The selection of different averaging approaches on whole-body vibration exposure levels of a driver utilising the ISO 2631-1 standard

by

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Declaration

I, Duane Bester, do hereby declare that this research report, submitted for the degree Master of Public Health at the University of Pretoria, is my own work, except where duly acknowledged, and has not previously been submitted by me for a degree at another university.

Student's Signature: .... Date: ....

Supervisor's signature: .... Date: …………………………..

Acknowledgements

I would like to acknowledge Dr Nico Claassen for his supervision and mentorship during the course of my MPH degree and Mr Henno Traut for acting as the test subject during the course of the study.

Dedications

I would like to dedicate this research report to my darling wife, Janita Bester.

Definition of terms

a_w:	The frequency-weighted root mean square acceleration.
a_{wxyz}:	The vector sum frequency-weighted root mean square acceleration for the three axes of translational movement.
BS:	British Standard
CEN:	The European Committee of Standardization
CF:	The ratio of the peak acceleration to a_w.
ICP:	Integrated Circuit Piezoelectric
ISO:	International Organization of Standardization
SAE:	Society of Automotive Engineers
SANAS:	South African National Accreditation System
VDV:	The fourth power vibration dose value.
WBV:	Whole-Body Vibration

Abstract

Limited research has been conducted on inconsistencies relating to whole-body vibration (WBV) field assessments. Therefore, this study aimed to investigate a certain possible contributor to inconsistencies in vibration assessment work, namely averaging intervals. To our knowledge, this was the first study investigating the effect of multiple averaging approaches on WBV results. WBV parameters were measured for a driver operating a vehicle on a preselected test route utilising ISO 2631-1:1997. This was achieved utilizing a Quest HavPro vibration monitor with a fitted tri-axial Integrated Circuit Piezoelectric (ICP) accelerometer pad mounted on the driver's seat. Furthermore, in an attempt to decrease differences between observed WBV results, an outlier detection method, part of the STATA software package was utilised to clean the data. Statistical analyses included hypothesis testing in the form of one-way ANOVA and Kruskal-Wallis one-way analysis of variance by ranks to determine significant differences between integration intervals. Logged data time-series durations showed a W_0 = 0.04, therefore indicating unequal variance. Omission of 60s from statistical analyses showed a W_0 = 0.28. The observed difference occurs when data is averaged over longer intervals, resulting in portions of data not being reflected in the final dataset. In addition, frequency-weighted root mean squared acceleration results reflected significant differences between 1s, 10s, 30s, 60s and SLOW averaging approaches, while non-significant differences were observed for crest factors and instantaneous peak accelerations. Vibration Dose Value results reflected non-significant differences after omission of 60 second averaging interval data. Cleaned data showed significant differences between various averaging approaches as well as significant differences when compared with raw vibration data. The study therefore outlined certain inconsistencies pertaining to the selection of multiple integration intervals during the assessment of WBV exposure. Data filtering could not provide a conclusion on a suitable averaging period and as such, further research is required to determine the correct averaging interval to be used for WBV assessment.

Keywords: *Occupational hygiene, whole-body vibration, averaging, exposure, outlier detection, HavPro, monitoring.*

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1. Introduction

The importance of accurately quantifying the exposure of workers to occupational hygiene stressors such as whole-body vibration (WBV) has become an important factor in managing and controlling occupational associated health risks. Variability in WBV results are addressed in the CEN 14253 standard, which states that “the experimenter shall determine the main sources of uncertainty and multiple measurements shall be made in order to determine the extent of the uncertainty and to calculate the standard deviation regarding the dominant sources of uncertainty”.[1] It is well known that variability is common in field assessments of WBV and the effects of systematic errors may have a significant influence on the end result if not properly accounted for. [1-3]

It is stated in Annexure B of the international standard ISO 2631-1 that biodynamic and epidemiological studies have given evidence for an increased risk of health effects due to long-term, high intensity WBV exposure. WBV therefore seems to follow a dose-response relationship. Sufficient data however does not exist to indicate a quantitative relationship between vibration exposure and health effects.[4]

Even though WBV exposure can’t yet be quantitatively compared to certain health outcomes, several health effects have been discovered. As the name implies WBV affects the entire body, with outcomes ranging from discomfort to decreased performance and/or detrimental health outcomes, including musculoskeletal, digestive, auditory, cardiac, neurological and vascular disorders.[5]

Two well-known standards currently exist for the quantification of vibration with regards to whole body exposures, namely BS 6841 (1987) and ISO 2631-1 (1997).[5,6] Although the BS standard was originally developed as an exclusively British standard, its use has spread worldwide, in some cases even in preference to the ISO standard. Recently, the use of the ISO method became the preferred standard to evaluate WBV in Britain.[2,5]

Both of the standards require tri-axial acceleration measurements to be taken on the seat pan by means of an accelerometer fixed in a 20 cm diameter semi-rigid disc as specified by the Society of Automotive Engineers (SAE pad). This disc is placed on the seat pan from where acceleration signals are then passed through a tri-axial accelerometer which is stimulated in three axes, namely x, y and z.[4,5,7] The axes represent the possible directions of movement for a complex stimuli in relation to the body, fore-aft (defined as the x-axis), laterally (defined as the y-axis) and vertically (defined as the z-axis). Once the accelerometer is stimulated, the signal is amplified, conditioned according to the set frequency weighting, the required calculations are made and the results are displayed on the instrument.[5]

The frequencies of the acceleration signals are weighted to provide the correct sensitivity for a specific sample population's bodily response to vibration at defined frequencies (the specific weightings differ according to the standard in use). For ISO 2631-1 the weightings set are W_d, W_d and W_k (all with an equal frequency range of 0.5-80 Hz) for the x, y and z-axes respectively.[4,5,7] In addition to the frequency weighting, ISO 2631-1 further requires that a scaling factor be applied to each of the axes (x-axis, k = 1.4; y-axis, k = 1.4; z-axis, k = 1.0).[4,5,7] The scaling factor is used for health risk assessment purposes at the specified frequency weightings as defined in the standard.[4,5,8]

Vibration in its essence is defined as a movement that oscillates around a fixed point. Therefore, the mean value of a vibration signal will be zero due to the fact that all the positive values cancel out the negatives as it completes a number of cycles for all the expressed frequencies.[4,5] This means that the magnitude of the signal can't be expressed through the mean. Utilising the Root-Mean-Square (RMS) for the vibration signal alleviates this problem by squaring each value in the signal, then taking the mean value and determining its square root. The RMS forms the basis for all data evaluation for health risk assessment purposes according to ISO 2631-1. Mathematically, the RMS can be expressed as:

$$a_{w\ r.m.s} = \sqrt{\frac{1}{T}\int_0^T a_w^2\,(t)dt}$$

Where:

- $a_{w\ r.m.s}$ is the frequency-weighted RMS acceleration
- T is the measurement duration
- $a_w(t)$ is the frequency-weighted acceleration at time t

No proposed averaging interval for RMS is currently defined in ISO 2631-1 and this formed the basis of the proposed study.[4,5,8] Vibration monitors, such as the Quest HavPro monitor used for this study, are capable of sampling at a magnitude of different frequency-weighted acceleration averaging intervals during which the RMS is calculated. The problem however, is that no research could be found pertaining to inconsistencies arising from WBV exposure assessments conducted with Quest HavPro equipment or studying the effects of different integration intervals on WBV results. Therefore, this study aimed to investigate the effects of different averaging intervals on WBV exposure results and to determine whether or not these differences were significant.

2. Materials and Methods

2.1. Study Design

2.1.1. Vehicle

During the completion of this study, an Opel Corsa 2008 Hatchback motor vehicle was used to obtain WBV data at different averaging intervals. The seat was adjusted prior to data acquisition according to the driver's personal preference. Only the volunteer and researcher were present in the vehicle during data collection. Roadworthiness was ascertained prior to the conduction of the survey in order to ensure driver and researcher safety.

2.1.2. Participant

A single consenting volunteer with a valid South African driver's license operated the vehicle during data collection. The participant was required to comply with national road traffic laws which included wearing a seatbelt at all times and adhering to all road signs. Ethics approval for this study was granted by the University of Pretoria, Faculty of Health Sciences Research Ethics Committee and the participant gave his informed consent prior to participating in the study (Ethics Reference No.: 79/2013, refer to Annexure A).

2.1.3. Test Route

A preselected test route of approximately 4 km in distance was used in order to conduct the study. The route is situated in a quiet suburban area within the Tshwane municipal district, Gauteng, South Africa (Figure 2.1) and driving activities were only conducted during non-peak traffic hours. The route contained shocks produced by speed humps and made provision for random vibration exposure in the form of stopping and accelerating, uneven surfaces and road bends.

Each monitoring phase (approximately 30 minutes) comprised of three rounds (approximately 10 minutes each) of the route and three monitoring phases were measured per averaging period. During driving activities, the participant was instructed to maintain a driving speed of 40 km/h and to decelerate to 20 km/h before making contact with speed humps. In addition, the driver was instructed to stop at all stop signs and remain stationary for 2s before accelerating to 40 km/h. This was followed with a 10s stop at the end of each round of the route and cessation of the monitoring phase once the vehicle came to a complete standstill at the end of the third round. Care was taken to ensure that acceleration and deceleration was performed smoothly and similarly for each subsequent action.

Figure 2.1. Route layout and major landmark positions on the selected test route

2.2. Data Acquisition

Data acquisition was performed by means of a three channel vibration monitor (Quest Technologies HavPro Human Vibration Meter) and a tri-axial Integrated Circuit Piezoelectric (ICP) accelerometer fitted in a flexible seat pad (Model 356B40; PCB Piezotronics; Depew, NY). Accelerometer calibration was performed by an external, South African National Accreditation System (SANAS) accredited laboratory prior to data acquisition. The seat pad was mounted to the driver's seat in accordance with the requirements of ISO 2631-1:1997 with the accelerometer interposed between the volunteer and the seat cushion.

Vibration parameters were assessed at 1, 10, 30, 60 second and SLOW averaging intervals. 1, 10, 30 and 60 second averaging periods are linear repeat averaging periods during which data is combined and averaged for the time specific setting. SLOW averaging is a 1 second exponential detector, which discards the first part of the average as the next part is collected, therefore maintaining a moving average of the signal. SLOW averaging is used in order to obtain the Maximum Transient Vibration Value (MTVV).[4] This value is used to assess vibration exposures when the Crest Factor (CF) exceeds 9 during vibration exposure monitoring, as stated in the ISO 2631-1:1997 standard.

Frequency weightings specifically assigned for assessing human health as a result of WBV exposure were used for the three different axes of vibration exposure. These included W_d for lateral and fore-aft; and W_k for vertical vibration directions. As further required by the standard, a scaling factor of 1.4 was assigned to horizontal vibration magnitudes. Upon completion of each monitoring phase, the data was downloaded from the human vibration monitor utilizing the QuestSuite Professional II software package.

The algorithms for calculating the required WBV exposure parameters were automatically performed by the vibration monitor. Due to memory restrictions, the instrument is only capable of storing a total of 120 sample log points when axis-peak accelerations are also stored. The instrument does however have an auto store function, which ensures that the instrument automatically resets and collects a new set of data, therefore allowing multiple fragments of the same study. These fragments were joined utilizing the Formulae stipulated in the ISO 2631-1 standard. This was however only present at 1s, 10s and SLOW averaging settings.

2.3. Whole-Body Vibration Parameters

The WBV parameters calculated and assessed during the study included:

- The frequency-weighted root mean square acceleration (a_w) for each axis of translational motion (x, y and z) on the supporting surface, measured in m/s^2.
- The Crest Factor (CF), defined as the ratio of the peak acceleration to a_w. The CF is a dimensionless quantity used to assess the applicability of using a_w when assessing WBV exposure.
- The Peak acceleration, which is the maximum instantaneous acceleration during the measurement period.
- The fourth power vibration dose value (VDV), used to assess WBV when the CF exceeds 9. The VDV is more sensitive to peaks than the basic evaluation method as it uses the fourth power of the acceleration time history as the basis for averaging.

The equations for the calculation of a_w and VDV are shown in Formulae (1) and (2) where $a_w(t)$ is the instantaneous frequency-weighted acceleration. Overall detailed assessment of vibration magnitudes were conducted utilizing the axis in which the highest level of frequency-weighted r.m.s. acceleration (including multiplying factors) was obtained as required by ISO 2631-1, but the vector sum was also utilized for additional comparison in certain cases. The Formula for calculating the vector sum for a_w (a_{wxyz}), is shown in Formula (3).

$$a_{w\,r.m.s.} = \sqrt{\frac{1}{T}\int_0^T a_w^2\,dt} \qquad (1)$$

$$VDV = \left[\int_0^T [a_w(t)]^4\,dt\right]^{\frac{1}{4}} \qquad (2)$$

$$a_{wxyz} = \sqrt{a_{wx}^2 + a_{wy}^2 + a_{wz}^2} \qquad (3)$$

2.4. Statistical Analyses

Statistical analyses were performed utilizing the Quest Suite Professional II in combination with Microsoft Office Excel 2007 and STATA 11 software packages. Statistical analyses were comprised of descriptive statistics, Shapiro-Wilk Normality testing, calculation of Levene's robust test statistic for the equality of variances and hypothesis testing to identify significant differences which may exist between vibration parameters measured at different averaging intervals.

Raw data obtained during the study was further filtered by means of a multivariate outlier detection method developed by Hadi[9] utilizing the *hadimvo* function in STATA. All detected outliers were omitted from time-series data and vibration parameters were recalculated in order to obtain the filtered variable results. Data filtering was conducted in order to remove the effect of possible artefacts on logged data results. Hypothesis testing was conducted on post-filtered data to determine significant differences. Filtering was applied on a_w, a_{peak} and CF time-series data for the dominant axis in which maximal frequency-weighted r.m.s. acceleration was observed. Significance (α) was assessed at a level of $p < 0.05$.

3. Results

3.1. Measurement Durations

All measurement time periods are indicated in seconds. Actual measurement durations ranged from 1724s to 1810s (M = 1779S, SD = 22.71), while logged durations ranged from 1724s to 1800s (M = 1769s, SD = 25.46). As expected, descriptive statistics (displayed in Table 3.1) suggest slightly higher actual real-time total measurement periods (M = 1779, SD = 22.71) than logged time total periods (M = 1769, SD = 25.46). Both actual and logged time measurements showed normal distributions (p = 0.44 for real-time data and p = 0.89 for logged time data). Levene's robust test statistic for equal variances (W_0) between the selected averaging periods indicated a non-significant p-value (p = 0.26) with regards to actual measurement times, but a significant p-value (p = 0.04) for logged time durations, therefore suggesting unequal variance between the logged time durations for different averaging periods. Visual inspection of SDs for the different logged time durations indicated no variation in 60s averaging interval data. Upon omission of the averaging period from further statistical analysis, W_0 showed a p = 0.28, therefore suggesting equal variance for logged time durations between the different averaging periods (60s omitted). No significant differences were observed for logged-time periods between 1s, 10s, 30s and SLOW averaging approaches, F(3, 8) = 0.46, p = 0.72. Similarly, no significant differences were found between the same averaging approaches relating to actual measurement periods, F(3, 8) = 0.61, p = 0.63. Differences between actual and logged time periods were also found to be non-significant, F(1, 22) = 0.02, p = 0.88. These findings therefore fail to reject the null hypotheses for equal values between averaging approaches relating to logged and actual time periods, as well as similarity between logged and actual measurement periods (with 60s averaging omitted from the dataset).

Table 3.1: Descriptive statistics for actual and logged time periods (in seconds)

	Averaging Approach											
Statistic	**1s**		**10s**		**30s**		**60s**		**SLOW**		**Total***	
Time	Actual	Logged	Actual	Logged	Actual	Logged	Actual	Logged	Actual	Logged	Actual	Logged
N	3	3	3	3	3	3	3	3	3	3	15	15
M	1767	1767	1775	1773	1794	1790	1784	1740	1773	1773	1779	1769
Min	1724	1724	1750	1750	1771	1770	1770	1740	1761	1761	1724	1724
SD	38.97	38.97	22.11	20.82	20.60	17.32	13.58	0.00	17.44	17.44	22.71	25.46
Max	1800	1800	1792	1790	1810	1800	1797	1740	1793	1793	1810	1800

N = Count

M = Mean

Min = Minimum

SD = Standard Deviation

Max = Maximum

* “Total” refers to the combined dataset for all applicable averaging periods

3.2. Raw Vibration Parameters

Raw a_w, instantaneous peak accelerations, CF and VDV measured on the seat pan within the vehicle are summarized in Table 3.2. Dominant frequency-weighted r.m.s. acceleration (a) occurred in the *z*-axis for all averaging approaches and ranged from 0.563 (10s averaging) to 0.605 m/s^2 (1s and 60s averaging) with an average of 0.582 m/s^2 (SD = 0.017). Maximal axis specific instantaneous peak accelerations (Amp) also occurred in the *z*-axis, ranging from 5.216 (SLOW averaging) to 8.653 m/s^2 (60s averaging) with an average of 6.853 m/s^2 (SD = 1.26). At least one axis per averaging period reflected a CF in excess of 9 in each of the averaging approaches, but differed in certain cases with regards to the axis in which it was observed. As expected, maximal VDV results were also found to be *z*-axis dominant, ranging from 6.020 (30s averaging) to 6.646 m/s$^{1.75}$ (60s averaging) with an average of 6.227 m/s$^{1.75}$ (SD = 0.197). Shapiro-Wilk testing reflected nonparametric distributions for a_{wz} and VDV$_z$ (p = 0.015 and p = 0.016 respectively). Similarly, the null hypothesis was also rejected for a_{wy} (p = 0.016) and a_{wxyz} (p = 0.013).

W_0 showed a p = 0.091 for a_{wz}, p = 0.73 for z-axis instantaneous peak acceleration and p = 0.78 for z-axis CF values, therefore indicating equal variances for the specific variables. The null hypothesis was however rejected for VDV$_z$ (p = 0.019), therefore indicating unequal variances between the assessed averaging approaches. VDV$_z$ results were converted to 8 hour equivalent exposure values, but the differences between variances were still significant (p = 0.04). Upon omission of 60s data however, differences between averaging periods with regards to variance was found to be non-significant (p = 0.09).

3.2.1. a_{wz} results

Kruskal-Wallis one-way analysis of variance by ranks indicated significant differences (p = 0.02) for a_{wz} values between averaging approaches therefore indicating significant differences between averaging periods with regards to a_{wz}. Wilcoxon rank-sum post estimation revealed significant differences between 1s averaging and 10s, 30s and

SLOW averaging (z = 1.96, p = 0.05 in all cases). Significant differences were also found between 10s and 60s (z = -1.964, p = 0.05), 30s and 60s (z = -1.964, p = 0.05), 30s and SLOW (z = -1.964, p = 0.05) and 60s and SLOW averaging (z = 1.964, p = 0.05).

3.2.2. CF_z results

Non-significant differences were found for CF_z between averaging periods following Kruskal-Wallis hypothesis testing (p = 0.44).

3.2.3. Z-axis instantaneous peak accelerations

Z-axis instantaneous peak acceleration differences between averaging periods were found to be non-significant (p = 0.37).

3.2.4. VDV_z results

After omission of 60 s averaging VDV_z data, due to unequal variance caused by the averaging period, non-significant differences were found between the remaining approaches (p = 0.07).

3.2.5. Vector sum results

Vector sum a_w results (Table 3.2) ranged from 0.620 (30s averaging) to 0.670 m/s^2 (1s averaging) with M = 0.642, SD = 0.020. W_0 showed a p = 0.19, therefore indicating similar variances. Shapiro-Wilk normality testing showed significant results (z = 2.24, p = 0.01), therefore indicating nonparametric data distribution. Kruskal-Wallis hypothesis testing showed significant differences between averaging periods (p = 0.02), with Wilcoxon post estimation testing delivering significant differences between the same averaging approaches as for a_{wz}.

Vector sum VDV results (Table 3.2) ranged from 6.062 (30s averaging) to 6.688 m/s^2 (60s averaging) with M = 6.275, SD = 0.199. Similar to VDV_z, W_0 showed a p = 0.02 and upon omission of 60s data, p = 0.15, therefore indicating equal variances between averaging approaches (60s omitted). Kruskal-Wallis hypothesis testing showed p = 0.07, therefore indicating non-significant differences between vector sum VDV results between averaging periods with 60s omitted.

Table 3.2: Descriptive statistics for obtained vibration parameters (raw data) at different averaging periods

Averaging Approach	a_{wx}	a_{wy}	a_{wz}	a_{wxyz}	Amp_x	Amp_y	Amp_z	CF_x	CF_y	CF_z	VDV_x	VDV_y	VDV_z	VDV_{xyz}
Unit	m/s^2				m/s^2			(Not Applicable)			$m/s^{1.75}$			
1 Second														
M	0.218	0.189	0.600	0.666	1.781	1.897	6.753	8.177	10.053	11.280	2.508	2.075	6.370	6.426
Min	0.212	0.186	0.590	0.659	1.719	1.756	5.657	7.550	9.320	9.350	2.439	2.018	6.328	6.385
Max	0.228	0.192	0.605	0.670	1.859	2.134	8.264	8.760	11.140	14.010	2.618	2.142	6.426	6.476
SD	0.008	0.003	0.009	0.006	0.071	0.207	1.352	0.606	0.960	2.431	0.096	0.063	0.051	0.046
Range	0.015	0.006	0.015	0.011	0.140	0.378	2.607	1.210	1.820	4.660	0.178	0.124	0.098	0.091
10 Second														
M	0.202	0.173	0.568	0.627	1.699	1.848	7.165	8.407	10.667	12.630	2.290	2.012	6.102	6.150
Min	0.199	0.172	0.563	0.622	1.619	1.800	6.565	7.770	10.370	11.610	2.236	1.973	6.092	6.139
Max	0.208	0.174	0.574	0.635	1.809	1.895	8.220	9.050	10.880	14.600	2.358	2.056	6.113	6.160
SD	0.005	0.001	0.006	0.007	0.099	0.048	0.916	0.640	0.265	1.706	0.063	0.042	0.011	0.011
Range	0.010	0.002	0.011	0.013	0.190	0.095	1.654	1.280	0.510	2.990	0.122	0.083	0.022	0.021
30 Second														
M	0.191	0.174	0.566	0.622	1.540	1.882	6.638	8.070	10.800	11.740	2.150	2.045	6.053	6.097
Min	0.189	0.172	0.564	0.620	1.477	1.709	5.506	7.810	9.930	9.710	2.103	1.973	6.020	6.062
Max	0.194	0.176	0.567	0.624	1.572	2.181	8.468	8.300	12.500	15.020	2.196	2.103	6.111	6.151
SD	0.003	0.002	0.002	0.002	0.055	0.260	1.600	0.246	1.472	2.867	0.047	0.066	0.050	0.048
Range	0.005	0.004	0.003	0.004	0.095	0.472	2.962	0.490	2.570	5.310	0.093	0.130	0.090	0.090
60 Second														
M	0.207	0.186	0.602	0.663	2.004	1.849	7.752	9.687	9.933	12.887	2.385	2.090	6.519	6.565
Min	0.205	0.186	0.598	0.660	1.719	1.659	6.136	8.270	8.860	10.140	2.366	2.086	6.433	6.482
Max	0.208	0.187	0.605	0.666	2.193	2.038	8.653	10.550	10.980	14.460	2.414	2.094	6.646	6.688
SD	0.002	0.001	0.003	0.003	0.251	0.190	1.403	1.237	1.060	2.387	0.026	0.004	0.112	0.109
Range	0.003	0.002	0.007	0.006	0.474	0.379	2.518	2.280	2.120	4.320	0.049	0.008	0.212	0.206
SLOW														
M	0.197	0.175	0.576	0.633	1.778	1.612	5.957	9.000	9.190	10.363	2.275	2.001	6.092	6.139
Min	0.192	0.174	0.569	0.625	1.619	1.517	5.216	8.440	8.510	8.980	2.230	1.978	6.069	6.114
Max	0.201	0.178	0.581	0.640	1.905	1.659	7.296	9.560	9.540	12.830	2.309	2.035	6.114	6.164
SD	0.005	0.002	0.006	0.008	0.145	0.082	1.162	0.560	0.589	2.141	0.041	0.030	0.023	0.025
Range	0.009	0.004	0.012	0.015	0.286	0.142	2.081	1.120	1.030	3.850	0.079	0.056	0.045	0.050
Combined Data *														
M	0.203	0.180	0.582	0.642	1.760	1.817	6.853	8.668	10.129	11.780	2.322	2.045	6.227	6.275
Min	0.189	0.172	0.563	0.620	1.477	1.517	5.216	7.550	8.510	8.980	2.103	1.973	6.020	6.062
Max	0.228	0.192	0.605	0.670	2.193	2.181	8.653	10.550	12.500	15.020	2.618	2.142	6.646	6.688
SD	0.010	0.007	0.017	0.020	0.197	0.184	1.265	0.879	1.009	2.192	0.133	0.054	0.197	0.199
Range	0.038	0.020	0.042	0.050	0.716	0.664	3.438	3.000	3.990	6.040	0.515	0.169	0.625	0.627

N = Count   M = Mean   Min = Minimum   SD = Standard Deviation   Max = Maximum $a_{wx, wy, wz}$ = Axis-Specific RMS accelerations $Amp_{x, y, z}$ = Axis-Specific Amplitudes $CF_{x, y, z}$ = Axis-Specific Crest Factors $VDV_{x, y, z}$ = Axis-Specific Vibration Dose Values
* “Combined Data” refers to the combined dataset of all applicable averaging periods

3.3. Filtered Data

3.3.1. Outlier to total log points ratio

Utilisation of the *hadimvo* STATA function showed outlier to total original time-series log point ratios as shown in Table 3.3. Ratios ranged from 0.024 (SLOW averaging) to 0.448 (60s averaging) with M = 0.132, SD = 0.129. Box-plots for total raw and filtered time-series a_{wz} results are shown in Figure 3.1. A high negative correlation (-0.65) was observed between the number of log points and the resulting outlier ratio, therefore indicating that outlier ratios decreased with an increase in the number of total log points.

Table 3.3: Outlier to logged point ratios for WBV monitoring at different averaging periods

Averaging period	Number of Readings	Number of Outliers	Ratio
1s	1800	63	0.035
1s	1777	86	0.048
1s	1724	96	0.056
10s	175	8	0.046
10s	178	6	0.034
10s	179	12	0.067
30s	60	17	0.283
30s	60	15	0.250
30s	59	14	0.237
60s	29	13	0.448
60s	29	7	0.241
60s	29	4	0.138
SLOW	1793	45	0.025
SLOW	1761	42	0.024
SLOW	1765	70	0.040

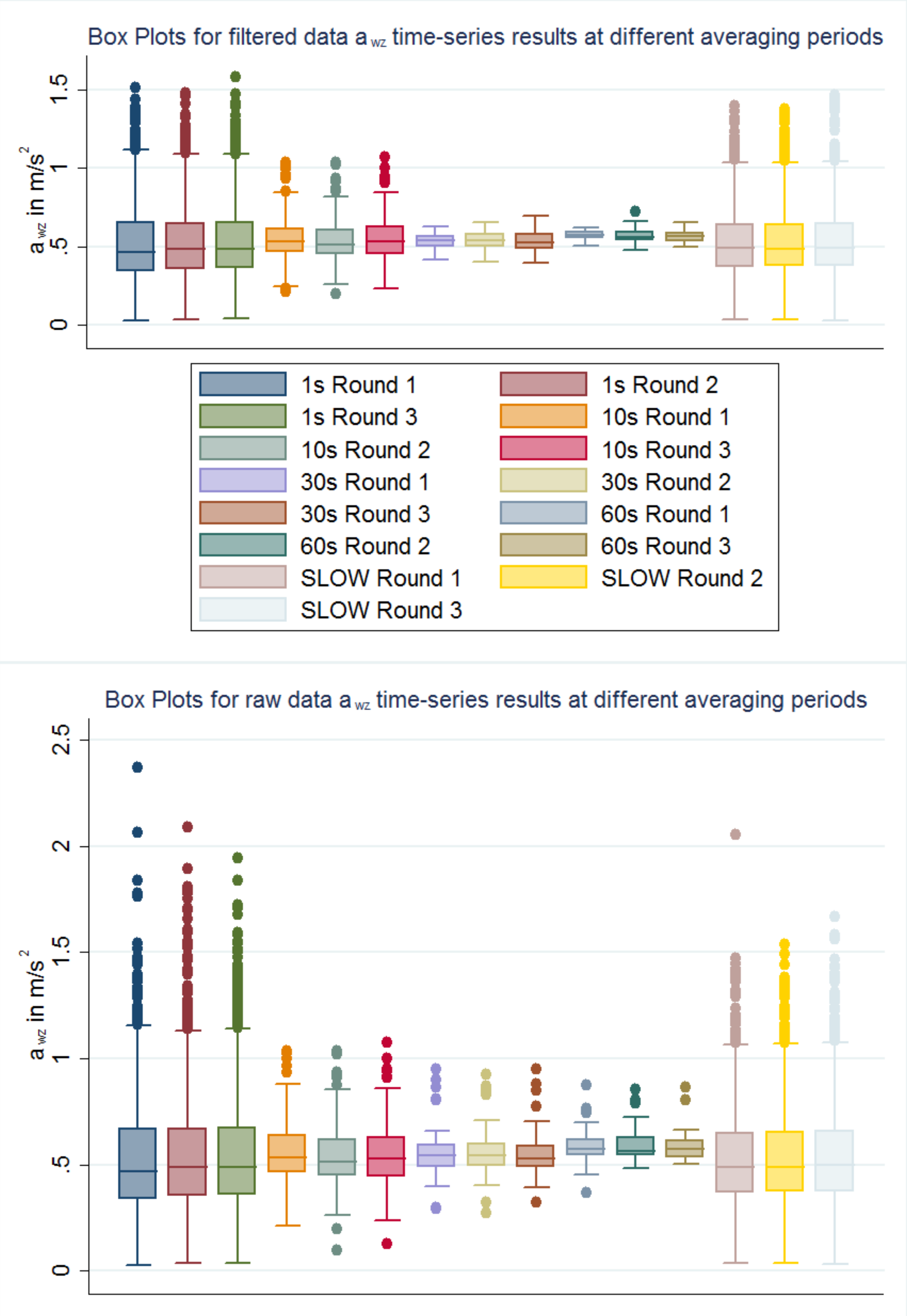

Figure 3.1: Box Plots for a_{wz} results obtained from raw and filtered time-series data

3.3.2. Filtered time-series aw$_z$ and eVDV$_z$ results

Filtered data results are tabulated in Table 3.4. Filtered a_{wz} results ranged from 0.536 (30s averaging) to 0.574 (60s averaging) m/s^2, M = 0.562 m/s^2, SD = 0.013. Shapiro-Wilk normality testing showed a p = 0.002, therefore rejecting the null hypothesis for normally distributed data. W_0 showed a p = 0.51, failing to reject the null hypothesis of equal variance between averaging approaches. Kruskal-Wallis one-way analysis of variance by ranks method showed a p = 0.03, therefore rejecting the null hypothesis that no differences between filtered averaging periods with regards to a_{wz} were present. Wilcoxon rank-sum post estimation revealed significant differences between all averaging approach pairings, except for 1s and 60s (z = -0.218, p = 0.83); 10s and 60s (z = -1.528, p = 0.13); and 10s and SLOW (z = -0.655, p = 0.51). All other pairings showed a p = 0.05.

*e*VDV$_z$ results ranged from 4.470 (60s averaging) to 5.149 (1s averaging) m/s^2 with M = 4.918 m/s^2, SD = 0.254. Data distribution was found to be nonparametric (p = 0.002) with unequal variances (p = 0.004), which, upon omission of 60s averaging data, showed a p = 0.49, therefore failing to reject the null hypothesis of equal variances between averaging periods (60s omitted). Kruskal-Wallis hypothesis testing on the remaining averaging approaches showed a p = 0.03, therefore rejecting the null hypothesis that eVDV$_z$ results were similar between averaging approaches. Wilcoxon post estimation only showed non-significant p-values between 1s and SLOW averaging (z = 1.091, p = 0.28); and 10s and SLOW averaging (z = -1.528, p = 0.13). As observed with raw data VDV$_z$ results, significant pair differences for filtered averaging approaches showed a p = 0.05 in all cases.

Table 3.4: Descriptive statistics for obtained vibration parameters (filtered data) at different averaging periods

Averaging Approach	a_{wx}	a_{wy}	a_{wz}	Amp_x	Amp_y	Amp_z	CF_x	CF_y	CF_z	$eVDV_x$	$eVDV_y$	$eVDV_z$
Unit	m/s^2			m/s^2			(Not Applicable)			$m/s^{1.75}$		
1 Second												
M	0.214	0.187	0.572	1.749	1.897	4.236	8.170	10.123	7.407	1.923	1.680	5.129
Min	0.208	0.185	0.569	1.668	1.756	4.110	7.610	9.380	7.170	1.845	1.674	5.096
Max	0.226	0.189	0.574	1.859	2.134	4.398	8.860	11.270	7.670	2.041	1.685	5.149
SD	0.010	0.002	0.003	0.099	0.207	0.147	0.635	1.007	0.251	0.103	0.006	0.028
Range	0.018	0.004	0.005	0.191	0.378	0.288	1.250	1.890	0.500	0.195	0.011	0.053
10 Second												
M	0.203	0.174	0.564	1.699	1.848	4.462	8.357	10.603	7.910	1.825	1.563	5.059
Min	0.200	0.173	0.558	1.619	1.800	4.398	7.750	10.390	7.850	1.800	1.550	5.029
Max	0.209	0.175	0.568	1.809	1.895	4.543	8.990	10.830	8.000	1.870	1.577	5.081
SD	0.005	0.001	0.005	0.099	0.048	0.074	0.620	0.220	0.079	0.039	0.014	0.027
Range	0.009	0.002	0.010	0.190	0.095	0.145	1.240	0.440	0.150	0.070	0.028	0.052
30 Second												
M	0.188	0.178	0.539	1.540	1.786	4.121	8.183	10.033	7.650	1.591	1.502	4.555
Min	0.186	0.172	0.536	1.477	1.422	4.055	7.960	8.280	7.560	1.575	1.441	4.498
Max	0.190	0.182	0.544	1.572	2.181	4.200	8.310	12.160	7.830	1.605	1.543	4.614
SD	0.002	0.005	0.004	0.055	0.380	0.073	0.194	1.967	0.156	0.015	0.054	0.058
Range	0.004	0.010	0.008	0.095	0.759	0.145	0.350	3.880	0.270	0.030	0.102	0.115
60 Second												
M	0.209	0.190	0.571	1.876	1.833	5.237	8.980	9.673	9.167	1.738	1.575	4.749
Min	0.205	0.185	0.567	1.719	1.610	5.022	7.930	8.610	8.760	1.688	1.538	4.470
Max	0.217	0.197	0.574	2.100	2.038	5.417	10.180	11.040	9.440	1.797	1.608	4.939
SD	0.006	0.007	0.004	0.199	0.214	0.200	1.132	1.243	0.359	0.055	0.035	0.247
Range	0.012	0.013	0.007	0.381	0.428	0.395	2.250	2.430	0.680	0.109	0.070	0.470
SLOW												
M	0.196	0.175	0.565	1.778	1.612	4.073	9.067	9.190	7.207	1.766	1.582	5.097
Min	0.190	0.174	0.560	1.619	1.517	4.011	8.500	8.520	7.150	1.724	1.566	5.070
Max	0.199	0.178	0.568	1.905	1.659	4.155	9.610	9.550	7.310	1.787	1.600	5.115
SD	0.005	0.002	0.005	0.145	0.082	0.074	0.555	0.581	0.090	0.036	0.017	0.024
Range	0.009	0.004	0.008	0.286	0.142	0.144	1.110	1.030	0.160	0.063	0.034	0.045
Combined Data *												
M	0.202	0.181	0.562	1.728	1.795	4.426	8.551	9.925	7.868	1.769	1.580	4.918
Min	0.186	0.172	0.536	1.477	1.422	4.011	7.610	8.280	7.150	1.575	1.441	4.470
Max	0.226	0.197	0.574	2.100	2.181	5.417	10.180	12.160	9.440	2.041	1.685	5.149
SD	0.011	0.007	0.013	0.158	0.212	0.455	0.714	1.101	0.738	0.123	0.065	0.254
Range	0.040	0.026	0.037	0.623	0.759	1.406	2.570	3.880	2.290	0.465	0.244	0.679

N = Count M = Mean Min = Minimum SD = Standard Deviation Max = Maximum $a_{wx, wy, wz}$ = Axis-Specific RMS accelerations $Amp_{x, y, z}$ = Axis-Specific Amplitudes $CF_{x, y, z}$ = Axis-Specific Crest Factors $eVDV_{x, y, z}$ = Estimated Axis-Specific Vibration Dose Values

* "Combined Data" refers to the combined dataset of all applicable averaging periods

3.4. Filtered Data vs Raw Data

eVDV$_z$ and a$_{wz}$ results were compared between filtered and raw data parameters. Data distribution for the two parameters were nonparametric ($p = 0.004$ and $p = 0.01$ respectively). W$_0$ for eVDV$_z$ showed a $p = 0.01$, therefore indicating unequal variances between filtered and raw eVDV$_z$ results. Omission of 60s data showed a $p = 0.76$, therefore indicating non-significant differences in variances between filtered and raw data eVDV$_z$ (60s omitted). W$_0$ for a$_{wz}$ results showed a $p = 0.08$, therefore indicating non-significant differences in variances in variances between filtered and raw a$_{wz}$ results.

Both eVDV$_z$ (60s data omitted) and a$_{wz}$ (for all averaging periods) showed significant p-values during Wilcoxon signed-rank testing ($p = 0.0001$ and $p = 0.01$), therefore indicating significant differences between raw and filtered datasets.

4. Discussion

4.1. Summary of Findings

4.1.1. Logged data findings

Measurement durations pertaining to the data collection process were divided into real- and logged time durations. The selected averaging interval integrates sets of data equal to its time constant. Due to this, a portion of the data at the end of the monitoring phase will be lost if the amount of time is not sufficient to be integrated. This effect was observed at 60s averaging logged-time results, which differed significantly from other averaging approaches with regards to its variance. This effect resulted in data loss ranging from 30 to 44 seconds for different 60s averaged monitoring periods. No significant differences were observed between averaging approaches (including 60s averaging) with regards to actual data collection periods.

The first hypotheses of the study focused on possible differences between averaging periods with regards to logged measurement times (H_1) and whether these differed from actual measurement time periods (H_2). 60s averaging was omitted from hypotheses testing due to the observed impact it has on variance between averaging approaches. The null and alternative hypotheses are stated below:

H_0: There is no difference between averaging periods with regards to the measurement period (whether actual or logged times).

H_1: There is a significant difference between averaging periods with regards to logged and actual time periods (60s omitted).

H_2: There is a significant difference between actual and logged time periods for the datasets (60s omitted).

One-way ANOVA assumes equal variances and a Gaussian distribution of data. Therefore, One-Way ANOVA testing was carried out on remaining averaging periods from the original dataset.

Hypothesis testing resulted in a failure to reject the null hypotheses for differences between averaging intervals with regards to logged and actual measurement periods (60s averaging omitted). Similarly, the difference between actual and logged time periods were found to be insignificant, therefore indicating equal measured and logged time periods after omission of 60s averaging time results.

4.1.2. Raw vibration parameters

The ISO standard stipulates that the dominant axis may be used to compare WBV exposures to statutory limits. If no dominant axis is present, the vector sum may be used in order to evaluate exposure.[4] Maximal WBV was obtained in the z-axis of translational movement and as such, data obtained from this specific axis was assessed along with the obtained vector sum parameters.

The obtained raw vibration parameter results were tabulated in Table 3.2 in order to provide a detailed view of the descriptive statistics for each of the used averaging interval datasets. This is standard practice in Occupational Hygiene report writing when WBV assessments are performed.

The hypotheses relating to the raw data obtained during data acquisition focused on differences in vibration parameters between averaging approaches. Due to the nonparametric nature of data distribution and similar variances for a_{wz}, z-axis peak accelerations, z-axis CF and VDV_z (60s omitted), the Kruskal-Wallis one-way analysis of variance by ranks method was used to test for differences between averaging periods relating to z-axis vibration parameters. The null and alternative hypotheses can therefore be defined as:

H_0: There is no difference in any single vibration parameter between different averaging intervals.

H_1: There are significant differences between averaging approaches with regards to vibration parameters.

Data obtained from 60s and 1s averaging approaches differed significantly from the remaining averaging periods. The same effect was also observed between 30s and SLOW averaging approaches.

The elevated WBV exposure results obtained from 60s averaging may be attributed to the loss of data during the acquisition phase. This loss in data occurred shortly after periods of high shocks generated by speed humps, which resulted in higher a_{wz} compared to other averaging approaches.

For 1s averaging, the main contributing factor for elevated a_{wz} may be attributed to the short linear integration period. This short period resulted in a higher sensitivity to peak exposure data, therefore resulting in higher instantaneous frequency-weighted accelerations ($a_w(t)$) in certain sections. An increase in $a_w(t)$ data furthermore resulted in an increase in a_{wz}.

The difference observed between 30s and SLOW averaging may be attributed to the different integration methodologies used to calculate $a_w(t)$ and also the great difference in the integration period duration. As previously discussed, SLOW averaging is used during the running RMS method in order to obtain the MTVV and is only recommended in situations where the Crest Factor exceeds 9. What makes the averaging approach unique is the fact that it makes use of a 1 second exponential detector that maintains a moving average of the obtained results. The resultant $a_w(t)$ results are then used in order to calculate MTVV, which is defined as the highest magnitude of $a_w(t)$ read during the measurement period. The standard states the following in relation to $a_w(t)$ results in relation to linear approaches, “The difference in result is very small for application to shocks of a short duration compared to (t), and somewhat larger (up to 30%) when applied to shocks and transients of longer duration.”[4] This therefore indicates that a greater difference will be observed for exposure results as the duration of shock periods compared to the integration interval increases.

CF_z and z-axis instantaneous peak acceleration results showed non-significant differences ($p = 0.44$ and 0.37 respectively). This may in part be attributed to the fact that both the CF and instantaneous peak acceleration calculations make use of highly variable peak values which are not dependant on the integration period used. This therefore results in highly variable CF levels for which significant differences could not be ascertained due to increased variances between averaging period results.

VDV_z differences were found to be non-significant ($p = 0.07$) after omission of 60s averaged VDV_z results. The insignificant differences obtained between different averaging approaches may be due to two factors, namely the measurement duration, as well as the sensitivity of the algorithm to shocks obtained during the measurement period, resulting in greater variability within specific averaging approaches.

The VDV algorithm accumulates instantaneous frequency-weighted accelerations as time increases and should therefore deliver similar results for all averaging intervals where similar conditions and logged time periods prevail. The non-significant differences obtained for logged and actual measurement periods (60s omitted), therefore indicates that similar VDV results should prevail. However, due to the fact that the VDV algorithm is more sensitive to shock data due to the use of a fourth power relationship[4,5] , a higher variance in VDV data is possible when compared to a_w. This increase in variance was observed between a_{wz} and VDV results and resulted in non-significant differences between averaging periods (60s omitted).

Vector sum vibration results showed similar differences as those obtained for dominant axis vibration and may be attributed to the same reasons as explained.

4.1.3. Filtered data

Data filtering was considered as a means to decrease the differences observed between averaging periods, by removing outlying artefacts from logged data results. Outlier detection (data filtering) resulted in a high negative correlation between total log points and the resulting outlier ratio of the data, therefore indicating a decrease in outliers with an increase in the total amount of log points. This effect resulted in maximal data loss of 44.8% for 60s averaging, compared to data loss of only 4% for SLOW averaging.

An issue associated with WBV data filtering is during calculation of the VDV. The VDV algorithm makes use of instantaneous acceleration data and increases as the logging period increases as shown in Formula (2) of section 2.3. Removing outlying data removes integrated portions of instantaneous acceleration data not displayed by the instrument, therefore making it impossible to calculate the VDV for the filtered dataset. As such, it is therefore recommended that data filtering only be applied to scenarios where the CF < 9 and only maximal a_w is required for comparison to exposure limit values. For comparative reasons, the estimated z-axis vibration dose value (*e*VDV_z) was calculated for filtered time-series data utilizing Formula (4).

$$eVDV = 1.4a_{w\,r.m.s.}T^{\frac{1}{4}} \qquad (4)$$

The resulting effect of data filtering showed slightly significant differences ($p = 0.05$) between the majority of averaging period pairings, with the exception of 1s and 60s; 10s and 60s; 10s and 60s; and 10s and SLOW.

4.1.4. Comparison between Filtered and Raw data

The final hypothesis of the study related to the similarity between raw and filtered data frequency weighted a_{wz} and $eVDV_z$ results. The Wilcoxon signed-rank test was used to determine significant differences between filtered and raw data parameters. The null and alternative hypotheses can be stated as:

H_0: There is no difference between raw and filtered data parameters with regards to either a_{wz} and $eVDV_z$ results.

H_1: Raw and filtered datasets differ with regards to a_{wz} and $eVDV_z$ results.

Comparison between filtered and raw $eVDV_z$ and a_{wz}, furthermore revealed significant differences between averaging periods for the selected parameters. Significant differences were therefore still present between averaging intervals following data filtering and as such a conclusion regarding a suitable approach could not be determined.

4.1.5. General discussion

The study investigated the effect of different averaging intervals on WBV exposure parameters of a driver travelling on a fixed route. To our knowledge, this was the first study demonstrating the effects of different averaging approaches on WBV exposure results utilizing the Quest HavPro vibration monitor. Identified studies utilizing the HavPro equipment consisted mainly of exposure assessments and either made no mention of the utilized averaging approach or only assessed exposures utilizing a single averaging approach.[10-12] Studies where uncertainties pertaining to WBV exposure assessments were documented, focused on factors such as operator work methods, variations in the characteristics and condition of various machines of the same kind, difference in travelling surfaces, uncertainties in the evaluation of exposure durations and systematic errors due to measurement equipment.[2,3,13] These studies however, did not make use of HavPro equipment and did not ascertain the effect of integration intervals on WBV exposure data.

4.2. Study Limitations

Design issues present one of the main limitations of the study. Due to the fact that data acquisition was performed on a “real world” fixed route, differences relating to random vibration exposure could not be controlled. Additionally, although disturbances caused while driving the route, i.e. traffic, were controlled as far as possible by driving during non-peak traffic hours, the presence of other vehicles on the road may have caused slight differences in the obtained WBV data. The study was also limited to a single piece of equipment and as such, the same effect could not necessarily be generalized and made applicable to all vibration monitoring equipment.

Another issue was the selected sample size. A larger sample would have allowed for more powerful analyses of hypotheses at which non-significant differences were obtained. This is especially the case when looking at VDV results. Due to increased variance observed within averaging approach groups caused by the fourth power relationship of the VDV algorithm, significant differences could not be ascertained.

Our study furthermore only focused on a single outlier detection method and did not compare several methods in order to determine a suitable averaging approach. Several outlier detection and time series smoothing methodologies exist which may deliver suitable results.

4.3. Opportunities for Future Research

Confidence in the results obtained during the study could be strengthened by measuring WBV parameters during highly controlled simulated activities, such as with ICP accelerometer calibration shakers. It is however important that shocks be introduced at the exact same time periods, due to the observed effects associated with logged time periods for different averaging intervals. Furthermore, more research should be conducted on the effects of time-series outlier detection or smoothing techniques to determine a suitable averaging approach for WBV assessment. Future studies could also focus on other human vibration monitors and whether the same effects are observed during measurement of WBV.

5. Conclusion

The study identified certain critical aspects relating to the effects associated with integration intervals on WBV results. 60s averaging showed the highest inconsistencies relating to WBV exposure due to its greater integration interval which may lead to the omission of large portions of data if the proper sampling time is not applied. If not properly accounted for, these inconsistencies may result in the reporting of erroneous data. Further research is therefore required to select proper data filtering approaches to minimize differences caused by selecting multiple integration intervals.

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Addendums

Annexure A: Ethical Clearance

UNIVERSITEIT VAN PRETORIA
UNIVERSITY OF PRETORIA
YUNIBESITHI YA PRETORIA

Faculty of Health Sciences Research Ethics Committee

28/03/2013

Approval Notice
New Application

Ethics Reference No.: 79/2013

Title: The selection of different averaging approaches on whole body vibration exposure levels of a driver utilising the ISO 2631-1 standard

Dear Duane Bester

The **New Application** for your research received on 5 March 2013 was approved by the Faculty of Health Sciences Research Ethics Committee on the 27/03/2013

Please note the following about your ethics approval:

- Ethics Approval is valid for 1 year.
- Please remember to use your protocol number (79/2013) on any documents or correspondence with the Research Ethics Committee regarding your research.
- Please note that the Research Ethics Committee may ask further questions, seek additional information, require further modification, or monitor the conduct of your research.

Ethics approval is subject to the following:
Standard Conditions:

- The ethics approval is conditional on the receipt of 6 monthly written Progress Reports, and
- The ethics approval is conditional on the research being conducted as stipulated by the details of all documents submitted to the Committee. In the event that a further need arises to change who the investigators are, the methods or any other aspect, such changes must be submitted as an Amendment for approval by the Committee.

The Faculty of Health Sciences Research Ethics Committee complies with the SA National Act 61 of 2003 as it pertains to health research and the United States Code of Federal Regulations Title 45 and 46. This committee abides by the ethical norms and principles for research, established by the Declaration of Helsinki, the South African Medical Research Council Guidelines as well as the Guidelines for Ethical Research: Principles Structures and Processes 2004 (Department of Health).

We wish you the best with your research.

Yours sincerely

DR R SOMMERS; MBChB; MMed(Int); MPharmMed.
Deputy Chairperson of the Faculty of Health Sciences Research Ethics Committee
University of Pretoria

The Research Ethics Committee, Faculty Health Sciences, University of Pretoria complies with ICH-GCP guidelines and has US Federal wide Assurance.

- FWA 00002567, Approved dd 22 May 2002 and Expires 20 Oct 2016.
- IRB 0000 2235 IORG0001762 Approved dd 13/04/2011 and Expires 13/04/2014.

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Annexure B: Research Protocol

UNIVERSITEIT VAN PRETORIA
UNIVERSITY OF PRETORIA
YUNIBESITHI YA PRETORIA

University of Pretoria
Faculty of Health Sciences
School of Health Systems & Public Health

The selection of different averaging approaches on whole body vibration exposure levels of a driver utilising the ISO 2631-1 standard

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Date: 04/03/2012

Executive Summary

Biodynamic and epidemiological studies have given evidence for an increased risk of health effects due to long-term, high intensity whole-body vibration (WBV) exposure. The problem however exists in the comparison of vibration exposure at a specific magnitude with specific health outcomes. Two well-known standards currently exist for the quantification of vibration with regards to whole body exposure, namely BS 6841 (1987) and ISO 2631-1 (1997). The problem with the ISO standard however is that a specific averaging period is not defined for measuring WBV. This is problematic, because it may result in the reporting of different whole body vibration levels for the same exposure. SLOW averaging is defined as an exponential time constant compared to the other linear time constant averaging periods. Furthermore, the length of the averaging period may play a role in masking the actual vibration dose experienced. The aim of the study is to determine whether significant differences exist between different averaging periods for frequency-weighted acceleration RMS values. Sampling will be conducted utilising a HAVPro vibration meter equipped with a triaxial accelerometer specific for seat transmitted vibration exposure. A standard sedan motor vehicle will be used on a route of approximately 4km in distance in the Tshwane municipal area. Three 30 minute samples comprising of three cycles of the course, will be taken for each of the five identified averaging approaches. A primary outcome of the project will therefore be to determine if a need exists to define a specific averaging approach to evaluate a driver’s whole-body vibration exposure level.

Contents

1. Introduction

It is stated in annexure B of the international standard ISO 2631-1 that biodynamic and epidemiological studies have given evidence for an increased risk of health effects due to long-term, high intensity whole-body vibration (WBV) exposure. WBV therefore seems to follow a dose-response relationship. Sufficient data however does not exist to indicate a quantitative relationship between vibration exposure and health effects.[1]

Even though WBV exposure can't yet be quantitatively compared to certain health outcomes, several health effects have been discovered. As the name implies WBV affects the entire body, with outcomes ranging from discomfort to decreased performance to health outcomes including musculoskeletal, digestive, auditory, cardiac, neurological and vascular disorders.[2]

Two well-known standards currently exist for the quantification of vibration with regards to whole body exposure, namely BS 6841 (1987) and ISO 2631-1 (1997).[2,3] Although the BS standard was originally developed as an exclusively British standard, its use has spread worldwide, sometimes even in preference to the ISO standard. Recently, the use of the ISO method became the preferred standard to evaluate WBV in Britain.[2,4]

Both of the standards require tri-axial acceleration measurements to be taken on the seat pan by means of an accelerometer fixed in a 20cm diameter semi-rigid disc as specified by the Society of Automotive Engineers (SAE pad) which is placed on the seat pan.[1,2,5] Acceleration signals are then passed through a tri-axial accelerometer which is stimulated in three axes, namely x, y and z. The axes represent the possible directions of movement for a complex stimuli in relation to the body, anterior-posterior (defined as the x-axis), laterally (defined as the y-axis) and superior-inferior (defined as the z-axis). Once the accelerometer is stimulated the signal is amplified, conditioned according to the set frequency weighting, required calculations made and the results displayed on the instrument.[2]

The frequencies of the acceleration signals are weighted to provide the correct sensitivity for a specific sample population's bodily response to vibration at defined frequencies (the specific weightings differ according to the standard in use). For ISO 2631-1 the weightings set are W_d, W_d and W_k (all with an equal frequency range of 0.5-80 Hz) for the x, y and z-axes respectively. Figure 1.1 shows the weightings applied to different factors including those for ISO 2631-1.[1,2,5] In addition to the frequency weighting, ISO 2631-1 further requires that a scaling factor be applied to each of the axes (x-axis, k=1.4; y-axis, k=1.4; z-axis, k=1.0).[1,2,5] The scaling factor is used for health risk assessment purposes at the specified frequency weightings as defined in the standard.[1,2,6]

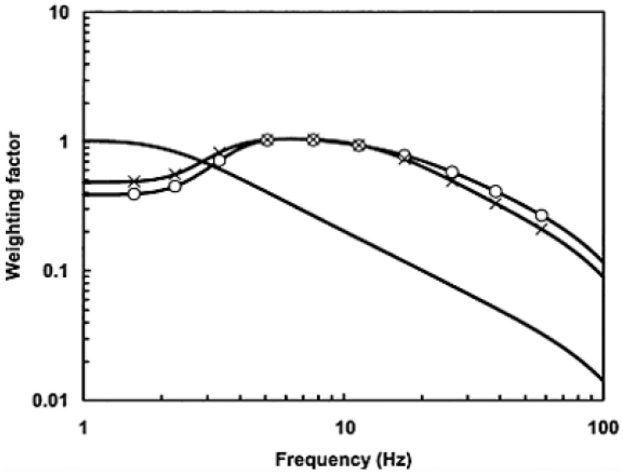

Figure 1.1: Frequency weighting curves as used by BS 6841 and ISO 2631-1. Vertical vibration: Wb (-O-) and Wk (-x-); horizontal vibration: Wd (__)^2.

Vibration in its essence is defined as a movement that oscillates around a fixed point. Therefore, the mean value of a vibration signal will be zero as all the positive values cancel out the negatives as it completes a number of cycles for all the expressed frequencies.[1,2] This means that the magnitude of the signal can't be expressed through the mean. Utilising the Root-Mean-Square (RMS) for the vibration signal alleviates this problem by squaring each value in the signal, taking the mean and finally taking the square root of the final value. The RMS forms the basis for all data evaluation for health risk assessment purposes according to ISO 2631-1. Mathematically, the RMS can be expressed as:

$$a_{w\,r.m.s} = \sqrt{\frac{1}{T}\int_{0}^{T} a_{w}^{2}\,(t)dt}$$

Where:

- $a_{w\,r.m.s}$ is the frequency-weighted RMS acceleration
- T is the measurement duration
- $a_w(t)$ is the frequency-weighted acceleration at time t

No proposed averaging period for RMS is currently defined in ISO 2631-1 and this will form the basis of the proposed study.[1,2,6] Vibration monitors are capable of sampling at a magnitude of different frequency-weighted acceleration averaging periods at which RMS is calculated. The problem arises especially when dealing with SLOW averaging versus all other averaging periods. SLOW averaging is an exponential time constant which starts with a 1 second average and as time passes, discards the first part of the average as the next sample is taken. In contrast, the other averaging time constants are linear and all previously collected data is disregarded with each subsequent sample collected.[7] The exponential and linear averaging approaches therefore may produce different values, especially during random vibration exposure as the acceleration data at a specific time may be incorporated into the total RMS acceleration in such a way that the actual exposure may be masked.

Another factor that has to be taken into account is the crest factor. It can be mathematically defined as the ratio of the peak acceleration to the RMS. The crest factor is significantly influenced by random, sudden force designated as shocks. It is calculated to determine whether RMS can be used as an appropriate evaluation tool.[1,2] ISO 2631-1 defines that a crest factor in excess of 9 requires the assessor to utilise additional measures to assess the risks involved. These measures include calculating the vibration dose value (VDV) and the maximum transient vibration value (MTVV).[1] The crest factor will therefore be an important factor to consider during data evaluation.

2. Hypothesis

The hypotheses for the study are:

1) The different averaging approaches will result into significantly different individual axis and total sum RMS values for whole body vibration monitoring,
2) The different averaging approaches will influence the crest factor

3. Aims and objectives

The aim of the study is to determine whether significant differences exist between different averaging periods for frequency-weighted acceleration RMS values for WBV exposure. The objectives to determine the aim of the study will consist of:

1) Determining the total sum and individual sum averages and how they relate to the specific averaging period selected.
2) Determining the crest factor related to the preselected averaging periods and how they relate to different averaging periods.

4. Methods

4.1 Study design

A controlled experimental design will be implemented to determine the effect different acceleration averaging periods have on the RMS value at SLOW, 1s, 10s, 30s, 60s averaging periods.

4.2 Study setting

The study setting will comprise of a course selected on a municipal road in Tshwane of approximately 4km in length. The course will contain shocks produced by speed humps and will make provision for random vibration exposure in the form of stop streets, uneven surfaces and road bends.

Figure 4.1. Proposed Study Setting for the research project.

4.3 Study population and sampling

4.3.1 Study population

As the study design is not focused on sampling a specific population at risk of contracting health outcomes, there will not be a study population but rather a controlled study setting. A single participant, acquainted with the investigator, will be recruited to aid in the conduction of the study by driving the vehicle. The participant is a mechanical engineer and a previous student of the University of Pretoria who is knowledgeable in the field of vibration.

4.3.2 Sampling methods and approach

Sampling will be conducted according to the standards set out in ISO 2631-1 utilising a properly calibrated Quest Technologies HAVPro vibration meter with a fitted Triaxial accelerometer fitted in a vibration seat plate (SAE pad) (Quest Technologies, S/N: 1140). The SAE pad will be correctly placed on the seat of the driver according to the designated axis's (x,y and z) indicated on the pad and will sample the whole body vibration exposure experienced during the sampling process. The vehicle will be driven through the course in the exact same manner and time to complete each round for each of the averaging periods. Whole-body vibration measurements will be taken at the following averaging periods: SLOW, 1s, 10s, 30s, 60s. These averaging periods form part of the standard settings of the vibration monitoring equipment and are preselected prior to a sample being taken. The inclusion of the selected averaging periods is based on the available settings for the vibration monitoring equipment and includes the non-linear SLOW averaging period together with linear averaging periods as defined by the time constant. A total of three 30 minute samples will be taken at each of the five specified averaging periods, with each sample comprising of three cycles of the course.

5. Data Management and Analysis

Numerical data captured by the vibration instrument will be downloaded using a personal computer with the data management program of the vibration meter. Mathematical calculations of the captured data will be done with the aid of the QuestSuite Professional II software package. Management of data will be done through the utilisation of Epidata and analysis will be conducted by making use of the STATA software package.

Data analysis will comprise of descriptive statistics in the form of means, medians, ranges, quartiles, minimums, maximums, standard deviation, variance and skewness. Furthermore data will be graphically displayed in box-plots, histograms and normality probability distribution graphs. In addition to the above, the Bland-Altman method will be used to determine the agreement among the different averaging periods.

Hypotheses testing will comprise of one way analysis of variance (ANOVA) testing to determine whether a significant difference does exist between data obtained from different averaging periods. Furthermore, Bonferroni normalization testing will be performed to determine whether any significant differences exist between specific averaging periods.

6. Ethical and legal considerations

There are no ethical considerations. All required measures will be taken to ensure that the driver complies with the set road traffic rules of South Africa during sampling procedures. A roadworthy vehicle will be used and the driver will at all times be required to wear a seatbelt while the vehicle is in motion. Conformance with regards to traffic signs and speed limits will be non-negotiable. The route on which the vehicle will be driven is located within a quiet suburban area within the Tshwane Municipal District and the sampling process will only be conducted during times of minimal traffic (Saturdays and Sundays from 05:00 to 07:00).

The participant who will assist the investigator in the conduction of the study is a mechanical engineer with a valid South African driver's licence who is knowledgeable in the field of vibration. No remuneration will be offered to the participant and consent will be granted by completing the patient information leaflet and consent form.

7. Logistics and time schedule

7.1 Project team

The project team will be comprised of:

1) The investigator and field worker, Duane Bester, who will be responsible for the data collection, management and statistical analysis, and the writing of the research dissertation,
2) The supervisor, Dr. Nico Claassen, will assist the investigator in all aspects with regards to academic mentoring and study progression,
3) The statistician, Dr Steve Olorunju, will assist the investigator with regards to the correct statistical methods required for the study and the statistical analysis of the obtained data.

7.2 Project management time table

Table 1: Gantt chart indicating planned activities to complete project

Activity	Mar-13	Apr-13	May-13	Jun-13	Jul-13	Aug-13	Sep-13
Literature review and compiling of report	🟨	🟨	🟨	🟨	🟨	🟨	🟨
Protocol approval	🟨	🟨					
Ethics			🟨	🟨			
Data capturing					🟨	🟨	
Data analysis						🟨	🟨

8. Budget

The total cost of the study will be personally funded by the investigator. The proposed budget is indicated in Table 2.

Table 2: Proposed budget for research project.

Expenditure	Unit price	Total units required	Total expense
Personal costs			
Travel expenses	R2.42/km	180	R 435.60
Communication	R1.40 per minute	20	R 28.00
Administrative costs			
Printing costs	R500.00	1	R 500.00
Total			R 963.60

References

1. International Organization of Standardization. ISO 2631-1 Mechanical Vibration and Shock—Evaluation of Human Exposure to Whole-Body Vibration—Part 1: General Requirements. 2631-1:1997(E). ed. Geneva, Switzerland: ISO; 1997.

2. Mansfield N. Human Response to Vibration. Boca Raton, Florida: CRC Press LLC; 2005.

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4. Paddan gs, griffin mj. Evaluation of whole-body vibration in vehicles. J.Sound Vibrat. 2002 5/23;253(1):195-213.

5. Eger T, Stevenson J, Boileau P-, Salmoni A. Predictions of health risks associated with the operation of load-haul-dump mining vehicles: Part 1—Analysis of whole-body vibration exposure using ISO 2631-1 and ISO-2631-5 standards. Int.J.Ind.Ergonomics 2008 0;38(9–10):726-738.

6. Dong RG, Welcome DE, McDowell TW. Some important oversights in the assessment of whole-body vibration exposure based on ISO-2631-1. Appl.Ergon. 2012 1;43(1):268-269.

7. Quest Technologies. HAVPro Human Vibration Meter User Manual: 2003.

Annexure C: Information Leaflet and Informed Consent for research Project

PIC 3 Updated 28/02/2007

INFORMATION LEAFLET AND INFORMED CONSENT FOR NON-CLINICAL RESEARCH

(e.g. educational, health systems or non-clinical operational research

TITLE OF STUDY: The selection of different averaging approaches on whole body vibration exposure levels of a driver utilising the ISO 2631-1 standard

Dear Participant:

1) INTRODUCTION

We invite you to participate in a research study. This information leaflet will helpyou to decide if you want to participate. Before you agree to take part you should fully understand what is involved. If you have any questions that this leaflet does not fully explain, please do not hesitate to ask the investigator.

2) THE NATURE AND PURPOSE OF THIS STUDY

Whole body vibration refers to the exposure of a person to low frequency vibration during the operation of machinery such as a motor vehicle. This type of vibration may produce negative health outcomes if exposure falls within set criteria as defined in international exposure assessment standards. The aim of this study is to assess whether the standard is affected by using different averaging settings on the exposure sampling equipment. The exposure assessment standard does not specify the averaging approach to use during sampling and results may be affected by this. You as a participant play a very important role as your exposure to whole body vibration will be assessed at these different averaging settings while driving a standard sedan motor vehicle.

3) EXPLANATION OF PROCEDURES TO BE FOLLOWED

This study involves you as the participant to drive a predetermined course on a public road within the Tshwane Municipal district while sitting on a vibration sampling plate. This plate will measure your exposure to whole body vibration during the course of the sampling procedure. While driving, the investigator will instruct you to maintain the speed of the vehicle at certain stages, stop and also to accelerate the vehicle to the desired speed. All necessary steps will be taken to ensure that you as the participant comply with national traffic rules and law during the conduction of the study.

4) RISK AND DISCOMFORT INVOLVED

There are very low risks in participating in the study as the level of vibration exposure is expected to be without hazard to health. Some discomfort may be experienced due to the length of time you will be asked to drive the vehicle. A total amount of approximately 600 minutes (10 hours) is required to obtain all necessary data, but this total time will be divided into cycles of no longer than two hours on a specific day. This means that we will require your assistance for five days to conclude the study.

5) POSSIBLE BENEFITS OF THIS STUDY

Although you will not benefit directly from the study, the results of the study will enable us to ensure that the correct methodology is used to assess an individual's exposure to whole body vibration.

6) WHAT ARE YOUR RIGHTS AS A PARTICIPANT?

Your participation in this study is entirely voluntary. You can refuse to participate or stop at any time during the study without giving any reason. Your withdrawal will not affect you in any way.

7) HAS THE STUDY RECEIVED ETHICAL APPROVAL?

This study has received written approval from the Research Ethics Committee of the Faculty of Health Sciences at the University of Pretoria and a copy of the approval letteris available if you wish to have one.

8) INFORMATION AND CONTACT PERSON

The contact person for the study is Duane Bester. If you have any questions about the study please contact him at 0840957144.

9 COMPENSATION

Your participation is voluntary. No compensation will be given for your participation.

10 CONFIDENTIALITY

All information that you give will be kept strictly confidential. Once we have analysed the information no one will be able to identify you. Research reports and articles in scientific journals will not include any information that may identify you.

11 UNIVERSITY OF PRETORIA, FACULTY OF HEALTH SCIENCES RESEARCH ETHICS COMMITTEE CONTACT DETAILS

Physical address:
University of Pretoria,
Faculty of Health Sciences
HW Snyman South Building

Rooms 2.33; 2.34 & 2.35
31 Bophelo Road, Gezina, Pretoria

Enquiries:
The Research Ethics Office:
Tel: 012 354 1330 or 012 354 1677
Fax: 012 354 1367
E Mail: manda@med.up.ac.za
E Mail: deepeka.behari@up.ac.za

CONSENT TO PARTICIPATE IN THIS STUDY

I confirm that the person asking my consent to take part in this study has told me about the nature, process, risks, discomforts and benefits of the study. I have also received, read and understood the above written information (Information Leaflet and Informed Consent) regarding the study. I am aware that the results of the study, including personal details, will be anonymously processed into research reports. I am participating willingly. I have had time to ask questions and have no objection to participate in the study. I understand that there is no penalty should I wish to discontinue with the study and my withdrawal will not affect me in any way.

I have received a signed copy of this informed consent agreement.
Participant's name ...WILLEM HENDRIK TRAUT.............(Please print)
Participant's signature: .... Date..20-05-2013.......
Investigator's name ...DUANE BESTER..(Please print)
Investigator's signature .... Date..20/05/2013.......
Witness's Name ...Janita Markgraaft...............................(Please print)
Witness's signature .... Date....20/05/2013.

VERBAL INFORMED CONSENT

I, the undersigned, have read and have fully explained the participant information leaflet, which explains the nature, process, risks, discomforts and benefits of the study to the participant whom I have asked to participate in the study. The participant indicates that s/he understands that the results of the study, including personal details regarding the interview will be anonymously processed into a research report. The participant indicates that s/he has had time to ask questions and has no objection to participate in the interview. S/he understands that there is no penalty should s/he wish to discontinue with the study and his/her withdrawal will not affect him/her in any way. I hereby certify
that the client has agreed to participate in this study.

Participant's Name ....WILLEM HENDRIK TRAUT..........(Please print)
Person seeking consent ..DUANE BESTER....................................(Please print)
Signature ....Date....20/05/2013.........
Witness's name: ....Janita Markgraalt...........................(Please print)
Signature ....Date....20/05/2013

Annexure D: Letter of Statistical Support

SOUTH
AFRICAN
MEDICAL
RESEARCH
COUNCIL
MRC
SOUTH AFRICA

BIOSTATISTICS UNIT

Private Bag X385, Pretoria, South Africa,
No. 1 Soutpansberg Road, Pretoria
Tel: 012 339 8519, Fax: 012 339 8582
URL://www.mrc.ac.za/

LETTER OF STATISTICAL SUPPORT

Date: 01/03/2013

This letter is to confirm that the student, **Duane Bester**, an MPH student studying at School of Health System and Public Health, University of Pretoria discussed the Project with the title "**The selection of different averaging approaches on whole body vibration exposure levels of a driver utilising the ISO 2631-1 standard"** with me.

I hereby confirm that I am aware of the project and also undertake to assist with the statistical analysis of the data generated from the project.

DATA ANALYSIS

The objective is to assess differences between averaging periods with regards to the obtained total sum average and individual sum averages and examining if differences exist between the "crest factors" obtained from different averaging periods. Data analysis will comprise of descriptive statistics in the form of means, medians, ranges, quartiles, minimums, maximums, standard deviation, variance and skewness. Furthermore data will be graphically displayed in box-plots, histograms and normality probability distribution graphs. In addition to the above, the Bland-Altman method will be used to determine the agreement among the different averaging periods.

Hypotheses testing will comprise of one way analysis of variance testing to determine whether a significant difference does exist between data obtained from different averaging periods and over periods. STATA 12 will be the package of choice.

SAMPLE SIZE

This is a controlled experimental design implemented to determine the effect different acceleration averaging periods on the RMS value at SLOW, 1s, 10s, 30s and 60s averaging periods.

Biostatistics Unit
MRC Pretoria

Tel: 0123398553

MEDICAL RESEARCH COUNCIL
Biostatistics Unit
Private Bag X385
Pretoria
0001
Tel: 012 339 8523 / Fax: 012 339 8582

Signature
Date 01/03/2013.

Annexure E: The Annals of Occupational Hygiene: Instructions for Authors

THE ANNALS OF OCCUPATIONAL HYGIENE

INSTRUCTIONS FOR AUTHORS

Please note that the journal now encourages authors to complete their copyright licence to publish form online

Open access options for authors - please see below for further details

Online Submission of Manuscipts

1. **All manuscripts must be submitted online.** Once you have prepared your manuscript according to the instructions below please visit the online submission web site. Instructions on submitting your manuscript online can be viewed here.
Any hardcopy correspondence should be sent to the Chief Editor, Dr Noah Seixas, Department of Environmental and Occupational Health Sciences, University of Washington, 4225 Roosevelt Way NE, Seattle, WA 98105-6099 or by email to AOHed@uw.edu. Alternatively, correspondence can be sent to the editorial office at The Annals of Occupational Hygiene, BOHS, 5/6 Melbourne Court, Millennium Way, Pride Park, Derby DE24 8LZ, UK, or by email to annals@bohs.org

What we publish

2. Annals of Occupational Hygiene publishes original research and development material that helps reduce risk of ill-health resulting from work, and welcomes submissions in these areas. For more details, including some categories which we do not normally consider, see http://www.oxfordjournals.org/our_journals/annhyg/about.html.

3. We define the categories of submission as follows:

Editorial
Editorials are short communications addressing issues of interest to the readership, especially those regarding issues of publication of the Annals. Editorials are generally authored by the Chief Editor or members of the Editorial Board, but may be submitted by a guest editor, or others if invited by the editor to do so. Editorials are generally under 1500 words. Peer review is at the Chief Editor's discretion, but will normally include at least one review by an editorial board member.

Commentary
Commentaries are discussions of topics of importance to occupational hygienists, including matters of policy, professional practice, or the science of occupational hygiene and occupational health. Commentaries may provide a perspective on controversial issues, but should be well founded on evidence as cited in the material presented. Commentaries are normally under 2000 words, and are peer reviewed through our normal process.

Letter to the Editor

A letter to the editor may be submitted by any reader on any topic of interest to the readership, including comments on papers having appeared previously in the Annals. Letters are normally less than 1000 words, and are peer reviewed at the discretion of the Chief Editor, but will normally include at least one review by an editorial board member.

Review Article

Review articles review the scientific evidence addressing a topic of interest to occupational hygiene scientists or practitioners. Articles should clearly state the scope of the review, provide a methodology for gathering the evidence reviewed, and summarize the results of that evidence comprehensively. The summary of evidence may be provided in text, or through quantitative analysis, as in a meta-analysis. Reviews are normally less than 5000 words and have up to six tables or figures, and are peer reviewed through our normal process.

Original Research Paper

Original research papers are reports of scientific investigations of matters affecting occupational risks, exposures, and methods of their assessment. Original research reports may be descriptive, observational and/or experimental investigations, and can usually be presented as hypothesis-driven research. Original research reports should be able to clearly state their aim, define the methods with which evidence is gathered and organized, describe the analytic methods used, and present the results of these analyses in a transparent and interpretable format. The conclusions of the paper must be supported by the data and their analysis. Original research papers are normally under 4000 words with a maximum of 5000, and have up to six tables or figures. Original research papers are peer reviewed through our normal process.

Short Communication

Short communications are descriptive studies, with limited data, that present new information of importance to the readership, but with insufficient data for a full original research report. Examples include: a description of an occupational disease case with a thorough investigation of the exposures likely to have given rise to the disease; a demonstration of a new measurement principle or device with potential for solving an important exposure measurement problem; evidence demonstrating the effectiveness of a novel exposure control strategy. In each case, the data available are insufficient to support a full original research paper or prove the validity of the observation, but provide potentially important information to occupational hygienists. Short communications will generally be less than 1500 words and have up to two tables or figures. Such reports will be peer reviewed through our normal process.

In addition, the editor may publish Corrigenda to correct previously published manuscripts.

4. The Annals aims to conform with the Code of Conduct and the Guidelines of the Committee on Publication Ethics (COPE) http://www.publicationethics.org/, and in making a submission authors agree to having their submission dealt with in accordance with these Codes and Guidelines.

5. **Submitted material must be original**, and not under consideration elsewhere. If the findings have been published elsewhere in part, or if the submission is part of a closely-related series, this must be clearly stated in the letter accompanying the manuscript, and the submitted manuscript must be accompanied by a copy of the other publications (or by a copy of the other manuscripts if they are still under consideration). These should be uploaded in the submission as supplementary files. Any deceitful attempt to republish material by the author or others that has already appeared

or submitted elsewhere will be treated as serious malpractice, and action will be taken in accordance with COPE procedures. Submitted manuscripts may be screened with iThenticate software.

Preparing a submission

6. *Language.*
Manuscripts must be in English and authors should try to write in a way which is simple and clear. British or American styles and spelling may be used, but should be used consistently, and words or phrases which might be unclear in other parts of the world should be avoided or clearly explained. It is the authors' responsibility to provide a text in good English, and authors whose first language is not English should seek help from a native speaker or competent translator. This must be done before first submission to ensure a thorough peer review. The editors are sympathetic to the difficulties of writing in a second language, but regrettably cannot do major work on English editing; major problems with English language or construction may lead to rejection. If English is not your first language, you may wish to have your manuscript edited for language before submission. Language editing does not guarantee that your manuscript will be accepted for publication. Oxford University Press lists some commercial services available for English language technical editing which can be found here.
Authors are responsible for all costs associated with such services.

7. *Brevity.* The necessary length of a paper depends on the subject, but any submission must be as brief as possible consistent with clarity. **The number of words, excluding the abstract, references, tables and figs, must be stated as a message to the Editor at the time of submission.** If this length is more than 5000 words, a statement must be included justifying the extra length, and papers without this information may be returned unread. Suitable extra material can be included in the online edition only (see para 17, *Supplementary Material* below).

8. *Title, abstract and keywords.* These are important because most readers find papers by internet search of subjects, not by browsing the journal. Titles should be constructed to succinctly describe the major issue or question examined by the paper and should not assert the research findings as a truth . Recognisable, searchable terms and keywords must be included to enable readers to more effectively find your paper. To optimise the visibility of your paper we advise you to make a list of the 10 most likely search terms (words and phrases) that your intended readers will use to find your work, and to ensure that these appear in your title, the abstract and the keywords. The 'number one' search term from your list should appear somewhere in the paper's title. This will usually not be just a single word; rather a short phrase summarising the main subject of the paper. The 'top 5' search terms (including 'number one') should each appear at least once in the abstract, with the 'top 3' appearing more than once if possible. It is important that your abstract is written in a naturalistic and engaging style that will encourage readers to follow up by reading the full paper. The 'bottom 5' search terms can then be added as keywords. It is important to include variants of the 'top 5' here if they exist, e.g. alternative names for chemicals or processes.

9. *Authorship*. Persons should only be named as authors if they have made significant identifiable intellectual contributions to the work; other contributions may be recognised by acknowledgement at the end of the submission. For further details of our policy, see
http://annhyg.oxfordjournals.org/content/51/8/651.full.pdf html

All names and affiliations of authors should be clearly stated at the beginning of the paper.

10. *Structure of paper*. Papers should generally conform to the pattern: Introduction, Methods, Results, Discussion, and Conclusions, unless these are clearly inappropriate. A paper must be

prefaced by an abstract of the argument and findings, which may also be arranged under the same headings. As with many other journals, we are unable to publish footnotes to the text. Please therefore incorporate this sort of material into the body of the paper, in brackets if appropriate.

11. *Design and analysis*. The quality of the data and analysis must always be good enough to justify the inferences and conclusions drawn. Particular attention should be given to design of sampling surveys, which should be planned using modern statistical principles, and to the treatment of results below the limit of detection (see http://annhyg.oxfordjournals.org/content/54/3/255.full.pdf html)

12. *Units and symbols*. **SI units must be used**, though their equivalent in other systems may be given as well.

13. *Figures.* These include photographs, diagrams and charts. The first submission should include good quality low resolution copies of Figures, and may be incorporated into the text or at the end of the manuscript.

The revised version of the paper, after review, should be accompanied by high-resolution electronic copies in a form and of a quality suitable for reproduction. They should be uploaded as separate files. They should be about the size they are to be reproduced, with font size at least 6 point, using the standard Adobe set of fonts. They should have a resolution of 600 dpi for line figures, and 300 dpi for half tones, saved as .tif, .jpg, .gif, .bmp or .eps files (with fonts embedded where appropriate). Graphics in word processor, Excel and Powerpoint formats may not be of sufficient quality. Fine hairlines should be avoided and clear hatching patterns should be used in preference to solid grey shadings wherever possible. Computer-generated graphics should be reproduced in grey-scale if they are to be published in black and white. Colour photographs should be scanned at 300 d.p.i. (600 dpi for colour line/tones) and be in CMYK colour mode. Figures will appear in colour in the online edition, but if colour is required in the print edition authors will be charged £350 per Figure. If a Figure is to appear in black and white in the print edition, authors should ensure that it makes sense without colour and that its caption does not refer to colour. Please state your preferred option (i.e. agreement to pay £350/figure for print or colour online-only with no charge) upon submission through the online site.

14. *Cover photographs.* We are keen to receive interesting and relevant photographs for the cover of the Annals of Occupational Hygiene. If you have an image which you wish to submit for consideration, which does not have to be one of the Figs in your paper, please email it at any time to annals@bohs.org. Quality is important: on the cover, images will be landscape, and should preferably be at least 2200 x 1800 pixels. Please ensure that there is no objection from any people shown in the photograph, or those responsible for any workplace shown in the photo.

15. *Tables.* Tables should be numbered consecutively and given a suitable caption. As with Figures, it is helpful to incorporate them into the text of the first submission, but in the revised version each table should be presented on a separate page. Footnotes to tables should be provided below the table and should be referred to by superscript lowercase letters.

16. *References.* References should only be included which are essential to the development of an argument or hypothesis, or which describe methods for which the original account is too long to be reproduced. References in the text should be in the form Jones (1995), or Jones and Brown (1995), or Jones et al. (1995) if there are more than two authors, and they should be incorporated

naturally into the text. For example:
Jones and Brown (1995) and Hospath et al (2006) observed total breakdown of control..., or
Total breakdown of control has sometimes been observed (Jones and Brown, 1995; Hospath et al., 2006).
Papers whose references are not properly arranged may be returned for revision without review.

At the end of the paper, references should be listed in alphabetical order by name of first author, using the Vancouver Style of abbreviation and punctuation. ISBNs should be given for books and other publications where appropriate. Material unobtainable by readers should not be cited. Personal Communications, if essential, should be cited in the text (e.g., Professor O.H. Poobah, Institute for Dusty Sciences). Internet material can be referred to if it is likely to be permanently available; the date on which it was last accessed should be given. References will not be checked editorially, and their accuracy is the responsibility of authors.

Examples:
Simpson AT, Groves JA, Unwin J, Piney M. (2000) Mineral oil metal working fluids (MWFs)—Development of practical criteria for mist sampling. Ann Occup Hyg; 44: 165–72.
Vincent JH. (1989) Aerosol sampling: science and practice. Chichester, UK: John Wiley. ISBN 0 471 92175 0.
Swift DL, Cheng Y-S, Su Y-F, Yeh H-C. (1994) Ultrafine aerosol deposition in the human nasal and oral passages. In Dodgson J, McCallum RI, editors. Inhaled Particles VII. Oxford: Elsevier Science. p. 77–81. ISBN 0 08 040841 9 H.
British Standards Institution. (1986). BS 6691: 1986. Fume from welding and allied processes. Part 1. Guide to methods for the sampling and analysis of particulate matter. London: British Standards Institution.
Morse SS. (1995) Factors in the emergence of infectious diseases. Emerg Infect Dis [serial online] 1995 Jan–Mar;1(1). Available from: URL: http://www.cdc.gov/ncidod/ EID/eid.htm (accessed 25 Oct 2010)

If you use EndNote and/or Reference Manager to facilitate referencing citations (not required for submission), this journal's style is available for use

17. *Supplementary material.* Supporting material that is not essential for the argument of the paper, but would nevertheless benefit the reader, can be submitted for the online edition only. Examples are more detailed descriptions of methods, extended data sets/data analysis, or additional figures (including colour), or audio or video files. The final version of a supplementary text file will be converted to a pdf and uploaded to the website as submitted if it is satisfactory, so care should be taken to clearly include title and authors and its relation to the paper which it supplements. Ensure that the supplementary material is referred to in the main text where necessary, for example as '(see supplementary material in online edition)' or '(see supplementary Figure 1 in online edition)'. Figures and Tables in the main paper and supplementary material should be numbered in different sequential series, using, for example, Fig S1, S2 etc in the supplementary material.

18. *Ethics.* If requested, authors must produce original data for inspection by the editor. Possible fraud may be referred to the authors' institutions. Studies carried out on human subjects, other than measurements in the course of their normal work activities, must have been approved by a competent ethics committee using the standards of the Helsinki Declaration of the World Medical Association http://www.wma.net/en/30publications/10policies/b3/.
The ethics committee which gave approval must be named in the paper.

19. *Funding and Conflicts of Interest.* At the time of submission of the paper a form concerning authorship and conflict of interest (available here) must be completed by the corresponding author on behalf of all co-authors. The following must be declared: contributions made by each author; contributors (if any) who are not identified as authors and their role; the role (if any) of the study sponsor, or other interested bodies, in preparing the research material, writing, reviewing or approving the submitted manuscript; the source of direct financial support for the work; any indirect sources of support including involvement of the authors in legal testimony or consultancy related to the material in the paper; any financial or other relationships with a body that could appear to influence what is in the paper, whether or not the content of the paper was discussed with that body, including any financial interest in products or companies producing products discussed in the paper. The sources of direct and indirect support must be declared in a statement for publication at the end of the paper. These interactions will not necessarily prevent publication, but must be declared. If in doubt, it is better to disclose any possible conflict of interest.

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How we work

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The publication process

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