SHORT REPORT

Exposure assessment in health assessments for hand–arm vibration syndrome

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Introduction

Understanding the dose–response relationship between exposure to hand–arm vibration and the presence and severity of hand–arm vibration syndrome (HAVS) is fundamental to establishing exposure limits that protect workers. The relative importance of vibration magnitude to exposure duration and the frequency weighting that underpin established exposure limit values have come under critical scrutiny [1–4]. There are concerns whether the frequency weighting within ISO 5349 reflects the risk of harm at high frequencies and the validity of the daily vibration exposure metric A(8), crucial to risk assessment, which inherently emphasises vibration magnitude relative to exposure duration [5].

However, the nature of the dose–response relationship has a practical impact within the health assessment of exposed workers, helping to confirm that presented symptoms are likely to be vibration induced or the possible future risk of HAVS. Historically, the determination of latency (years between commencing occupational vibration exposure and presentation of first symptoms) was a parameter collected for individual HAVS cases. However, more complex descriptors of cumulative exposure can be constructed.

Any constructed exposure estimate is invariably based on employee recall, where recall uncertainty and overestimation of ‘trigger time’ are well-known phenomena.

This study investigates various HAVS dose–response relationships derived using retrospective cumulative exposure estimates based on a standardized questionnaire. These were completed as part of HAVS health assessments or cross-sectional workplace studies. It attempts to identify the most practicable and useful exposure measure that can be collected to aid in the health assessment of workers exposed to hand–arm vibration.

Background

Assessing past cumulative vibration exposure is part of assessing the risk of hand–arm vibration syndrome (HAVS) in workers exposed to hand–arm vibration and invariably forms part of a medical assessment of such workers.

Aims

To investigate the strength of relationships between the presence and severity of HAVS and different cumulative exposure metrics obtained from a self-reporting questionnaire.

Methods

Cumulative exposure metrics were constructed from a tool-based questionnaire applied in a group of HAVS referrals and workplace field studies. These metrics included simple years of vibration exposure, cumulative total hours of all tool use and differing combinations of acceleration magnitudes for specific tools and their daily use, including the current frequency-weighting method contained in ISO 5349-1:2001.

Results

Use of simple years of exposure is a weak predictor of HAVS or its increasing severity. The calculation of cumulative hours across all vibrating tools used is a more powerful predictor. More complex calculations based on involving likely acceleration data for specific classes of tools, either frequency weighted or not, did not offer a clear further advantage in this dataset. This may be due to the uncertainty associated with workers’ recall of their past tool usage or the variability between tools in the magnitude of their vibration emission.

Conclusions

Assessing years of exposure or ‘latency’ in a worker should be replaced by cumulative hours of tool use. This can be readily obtained using a tool-pictogram-based self-reporting questionnaire and a simple spreadsheet calculation.

Key words

Exposure assessment; HAVS; health assessment.
Methods

A standardized tool-pictogram exposure questionnaire has been used for recent Health and Safety Laboratory (HSL) research studies and workers referred for a tier five health assessment as described in current Health & Safety Executive (HSE) guidance [5]. Workers complete the questionnaire, giving estimates of their average exposure on a daily and yearly basis to any of ~40 categories of commonly used vibrating tools, described both by text and line drawing.

Typical vibration magnitudes for tools, both unweighted and weighted (ISO 5349-1:2001), are available from an HSL database based on measurement in real or simulated work activities. We employed dose estimates that have been used in other research studies investigating dose-response models [1,3], including simple time from commencing exposure to first symptoms (i.e. latency) or questionnaire completion date for unaffected workers and a generic life time exposure model for each individual calculated by summing the exposure for all tools used: \( \sum_{i} a_{i} t_{i} \), where \( m = 0,1,2 \) and where \( a_{i} \) is either the mean weighted, according to ISO 5349-1:2001, or unweighted acceleration magnitude for each tool.

### Table 1. Table showing statistical outcomes from logistic regression analyses, adjusted for age

<table>
<thead>
<tr>
<th>Dose definition</th>
<th>Vascular HAVS (yes/no)</th>
<th>Neurosensory HAVS (yes/no)</th>
<th>Vascular staging (0V–3V)</th>
<th>SN staging (0Sn–3Sn)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Years of exposure, ( t ) (years)</td>
<td>LR 34.1 BIC 328.6 HL 0.39 AUC 0.76</td>
<td>LR 48.1 BIC 341.7 HL 0.16 # AUC 0.77</td>
<td>LR 4.5 BIC 539.1 HL 0.36 AUC 0.77</td>
<td>LR 22.0 BIC 560.7</td>
</tr>
<tr>
<td>Tool hours, ( \sum_{i} t_{i} ) (hours)</td>
<td>LR 6.8 BIC 355.9 HL 0.53 AUC 0.67</td>
<td>LR 31.6 BIC 358.1 HL 0.79 AUC 0.73</td>
<td>LR 21.6 BIC 522.0 HL 0.48 AUC 0.72</td>
<td>LR 47.1 BIC 535.6</td>
</tr>
<tr>
<td>Weighted acceleration, ( m = 1, \sum_{i} a_{i}^{w</td>
<td>t</td>
<td>} t_{i} ) (hours)</td>
<td>LR 8.2 BIC 354.5 HL 0.48 AUC 0.68</td>
<td>LR 35.7 BIC 354.1 HL 0.49 AUC 0.74</td>
</tr>
<tr>
<td>Unweighted acceleration, ( m = 1, \sum_{i} a_{i} t_{i} ) (hours)</td>
<td>LR 8.1 BIC 354.6 HL 0.79 AUC 0.68</td>
<td>LR 26.5 BIC 363.3 HL 0.41 AUC 0.72</td>
<td>LR 21.6 BIC 522.0 HL 0.41 AUC 0.72</td>
<td>LR 47.1 BIC 535.6</td>
</tr>
<tr>
<td>AUC 0.72</td>
<td>LR 16.8 BIC 526.9</td>
<td>LR 52.0 BIC 530.7</td>
<td>LR 21.6 BIC 522.0 HL 0.41 AUC 0.72</td>
<td>LR 47.1 BIC 535.6</td>
</tr>
<tr>
<td>Weighted acceleration, ( m = 2, \sum_{i} a_{i}^{w</td>
<td>t</td>
<td>} t_{i} ) (hours)</td>
<td>LR 0.1 BIC 356.6 HL 0.83 AUC 0.67</td>
<td>LR 28.2 BIC 361.6 HL 0.78 AUC 0.72</td>
</tr>
<tr>
<td>Unweighted acceleration, ( m = 2, \sum_{i} a_{i} t_{i} ) (hours)</td>
<td>LR7.3 BIC 355.4 HL 0.36 AUC 0.67</td>
<td>LR 34.5 BIC 355.3 HL 0.41 AUC 0.72</td>
<td>LR 20.4 BIC 523.2 HL 0.41 AUC 0.72</td>
<td>LR 48.9 BIC 533.9</td>
</tr>
</tbody>
</table>

Likelihood ratios refer to likelihood ratio statistic (highest likelihood ratio preferred); BIC refers to BIC (lowest BIC preferred) and HL refers to Hosmer-Lemeshow statistic P-value (non-significance indicates good fit). # Indicates H-L test is unreliable. AUC refers to the area under the receiver operating characteristic curve and provides a measure of the prediction ability of the logistic model. There was no evidence of overly influential observations within the data. There were 263 workers common to each outcome analysis and a further 12 individuals that were included in one or more outcome analysis.

HAVS outcomes from referrals to HSL used the physician’s assessment of their Stockholm workshop stage [5–7]. For those workers completing the exposure questionnaire as part of a field study, negative responses to a number of standard HAVS screening questions [8] were used to identify those subjects as non-HAVS cases (0Sn/0V Stockholm Workshop scale).

Dose–response relationships were developed using the presence or not of vascular and neurosensory HAVS and the Stockholm Workshop stage. Logistic regressions were completed on these HAVS outcomes for the various dose calculations, after adjusting for age, using quintiles of dose (except for vascular staging where tertiles were used due to otherwise small cell counts). Models were compared using Likelihood ratios, Bayesian Information criterion (BIC) and Hosmer-Lemeshow (HL) statistics for goodness of fit. Plots of residuals against leverages were examined for influential observation. Statistical analyses were performed using StataSE 11.

Participants gave informed consent, with ethics approval via the HSE Research Ethics Committee. Data were analysed on those workers where estimates of mean accelerations both weighted and unweighted frequency were available for all vibrating tools used, where the
questionnaire had been completed and they had a Stockholm workshop staging as described above. Workers were employed in construction, road working, gardening, motor vehicle repair and foundries.

Results

For the dichotomous outcomes, i.e. vascular and neurosensory HAVS yes or no, a non-linear relationship between outcome prevalence by quintiles of $t$ (years) was noted, and goodness-of-fit tests (H-L) for the neurosensory component was unreliable (Table 1), making it difficult to determine the appropriateness of the model. For all other dose estimates, no single calculation appeared significantly superior to the others.

For the dose–response models using the Stockholm Workshop staging as outcomes, the use of simple time dependency (years of exposure) as the exposure metric gave the poorest model, with lower likelihood ratios and higher BICs. There was no exposure term within the general formula $\sum a_i t_i$, where $m = 0,1,2$; frequency weighted or unweighted that was clearly constantly better in modelling the ordered Stockholm Workshop stages (0Sn–3Sn; 0V–3V).

Discussion

Our study found that using simple years of exposure was a weak predictor of HAVS or its increasing severity. The calculation of cumulative hours across all vibrating tools used was a more powerful predictor.

Like many recent studies investigating HAV dose–response relationships, our study was cross-sectional [1,2], using retrospective exposure history constructions based on worker recall. The significant element of uncertainty associated with this method may obscure identification of the best exposure–response relationship. Other factors such as tool maintenance schedules, training and experience of operatives may also influence the uncertainty between self-reported duration of exposure and risk of HAVS.

Some of the published data have suggested that the frequency weighting [1,3] and emphasis on the relative importance of vibration amplitude rather than duration of vibrating tool use [1] are not warranted, although currently they underpin current exposure standards. It is likely that further studies, especially prospective ones [3], will be needed to identify the best exposure metric to identify the risk of HAVS and its increasing severity.

Our data suggests that, while some consideration of past vibration exposure is a necessary element of any health assessment, the most pragmatic solution is to calculate a worker’s cumulative exposure to all vibrating tools. A simple spreadsheet can automatically calculate the cumulative exposure time from our tool-pictogram questionnaire. Any increase in exposure complexity by including estimates of tool emissions appears unwarranted in terms of better information within the context of health assessment. The historical calculation of latency in years, using the admittedly two simple questions of ‘when did you start using vibrating tools’ and ‘when did symptoms first appear’ (for HAVS cases) or date of assessment in non-cases, is less informative.

Key points

- Simple years of exposure appears a weak predictor of hand–arm vibration syndrome or its increasing severity, the calculation of cumulative hours across all vibrating tools used was a more powerful predictor.
- Incorporating mean tool emission data, weighted or unweighted, within the cumulative exposure assessment did not increase its power to predict HAVS or its likely severity.

Funding

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Conflicts of interest

None declared

References