Relative Performance of Frequency Weighting W_H and Candidates for Alternative Frequency Weightings When Used to Predict the Occurrence of Hand-Arm Vibration Induced Injuries

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1. INTRODUCTION

Exposure to hand-arm vibration is usually assessed according to International Standard ISO 5349-1:2001, which defines an evaluation procedure using the W_h frequency weighting. In September 2008, members of the Hand-transmitted vibration working group (WG 3) of ISO technical committee ISO/TC 108/SC 4 Human Exposure to Mechanical Vibration and Shock agreed that there is a case to consider frequency weightings in addition to, or in place of, the existing W_h frequency weighting defined in ISO 5349-1:2001. However, the evidence to support specific alternative weightings is currently limited.

Different methods of determining cumulative vibration dose using the alternative frequency weightings have been investigated and compared to the development of sensorineural and vascular hand-arm vibration (HAV) injury. The comparison is based on a large historical database of measured HAV spectra from a wide range of industrial machines, and a database of exposure history and injury from subjects attending the Health and Safety Laboratory's (HSL's) referral centre.

2. FREQUENCY WEIGHTINGS

The ISO/TC 108/SC 4/WG 3 candidate frequency weightings are:

- W_h: ISO 5349-1:2001 frequency weighting
- W_{hbl}: Band-limiting component of Wh (5-1200Hz)
- W_{hT}: weighting based on work by Tominaga (2005) which suggested a better relationship for vascular injury
- W_{hf}: Finger-weighting, based on power absorption model by Dong *et al* (2008)

The following weightings have also been considered:

- W_{h50hp}: Based on German guidance: VDI 2057 part 2, where the component of Wh above 50Hz is used as indicator of increased risk of vascular and neurological injury
- W_{h50lp}: Also based on German guidance: VDI 2057 part 2, where the component of Wh below 50Hz is used as indicator of increased risk of musculoskeletal injury
- W_{h100lp}: Wh low-pass filtered at 100Hz
- W_{h200lp}: Wh low-pass filtered at 200Hz
- W_{h500lp}: Wh low-pass filtered at 500Hz

All the frequency weightings are illustrated in Figure 1.

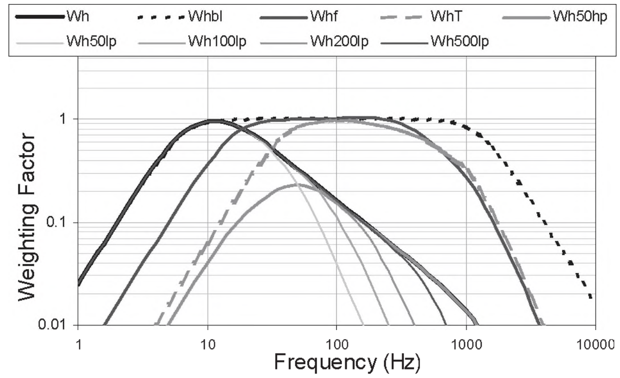

Figure 1. Candidate frequency weightings.

3. WEIGHTED MAGNITUDES

Acceleration spectra from the HSL HAV database were analysed to give weighted values for each of the alternative frequency weightings. The frequency-weighted values (a_x where x represents the weighting W_x) were then plotted against one-another and simple regression analysis performed to see if frequency-weightings are different.

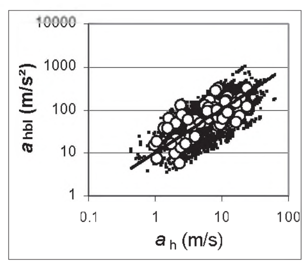

Figure 2a. a_{hbl} vs a_h

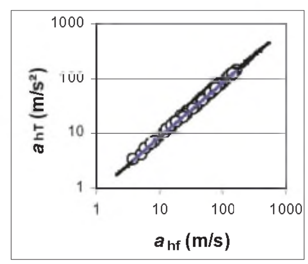

Figure 2b. a_{hf} vs a_{hT}

Two extreme situations are illustrated in Figure 2 for individual data (dots) and data grouped by machine category (circles). The coefficients of determination, R^2, for Figure 2a are low; for Figure 2b, they are very close to 1. Figure 2b shows that W_{hf} and W_{hT} are very closely related, as are pairs such as W_h and W_{h100lp}. The relationships between such weightings are probably too close for them to be considered separately in further analysis.

Table 1. Frequency-weighting group representatives.

Original weightings	W_h	W_{h500lp}	W_{h200lp}	W_{h100lp}	W_{hbl}	W_{hf}	W_{hT}	W_{h50lp}	W_{h50hp}
Group representative	W_h				W_{hbl}	W_{hf}		W_{h50lp}	W_{h50hp}

Table 1 shows how, based on the analysis of R^2 values, the alternative frequency weightings can be represented by just five weightings: W_h, W_{hbl}, W_{hf}, W_{h50lp} and W_{h50hp}.

4. LIFETIME VIBRATION DOSE

HSL's Hand Arm Vibration Syndrome (HAVS) referral centre collects data on diagnosis of HAVS and the history of symptoms. Information is also collected against 34 machine categories on daily and lifetime usage. These data, along with typical vibration magnitude values derived from the HSL HAV database, allows estimates of lifetime vibration dose to be made using different frequency weightings.

Statistical analyses have been carried out to investigate the relative strengths of vibration dose measures in the form: dose = $\Sigma a_{xi}^{m} t_i$ where, for machine category i, t_i is lifetime exposure duration and a_{xi} is the acceleration magnitude evaluated using frequency weighting x. The power m is given the value 0, 1, 2 or 4.

Table 2. Prevalence of vibration injury.

Diagnosed	HAVS	Vascular	Sensorineural
No	157 (41%)	250 (66%)	164 (43%)
Yes	224 (59%)	131 (34%)	217 (57%)

The analyses have looked for correlations between lifetime exposures (up to time of first symptoms) and three hand-arm vibration injury groups: those with any form of HAVS, those with vascular HAVS and those with sensorineural HAVS. Table 2 summarises the numbers diagnosed (and prevalence) within the referral population of 381.

5. RESULTS

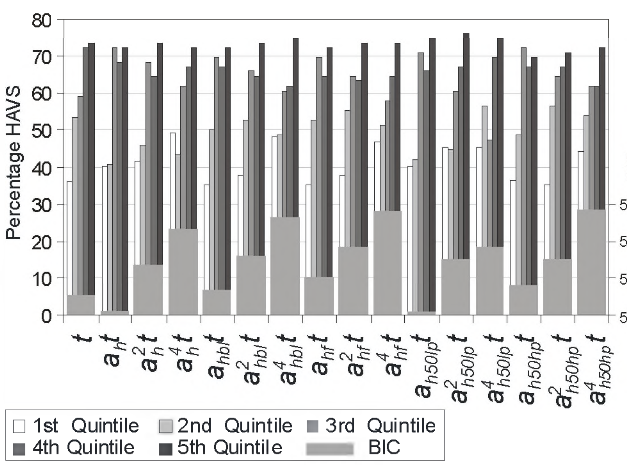

Figure 3. Prevalence of HAVS by vibration magnitude quintiles and BIC values for candidate weightings.

The vibration doses of the referral subjects have been divided into quintiles and the prevalence of injury in each quintile determined. Figure 3 shows the resultant relationships for the prevalence for any form of HAVS. In these analyses increasing prevalence with percentile suggests a useful dose measure. Also shown in Figure 3 are values for the Bayesian Information Criterion (BIC), used to assess the strength of the alternative dose measures. Lower BIC values suggest stronger dose measures; differences between BIC values of less than two suggest weak evidence for favouring one relationship above another; differences greater than 10 suggest very strong evidence.

Results similar to those shown in Figure 3 for any form of HAVS are also seen for sensorineural injury (this is probably due to the large overlap in the two populations, see Table 2). For vascular injury the quintile relationships appear generally weak and the BIC was unable to discriminate between most of the dose measures.

6. DISCUSSION AND CONCLUSIONS

A database for vibration injury and associated self-reporting of vibration exposure histories has been analysed to estimate values for lifetime vibration dose based on five different frequency weightings. Comparison of the dose measures using BIC suggests that values based on the first power of the two weightings W_h and W_{h50lp} provide the strongest indicators for both developing any form of HAVS and for developing sensorineural HAVS. For vascular HAVS no clear evidence to support individual dose measures could be shown.

Visual inspection of the quintile data can appear to support other relationships (e.g. $a^4_{hf}\,t$ in Figure 3), however, these are not supported by the BIC values. This is believed to be due to uncertainties associated with individual quintile data.

The HSL data is based on 381 referral subjects who, in many cases, have reported the use of a wide variety of machines. Further work is being considered to refine the statistical analyses, for example to focus on cases that have less complex exposure histories.

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