Could deviation from static and declared vibration dosage assumptions in the real use by workers of power tools be preventing further progress on reducing HAVS in affected populations?

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Abstract

In many countries, tool manufacturers are required to provide tool vibration dose based on specific test protocols identified within ISO 28927 which are unlikely to represent the tool's use in a real worksite. A point in time testing of a tool's vibration dose at the work site following ISO 5349-2 is also limited in the scope of variability it can capture as operator technique and posture are likely to vary as will substrate and tool condition when the tool is later deployed within a varied work force.

In this paper we examine the extent to which real work site Hand Arm Vibration (HAV) daily exposure varies compared to the static vibration dose data employed in risk assessments of HAV daily exposure by comparing daily exposure based on a static vibration dose with daily exposure assessed using real use monitoring from over 400 organisations currently employing wearable monitoring technology. The investigation shows that significant variances exist between HAV exposure calculated from assuming a static vibration dose and that determined from real use monitoring, indicating a potential for an increased risk of developing HAVS for exposed workers than expected.

1. Introduction

Hand Arm Vibration Syndrome (HAVS), an industrial health condition directly linked to excessive exposure to occupational mechanised vibration has been formally recognised for more than three decades (Bovenzi 1998). Despite the existence of international standards concerning exposure assessment and regional legislation regarding working practices, reported cases of HAVS remain significant as indicated by disability benefit claims in the UK (HSE 2018). It should be noted that this data does not reflect all diagnosed cases of the conditions, only those sufferers choosing to claim disability benefit from the UK Government. While all parties agree that vibration exposure reduction should be the ultimate objective for all organisations, it is generally accepted that a degree of mechanised tool use is unavoidable in many sectors for the foreseeable future. In light of this reality it remains desirable to understand the risks faced by tool operators such that all measures might be taken to reduce this risk to it's lowest practicable level through intelligent task design and procurement policies. The current practice of estimating exposure based on a static single vibration dose for each

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tool together with an estimated exposure time has been in place for more than a decade in the UK however the number of new cases of vibration induced white finger (VWF) reported annually remains essentially unchanged (HSE2018). This paper examines whether the static vibration dose data used for the purposes of risk assessments is truly representative of the real risks being faced by operators in the field and poses the question of whether under-estimation of risk for some of the affected population may be contributing to inadequate control measures and unnecessary exposure to risk.

Studying the effectiveness of risk assessment data for affected populations relative to a real use assessment of HAV exposure in the workplace has not previously been practical due to the challenges in acquiring HAV exposure data sets of an adequate size. However, advances in digital monitoring and the growing adoption of such wearable sensor technologies now offer the opportunity to examine the effectiveness of a risk assessment based on a static vibration dose and the controls designed around it. The present study analyses HAV exposure data gathered from wearable sensors deployed across a range of industry sectors acquiring HAV exposure data during real use as assessed on the tool user and simultaneously as assessed using static vibration dose data for the tool's used. In this data set the static vibration dose data input into the wearable device represents the vibration dose data the target organisation would normally use in a risk assessment for a given tool or task. The authors seek to examine to what degree this data varies relative to a real time HAV exposure assessed on the tool user. It should be noted that this data was acquired from a population where digital monitoring and real time feedback from the wearable sensors were employed, in some part, as a control measure and therefore variance and exposure levels in populations not employing such technology may be even greater. A study reported by the authors (Maeda et al 2017) illustrated the range of variance possible from a task HAV exposure risk assessment based on static vibration dose data and a monitored HAV exposure assessment of the same task when individuals were instructed to work as normal and not respond to the monitoring data. While the task assessment established a max risk for an individual of an A(8) of 2.4m/s^2, the maximum recorded for each monitored individual ranged from an A(8) of 1.5 to 4.8m/s^2.

In the data set of daily HAV exposure of the monitored population examined in this paper, there is a common trigger exposure time to vibration but two approaches to determining the vibration dose of the exposure during monitoring. The static vibration dose data predominantly consists of manufacturers declarations acquired in accordance with ISO 28927 or a point in time tool vibration measurement acquired in accordance with ISO 5349, either of which may or may not have an uncertainty (K) factor applied to it, reflecting the broad spectrum of approaches to HAV risk assessment in industry. The real use vibration dose data has been acquired through a wearable sensor attached to the operator's wrist. The wearable sensor has been shown through independent validation (Graveling et al 2018) to produce vibration dose data which is comparable with that produced concurrently by ISO 8041 instrumentation used in accordance with ISO 5349 and would inform a suitable and sufficient risk assessment. Therefore, the author's believe that a comparison of the two data sets on relative terms is valid for the purposes of this investigation.

2. Method

Data acquired from over 400 private and government organisations currently employing a wearable HAV exposure monitoring system was analysed. The wearable system calculates daily exposure to HAV using two different methods concurrently. The first method, referred to as the static method, utilises a single vibration dose programmed into an RFID tag attached to the tool in use and calculates HAV exposure dose by capturing the duration of the trigger pull for each tagged tool and applying equation 1 as specified within ISO 5349-1(BSI, 2001a). In this first method a_{hv} is the vibration total value of frequency-weighted r.m.s. acceleration (vibration dose) programed into the RFID tag.

$$A(8) = a_{hv}\sqrt{\frac{T}{T_0}} \qquad \textbf{Equation 1}$$

Where
a_{hv} = is the vibration total value of frequency-weighted r.m.s. acceleration;
T = is the duration of exposure to the vibration, a_{hv};
T_0 = is the reference duration of eight hours

The second method, referred to as the monitored method utilises a real time vibration dose where a_{hv} is calculated using data captured on the wearable device from a 3 axis accelerometer sampling at 1.6kHz for 0.66 seconds every 1.5 seconds. Transfer functions are applied to each corresponding frequency point value across the spectrum to compensate for attenuation through the hand arm system. Overall vibration value a_{hv} is calculated by means of a continuous rolling r.m.s. acceleration for the duration of the trigger time. Exposure is then calculated using equation 1.

Each time a tool operator pulls the trigger on a piece of vibrating machinery the wearable sensor creates a tool record containing vibration dose data from the two concurrent methods along with trigger time and details of the tool in use. Data from approximately four million tool records is stored in an online data base which can be sorted according to a number of fields including tool type and industry. Approximately 40,000 individual tool operators have been registered on the wearable system across all monitored organisations.

The authors analysed data from approximately 246,500 days of operator HAV exposure data, accrued from over 400 organisations across a range of industry sectors in a 9-month period between September 2017 and May 2018. Both public and private organisations were included in the study with sectors including civil engineering, steel fabrication, rail, demolition, grounds maintenance, local authorities, and industrial manufacturing.

Beyond understanding the distribution of exposure discrepancy across industry sectors the authors sought to identify potential sources of variation by analysing sources of vibration exposure relative to the static vibration dose data used by organisations when risk assessing tools in the workplace. Specifically, the study analyses five specific tool types by comparing their static and monitored vibration dose data.

3. Results & Discussion

The data was first sorted on an industry by industry basis and then analysed to examine the relative number of days in which operator's daily HAV exposure fell within three specific ranges using the two concurrent assessment methodologies. Daily HAV exposure ranges selected where equivalent to an eight hour dose of A(8) = < 2.5 m/s², A(8) = >2.5 m/s² to <5.0 m/s² and A(8) = > 5.0 m/s².

Table 1 shows the relative distribution of HAV exposure within the chosen ranges, within different industry sectors in terms of number of operator days in which the average daily exposure for an individual operator using the two HAV exposure assessment methods fell into each HAV exposure range.

Table 1 Distribution of exposure levels across industry sector

		Static HAV Exposure Assessment Method		**Monitored HAV Exposure Assessment Method**	
	Bin	Count	% of Total	Count	% of Total
Construction	< 2.5 m/s²	40,566	77%	36,321	69%
	2.5 - 5.0 m/s²	11,392	22%	11,859	23%
	> 5.0 m/s²	410	1%	4,188	8%
Steel fabrication	< 2.5 m/s²	1,611	46%	1,451	42%
	2.5 - 5.0 m/s²	1,714	49%	1,245	36%
	> 5.0 m/s²	151	4%	780	22%
Rail	< 2.5 m/s²	2,336	79%	1,917	65%
	2.5 - 5.0 m/s²	596	20%	777	26%
	> 5.0 m/s²	18	1%	256	9%
Demolition	< 2.5 m/s²	29	74%	18	46%
	2.5 - 5.0 m/s²	9	23%	13	33%
	> 5.0 m/s²	1	3%	8	21%
Industrial	< 2.5 m/s²	14,923	54%	19,723	72%
	2.5 - 5.0 m/s²	12,181	44%	6,452	24%
	> 5.0 m/s²	279	1%	1,208	4%
Oil & Gas	< 2.5 m/s²	270	77%	314	90%
	2.5 - 5.0 m/s²	72	21%	35	10%
	> 5.0 m/s²	8	2%	1	0%
Local Authority	< 2.5 m/s²	34,290	88%	31,836	82%
	2.5 - 5.0 m/s²	4,463	11%	6,377	16%
	> 5.0 m/s²	287	1%	827	2%
Grounds maintenance	< 2.5 m/s²	30,440	88%	29,589	85%
	2.5 - 5.0 m/s²	3,813	11%	4,343	13%
	> 5.0 m/s²	360	1%	681	2%

As an example looking at static HAV exposure data, operators in the Rail sector have 79% of operator days reporting at or below an A(8) of 2.5m/s^2 but this declines to 65% when real time monitored HAV exposure data is examined. The steel fabrication sector has the highest percentage of operator days reporting above an A(8) of 5.0m/s^2 at 4% however this increases to 22% when real time monitored HAV exposure data is examined. The construction sector shows just over 400 monitored days with an A(8) >5m/s^2 based on the static data but this moves to over 4,000 days based on the monitored assessment.

Notable in the results was that seven of the eight industries analysed indicated a higher percentage of HAV exposure days exceeding an A(8) = > 5.0 m/s^2 when using monitored HAV exposure assessment method as opposed to static HAV exposure assessment method. Sectors encompassing more repetitive and tightly controlled environments such as Industrial, grounds maintenance and local authorities showed the smallest variance between static and monitored HAV exposure methods while the demolition and steel fabrication sectors as might be expected demonstrated the largest variance of +18%. Oil and Gas was the only sector analysed to show a negative variance of -2% between static and monitored assessment methods within this exposure range which the authors speculate may be due to the greater prevalence of tool maintenance and frequent tool vibration testing seen within that sector.

Differences in the distribution of exposure across two industries with significant data sets but showing marked differences in the level of control can been seen in figures 1 & 2. The reader is reminded that this is not a variance of overall exposure but rather the variance in the number of operator days where exposure exceeded fell into the daily exposure ranges shown. The presence of this variance between static and monitored assessment methods among daily records at the high end of the HAV exposure range is a cause for concern in that it indicates that operators at the greatest risk are potentially using the least reliable data in their risk assessments.

It should be noted that the data presented has been acquired from a population employing electronic monitoring technology with operator feedback and therefore a degree of behavioural change will be present which would be absent in a population not employing such a technology. Also that the wearable technology is deployed by the vast majority of organisations choosing to display to the operators the static assessment of risk during use of the wearable devise as opposed to the monitored assessment of risk. While not the object of this study, it was noted that overall the results demonstrated a positive benefit of monitoring in general in that the number of operator days exceeding an A(8) = > 5.0 m/s^2 was relatively small in most industries and the majority of operator days in most industries fell into the lowest exposure category. Such a distribution of exposure may not be present in populations not using such a system.

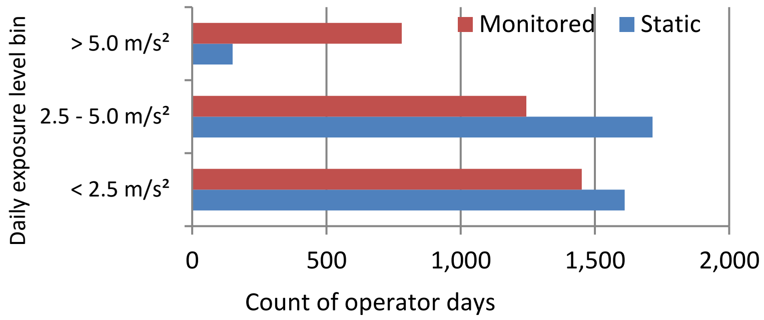

Figure 1 Exposure levels reached within the steel fabrication sector

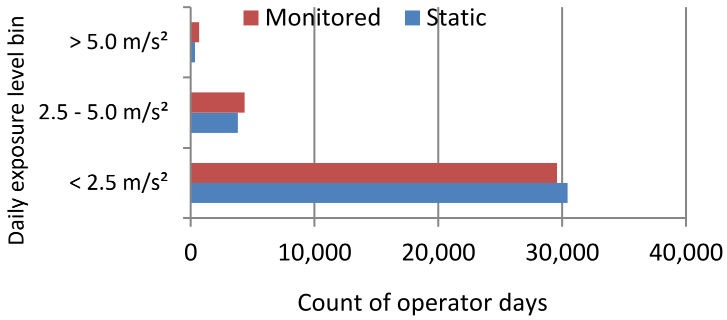

Figure 2 Exposure levels reached within grounds maintenance

To further investigate the relative exposure levels of the population based on the static versus the monitored HAV exposure assessment methods, an analysis was carried out of the number of individual operators who represented the greatest level of HAV exposure. The data set was analysed by anonymised individual and sorted from highest to lowest by the individuals exposed to the highest daily average HAV exposure most frequently. Table 2 below tabulates by both the static assessment method and the monitored assessment method, the number of individuals within the total population that incurred various percentages of the overall exposure. For example based on the static assessment method the individuals who incurred the top 20% of the overall HAV exposure was 160 individuals which as only 1.2% of the monitored population. Based on the monitored assessment method only 97 individuals incurred the top 20% of the total HAV exposure.

In the 9 months of the monitored period the average number of days monitored per operator was 25 days, the average daily exposure across the population based on the static assessment was an A(8) of 1.8m/s^2 and 2.3m/s^2 based on the monitored assessment method. It should be noted that the average of 25 days in a 9 month period indicates the extent to which the wearable is used to regularly assess risk as opposed to being used as a control measure on an everyday basis.

Table 2 Number and percentage of population contributing to various percentage levels of the total monitored exposure

% of overall population incurring stated % of overall exposure	Static Assessment		Monitored assessment	
	Number of individuals contributing	% of population	Number of individuals contributing	% of population
Top 20%	160	1.2%	97	0.7%
20 - 40%	385	2.8%	319	2.3%
40 - 60%	781	5.6%	694	5.0%
60 - 80%	1,633	12%	1,506	10.9%
Bottom 20%	10,872	79%	11,215	81.1%

For the monitored assessment across each section of the population the average of the daily HAV exposure for that population based on the static and the monitored assessment method was calculated and tabulated in table 3.

Table 3 Average daily HAV exposure by static assessment method and monitored assessment method for individuals identified in table 2 from the monitored assessment

% of overall population incurring stated % of overall exposure	Monitored assessment			
	Number of individuals contributing	% of population	Population mean A(8) m/s^2 from static assessment	Population mean A(8) m/s^2 from monitored assessment
Top 20%	97	0.7%	3.0	6.2
20 - 40%	319	2.3%	2.8	3.6
40 - 60%	694	5.0%	2.1	2.6
60 - 80%	1,506	10.9%	1.7	2.0
Bottom 20%	11,215	81.1%	1.5	1.5

The data shows that the monitored assessment method indicates that those incurring the highest portion of the overall monitored HAV exposure is attributable to fewer people based on the monitored assessment versus the static assessment and that the individuals with the greatest level of exposure have the greatest variance between monitored assessment and static assessment of the risk they face.

The authors next examined the static dose data of specific tools by examining tool records from 5 widely used power tool types from across a range of industries within the data set. Except for the chainsaw data, the data is from a specific tool of the generic tool type, being the most popular tool of that type for which data has been collated. Analysis of the data showed that all 5 tool types analysed, displayed higher mean monitored vibration dose from the wearable sensor in real use compared with the mean of the static vibration dose used during monitoring. Chipping hammers displayed the greatest variance in mean vibration dose at +4.2 m/s^2 or +61%. This difference would result in the time to achieve the Exposure Action Value as defined in the Control of Vibration at Work Regulations

2005 (Statutory Instruments; 2005) being 63 minutes for the static vibration dose or only 24 minutes for the mean monitored vibration dose, therefore suggesting organisations may be underestimating the risk significantly for some operators.

Table 4 Table of time of use weighted mean static vibration magnitude and mean monitored vibration magnitude where range is the 25th to 75th percentile of the data set for specific tools

Tool	Static Vibration (m/s^2)		Monitored Vibration (m/s^2)		Trigger Time (hrs)
	Mean	Range	Mean	Range	
Grinder 12"	6.0	6.0 – 6.0	6.7	4.4 – 7.0	962
Chipping Hammer	6.9	5.0 – 7.5	11.1	7.9 – 13.4	2,850
Impact Drill	8.1	7.5 – 8.8	10.6	7.0 – 12.4	4,811
Chainsaw	4.6	3.5 – 4.7	6.0	4.7 – 6.7	4,543
Circular saw	4.3	3.9 – 3.9	6.3	4.1 – 7.0	1,755

To understand the distribution of vibration dose, in real tool use, from the wearable sensor in greater detail a histogram of the number of operator days within set vibration dose ranges was analysed for three widely used tools and a second histogram plotted of the static vibration dose data used within the same tool records.

The specific tools were used by multiple different organisations within the data set across a range of industries and comprised tool records totalling hours of trigger time as per table 3. In Figure 3 the chipping hammer shows a broad distribution of vibration dosage from the real time monitoring with a clear peak between 10 m/s^2 and 12 m/s^2. This can be compared with Figure 4 where an equivalent histogram is populated using the static vibration dose data used by the subject organisations in their risk assessments of this tool in their specific tasks. In the static vibration dose data it is clear that the vast majority of trigger hours have been recorded against vibration dosages which are either directly derived from manufacturers' declared vibration dose or manufacturers' vibration dose with a 'K' factor applied. These static values predominantly fall well below the mean value seen in the real time monitored vibration dose implying again an underestimation of the risk. By contrast the other two tool types show a static vibration dose closer to the mean of the monitored vibration dose.

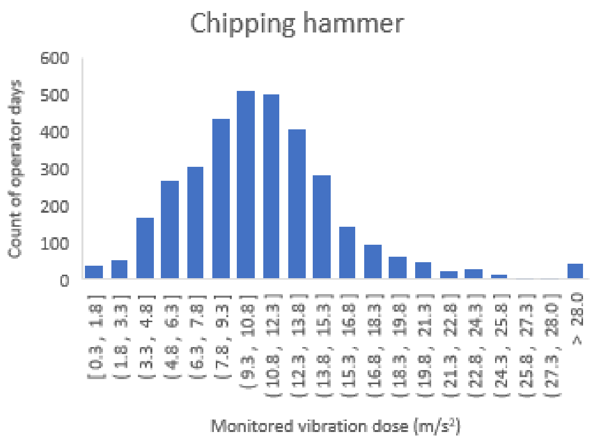

Figure 3 Operator day instances of in-use monitored vibration magnitude – chipping hammer

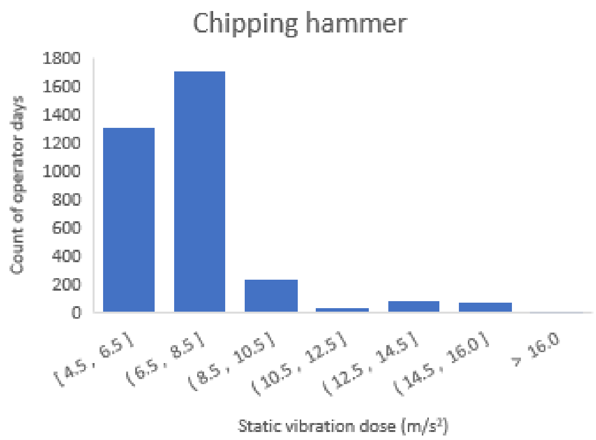

Figure 4 Operator day instances of static vibration magnitude – chipping hammer

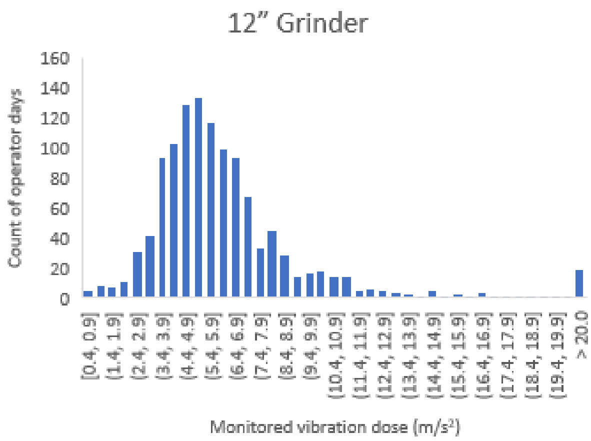

Figure 5 Operator day instances of in-use monitored vibration magnitude – grinder

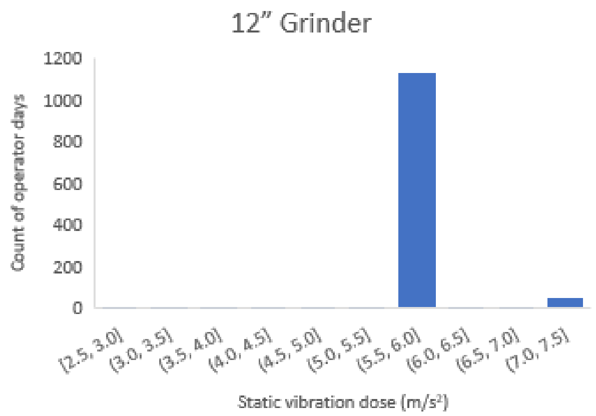

Figure 6 Operator day instances of static vibration magnitude – grinder

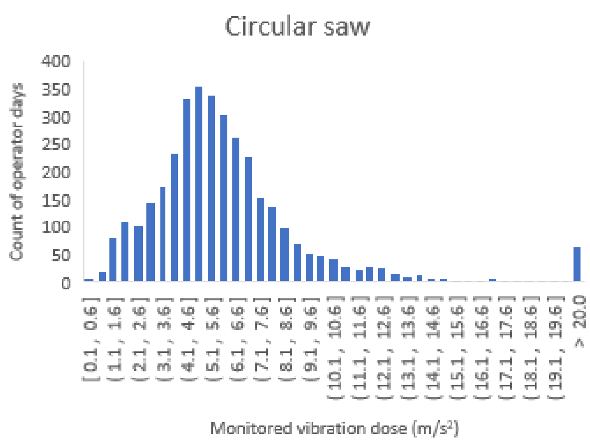

Figure 7 Operator day instances of in-use monitored vibration magnitude – circular saw

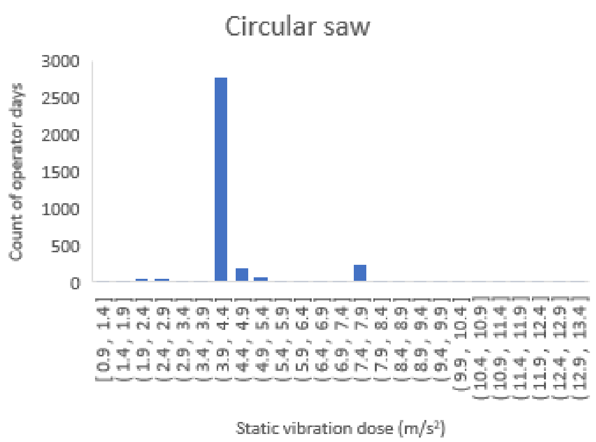

Figure 8 Operator day instances of static vibration magnitude – circular saw

Given the static vibration dose data in figures 4, 6 and 8 is used as a basis for determining risk assessments and design of control measures within the context of a risk assessment, it is likely that some operators utilising these tools within the real work site may be experiencing greater exposure than previously thought. The authors propose that this underestimation of exposure through the use of static vibration dose data may be contributing to a higher risk of developing the condition within subject organisations. Given that elevated vibration dosages can be linked to poor operator proficiency it is conceivable that exposure to elevated vibration dosages may be concentrated to certain individuals further increasing risk to those specific operators as would be supported by the data of table 3.

An analysis of the data was then performed on a manufacturer by manufacturer basis to look for any specific relationships. Table 5 indicates that there is a range of variance between the static vibration dose data and the mean vibration dose determined by the wearable sensor during monitoring. The variance has been graded with a conditional formatting where green is <0% and red is >+30%. Unfortunately, the most popular tools for monitoring are those showing some of the greatest positive variances between the monitored vibration dose and static vibration dose, suggesting that these are the highest risk tools as perceived by the monitoring organisations.

Table 5 Table of time of use weighted mean static vibration magnitude and mean monitored vibration magnitude by tool manufacturer

MANUFACTURER	Trigger Hours	Weighted static Vibration (m/s^2)	Weighted monitored Vibration (m/s^2)	Variance
A	30,877	3.8	4.7	25%
B	15,709	7.4	10.2	38%
C	13,154	5.6	6.1	10%
D	12,887	6.3	6.8	8%
E	9,225	8.8	5.5	-37%
F	9,223	3.8	5.3	42%
G	5,334	6.3	6.4	3%
H	4,005	6.4	7.3	14%
I	3,765	9.3	9.4	1%

4. In Summary

The authors have analysed a large data set of records from the monitoring of operators exposed to Hand Arm Vibration over a 9-month period from September 2017 to May 2018, from within over 400 private and public organisations totalling over 246,500 days of monitored HAV exposure. The data set contained two differing assessments of the daily exposure to the individuals. Both assessment methods were based on the trigger time of tool use while one method used a static vibration dose chosen by the monitoring organisation to be suitable for a risk assessment and the second method used a real use vibration dose determined by a wearable sensor positioned on the wrist of the operator for the full monitored day.

The wearable sensor has been developed to calculate a transformed vibration dose which is equivalent to a vibration dose measurement made on a tool handle, by way of correcting algorithms. Independent research, (Graveling et al 2018), has been published on the validity of the wearable sensor in developing a vibration dose which would inform a suitable and sufficient risk assessment.

Analysis of the data set indicates that in general operators are exposed to a higher level of daily HAV exposure than is assessed using a static vibration dose. The variance in assessed HAV exposure by the two methods is at it's greatest in the highest risk industries and with the highest vibration dose tools. The greatest variances appear to be with high vibration tools and the use of manufacturers declared vibration dosages.

The authors believe there is an opportunity to more intelligently develop HAV exposure control measures with a more detailed insight to the drivers of HAV exposure risk than that developed from generic HAV risk assessments based on assumed static vibration dosages.

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