitudes for the HAVwear in the grinding tools is largely due to one tool - the orbital sander.

- Within the limitations of the comparisons which can be made it is evident that there is some overlap in the ranges of the HAVwear data and the published data. There are however some disparities, in particular with the impact wrench.

6 DISCUSSION

6.1 Background

The Control of Vibration at Work Regulations require employers to make 'a suitable and sufficient assessment' of the risk created by the work. Such an assessment requires assessment of individuals' daily exposure to vibration; this can be achieved through; observations; reference to relevant information, such as probable magnitudes; and measurement of vibration magnitudes. The aim of the assessment is to determine whether any employee is likely to be exposed to vibration at or above an exposure action level or above an exposure limit value.

Some employers routinely log hand arm exposure using log books, some use timers and wearable devices while some simply measure typical exposures on which to base their risk assessment. There is no legal requirement for continual monitoring and recording of vibration exposure. However, an employer must determine what the workers' exposure is likely to be; therefore, a period of monitoring to understand how long workers use particular tools in a typical day or week is considered necessary.

An important aspect of the risk assessment is to reduce the exposure and the risks, where necessary, and to be able to demonstrate such a reduction. The Regulations also require that exposure is reduced to 'as low as reasonably practicable'. Regular monitoring may assist in demonstrating that exposure is reduced and reducing. Monitoring exposure may be especially important when an individual employee has restrictions placed upon them in relation to their hand arm vibration exposure.

The Guidance on the Regulations recognises that exposure to vibration will vary from day to day for individuals and that sufficient information is required to establish whether it is likely that the exposure action or limit will be exceeded. The Guidance states that it may be possible to do this without having to make measurements within the workplace and that tool manufacturers or suppliers can be an important source of information. HSE strongly recommend that verification of measurement results by comparison with data from other sources e.g. HSE guidance, machine manufacturers, trade associations etc.

Research conducted by HSE reports that errors arise during sampling and measuring of vibration magnitude and that estimating exposure from exposure duration and points calculations duration can result in errors of +/- 20% of the average exposure levels. Estimated exposure assessments should take account of such errors and factor them in in the risk assessment.

6.2 Aims and Objectives

This work was designed to answer a number of questions, including:

1. Does the Reactec Analytics Platform, incorporating the HAVwear, provide information which is useful in the completion of a suitable and sufficient risk assessment of the risk of HAVS to the tool user?

2. Does the sensed vibration provided in the Reactec Analytics Platform reporting software and the calculation of Sensed Exposure Points from this reflect the probable vibration experienced during real tool use?

3. Does the information produced support a risk assessment which is more realistic than the use of trigger timers and manufacturers' data or paper records and manufacturers' data or historic ISO5349 test data?

4. Does the information on tool users and tool behaviour in the Reactec Analytics Platform support the development of controls to reduce the risk to employees from tool use?

The data analysed in both Phase 1 and 2 informs these questions in the following manner.

6.2.1 Is the HAVwear data useful in completing suitable and sufficient risk assessments?

The sensed vibration and SEP data collected and reviewed in both Phases 1 and 2 shows that the Reactec Analytics Platform, incorporating the HAVwear, does provide information which is useful in the completion of a suitable and sufficient risk assessment of the risk of HAVS to the tool user.

The data collected by the HAVwear system, during real use of various tools, is in general, comparable with the measurements achieved by conventional means. Taking account of the variations which may occur when measuring hand arm vibration, the data generated by the HAVwear system provides a useful source of information to inform a suitable and sufficient risk assessment.

6.2.2 Does the HAVwear data reflect the probable vibration experienced by the wearer during real tool use?

The availability of the manufacturer's data provides another reference point to assess the comparability of the HAVwear device to the industry standards. The review of the published and measured data shows an overlap in the ranges of HAVwear and the manufacturer's data in the tool scenarios (for example, see Figure 2.5). However, such an overlap also occurs when comparing conventionally made measurements with the manufacturers data.

Comparing the experimental data the concordance of HAVwear readings is quite comparable to that of the conventional measurement devices.

The data obtained during Phase 2 of this investigation indicates that the HAVwear module results are, in general, quite consistent and in alignment with measurements taken using conventional measurement methods. As both the HAVwear and the conventional assessments were made under the 'real use' of the tools they reflect the exposure of the user when carrying out the tasks in the normal manner.

The conclusion is therefore that although the HAVwear system does not measure vibration 'on tool' in accordance with the requirements of BS EN ISO 5349-1: 2001 it does provide information comparable with that produced by conventional measurement techniques.

6.2.3 Does the information produced provide a risk assessment which is more realistic than the use of trigger timers and manufacturers' data or paper records and manufacturers' data or historic ISO5349 test data?

The guidance on the Vibration Regulations, as detailed in L140, advices that any system used to determine risk from hand-arm vibration should be based on either exposure in m/s2 A[8] or exposure points. The data produced by the HAVwear system does create a risk assessment which is realistic with respect to the actual tool use. As the system assesses vibration exposure during the entire use of the tool it may therefore be more accurate than the use of trigger times and manufacturers' data compiled for a limited range of tool activity use. The system may also provide the ability to look specifically at tool use, and potential exposure, for individuals.

The means of obtaining the information to inform risk assessments, using the HAVwear system offers a simple mechanism whereby assessment of exposure, and changes in exposure, can be readily monitored over extended periods of time.

6.2.4 Does the information on tool users and tool behaviour in the Reactec Analytics Platform support the development of controls to reduce the risk to employees from tool use?

The aim of carrying out risk assessments is to determine the potential exposure of individuals in relation to action and limit values; and to identify effective control measures. Conducting risk assessments using limited conventional measurement techniques (e.g. on one or two occasions) clearly provides information for the risk assessment. However, it does not readily give data on changes of use of the tool by the user which may result in a reduction in exposure, nor does it identify if maintenance, servicing or other modifications are affecting vibration exposure.

The HAVwear information, gathered on a regular basis, does inform the development of risk reduction control measures and can be used to identify trends in risk reduction.

7 CONCLUSIONS

Data created from the operation of 23 tools using the HAVwear system, and up to three vibration measuring methodologies simultaneously, as supplied by Reactec, was reviewed. In addition, data from numerous repeat measurements of vibration magnitudes on tools in real life usage, measured simultaneously by HAVwear and conventional means, were analysed.

Correlations between the HAVwear results and conventional measurement meters were generally strong. Overall, it was noted the median vibration magnitudes of the HAVwear data often displayed a higher reading than the conventional devices. The magnitude and direction (i.e. higher or lower) of the differences between the HAVwear system and the LD/Svantek measurements varied between tools. However, this variation also existed when comparing the HAVwear and LD/Svantek readings to the manufacturer's data for each tool.

Some variability was noted when comparing the measurement results obtained when the tools were used on different substrates. The HAVwear readings were, on the whole, higher or the same across substrates. No statistical association was identified between the difference (%) in HAVwear and conventionally measured vibration magnitudes with trigger time.

The above findings do not raise any initial concerns about the HAVwear system and the information it provides. While recognising that the HAVwear system does not measure the level of vibration in the same manner as the methods detailed in BS EN ISO 5349 it does produce data which can be used as a Risk Assessment tool and/ or as a Risk Management tool.

APPENDIX 1 – STATISTICAL METHODS OF ANALYSIS

Statistical Methods of Analysis

Statistical tests were completed to identify any differences between the readings of the HAVwear and other currently used vibration meters. Within the dataset for each tool, the vibration magnitude for the HAVwear unit was compared to that of either the Larson Davis (LD) or Svantek vibration meters.

Since each trial was conducted with the HAVwear meter and either the LD or Svantek device, it was not possible to compare the magnitudes of these two units. Whilst the Bruel & Kjaer (B&K) monitoring device was also included in some testing, the number of trials was too few to allow for statistical analysis within each tool and therefore B&K results were omitted. Analysis of the Makita HR2610 results was completed separately using three categories to account for the use of different drill bits. All data processing and analysis were completed using Stata (13.1).

Comments for individual trials included with the data were cross-referenced to identify any outlier vibration magnitude values. One outlier was removed in the "Makita SDS DHR202 6mm bit" dataset due to a "Battery out" comment that coincided with a low LD value.

Testing for normality of the vibration magnitude data within each tool were completed via Shapiro-Wilk tests. Data were non-normal (or borderline non-normal at $p<0.05$) in roughly half the tools. Based on this information, non-parametric tests were performed.

Overall Agreement

To test for the overall agreement of the HAVwear with the other devices, Spearman rank correlations were performed. This test compares the ranks of two variables rather than the actual values. Results of this test produce a "rho" value of -1 to 1, which can be assessed using five categories of strength. The HAVwear was most associated with the Svantek meter (rho = 0.85; $p<0.001$), considered to be "very strong". The HAVwear was least associated with the LD device (rho = 0.62; $p<0.001$), though still considered to be a "strong" correlation. For all tools combined, correlations between HAVwear and each other unit were "strong" (rho = 0.62; $p<0.001$).

Differences by Individual Tool

The Wilcoxon signed rank sum test was performed for each tool scenario where there were at least 10 observations for both the HAVwear and LD/Svantek devices. This test is used to examine differences in paired data. The HAVwear vibration magnitudes were found to be significantly higher in 9/23 tools (median values ranging from +16.5 to +317.1%), lower in 6/23 tools (two are the same tool) (from -16.2 to -56.4%) and not different in 8/23 cases (half are scenarios for which statistical analysis could not be undertaken).

Differences by Substrate

Statistical tests using the same method were undertaken to examine differences in vibration magnitudes by substrate material. In the different substrates, the HAVwear had higher measurements than the other units in timber (n=218; p=0.010), where the HAVwear median was 38.0% higher.

The HAVwear values were found to be lower in wood, but when these data (representing one tool) were included with timber, the HAVwear vibration magnitude values were still higher, with medians of 6.2 vs 4.7 (p=0.045). The HAVwear device median value was significantly higher in the grass substrate (+95.3%) and lower where substrate was not applicable (tool = blower) (-30.0%), but only one tool was tested in each of these two scenarios.

Effects of Trigger Time

Trigger times for each test varied among the tools, with median values ranging between (28s (MS231) to 180s (Makita DHP456)). Potential differences due to trigger times were evaluated using Spearman correlations between the absolute percentage difference between the HAVwear and LD/Svantek vibration magnitudes and the trigger time. The Spearman's rho value (-0.08) was not significant (p>0.05), so there was no evidence of such an effect.

APPENDIX 2 – LIST OF TOOLS TESTED IN PHASE 1

List of Tools Tested in Phase 1

1	54 Mower
2	Dewalt DC224
3	Hilti TE1000
4	Husqvarna FS 450
5	Makita 4011C
6	Milwaukee M28
7	MS231
8	Makita 5903R
9	Makita DHP456
10	Makita DTD 146
11	Makita HR2610 8
12	Makita HR2610 8mm (long)
13	Makita HR2610 8mm (short)
14	Makita JIG 121
15	Makita Jigsaw 35
16	Makita Paddle Mi
17	Makita Recip Saw
18	Makita SDS DHR20
19	Metabo 5 inch G
20	Milwaukee 28 G20
21	Stihl BG 56C
22	Stihl MS 461
22	Sullair SK12

APPENDIX 3 – LIST OF TOOLS TESTED IN PHASE 2

List of Tools Tested in Phase 2

1	1" Impact Wrench
2	4.5" Angle Grinder
3	9" Angle Grinder
4	Battery Drill
5	Brush Cutter
6	Chainsaw
7	Hedge Trimmer
8	Jigsaw
9	Leaf Blower
10	Orbital Sander
11	Pneumatic Drill
12	Pneumatic Impact Wrench
13	Rammer
14	Road Breaker
15	Road Saw
16	Wacker Plate

APPENDIX 4 – GLOSSARY OF TERMS FOR HAND ARM VIBRATION

Glossary of Terms for Hand Arm Vibration

Aeq Acceleration Equivalent Value

Once you have measured a tool, the result will be given as an Aeq. The term Aeq simply stands for the Acceleration equivalent value. Acceleration is the vibration parameter used in human vibration measurements and is measured in metres per second squared (m/s2). The 'equivalent' part of the term simply means the average vibration level

Aeq is a single number that represents the equivalent energy of a varying source. In other words you get the same amount of energy from the varying vibration level as you would from the continuous, equivalent value. You can expect results to range from around 0.5m/s2 to about 20m/s2 Anything above 25m/s2 would be considered to be extremely high.

M/s^2 Meters per Second Squared

Meters per second squared, or M/s^2, is the standardised measurement unit of acceleration or vector magnitude. Within vibration monitoring M/s^2 is defined either as an average over time or as an instantaneous reading.

RMS Root Mean Squared Amplitude

Root Mean Square Amplitude, or RMS, is the square root of the average of the squared values of the vibration waveform.

RMS takes into account the time history of the waveform, giving an amplitude value which directly relates to the energy content. RMS is therefore considered the most relevant measure of amplitude in order to assess levels of damage.

EAV Exposure Action Value

The Exposure Action Value is a daily amount of exposure which employers are required to take action to control exposure to eliminate risk or reduce exposure to as low as is reasonably practicable. Set and enforced by The Control of Vibration at Work Regulations 2005, the EAV level is set at 2.5 m/s^2 average over 8 hours (A(8)).

ELV Exposure Limit Value

The Exposure Limit Value (ELV) is the maximum amount of vibration an employee may be exposed to on any single day. The Exposure Limit Value is the level of exposure where employers must take immediate action to reduce their exposure below the limit value. The EAV level is set at 5 m/s^2 average over 8 hours (A(8)).

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