LONGITUDINAL STUDY OF SUOMUSSALMI FORESTRY WORKERS II - VIBRATION EXPOSURE

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1. INTRODUCTION

A thirteen-year prospective study has been conducted of an open cohort of forestry workers, all of whom operate the same model, low-vibration power tools in the Suomussalmi region of Finland. During the course of the study, the work practices changed. Mechanized tree harvesting was introduced, and brush cutters replaced chain saws for much of the manual work. The change resulted in a reduction in vibration exposure. The purpose of this work is to reconstruct the current vibration exposure using either the ISO frequency weighting, or an unweighted bandpass filter (ISO 5349-1:2001).

In this paper, methods are described for recording the vibration at the hands, which provide an estimate of the annual exposure when combined with the work history obtained from workers by questionnaire. Changes in vibrotactile perception thresholds observed at the fingertips of these workers are reported in a companion paper at this conference.

2. APPARATUS AND METHOD

2.1. Apparatus

Vibration Exposure Data Logger

Day-long vibration exposures at the hands of workers during normal forestry operations were monitored using a compact, custom-built, data-logger based system. The device was designed to collect samples from three analog channels and record: single axis, broadband (4 - 1250 Hz, frequency "unweighted"), and ISO frequency-weighted accelerations (ISO 5349-1:2001) at the palm of the hand, and; the contact force between the hand and the tool handle (Peterson et al., 2008). The sensors were mounted on the palm using a custom-designed housing, which was positioned with elastic straps. The activation axis of both sensors was perpendicular to the skin surface. The signals from the accelerometer (PCB model 352C22) and force sensitive resistor (Interlink Electronics, model 400) were conditioned by custom-designed analog circuits. The circuits filtered the accelerometer signal (ISO and band pass filters) and force signal (1250 Hz low pass filter), and interfaced with the commercial data logger (Onset Computer, Tattletale model 8v2). The three signals were digitized (12-bit), processed and stored.

Field Measurement of Vibration at Tool Handles

A backpack mounted measurement system was used to record the component accelerations of power tool handle vibration, and the force with which the hand held the tool handle. The measurement system consisted of six, single-axis shock accelerometers (PCB model 350B23), three of which were mounted orthogonally on each tool handle. The accelerometers were attached to the handles by hose clamps. Force sensors (Tekscan, *FlexiForce*) were attached to the palm of each hand near the MCP joint. The analog signals were amplified and digitized by a 12-bit signal conditioning system (IO-Tech WaveBook 512 / WBK 14), and the 8-channel output was multiplexed and streamed to the hard drive of a portable computer. Analysis of the waveforms was performed subsequently in the laboratory.

2.2. Methods

Before the vibration exposure data logger was attached to the hand of a subject, the performance of the accelerometer and conditioning electronics was checked. The force sensor was calibrated after attaching the sensor housing to the hand, by squeezing the handle of a modified grip dynamometer to produce preset forces. When work commenced, the data logger was set into the "run" mode, whereupon the root mean square (RMS) accelerations (frequency weighted and unweighted), and contact force were calculated every 60 s and stored.

The backpack mounted measurement system required a portable generator for field operation. The generator and measurement system were first positioned so that a forest worker wearing the backpack could perform a complete set of operations on one tree, or small area of underbrush. Each recording consisted of a set of operations that lasted for up to about 90 s, and included machine idling as the worker moved into position to perform different tasks within the operation. The mean component accelerations and vector acceleration sums (VASs) were calculated for each record.

2.3. Subjects

The equipment operators were professional forestry workers. Their participation in the study was voluntary, and they gave their informed consent. The study protocol was approved by the ethics committees of the participating organizations.

Table 1. Mean (±SD) Eight-Hour Energy Equivalent z_h-Component RMS Accelerations ($m.s^{-2}$)

Tool	Frequency Weighting	
	ISO	4-1250 Hz
BC	1.5±0.3	5.5±0.7
CS	3.1±0.8	10.9±3.6

3. RESULTS

The exposures of four forest workers brush cutting, and another four workers tree harvesting, are given in Table 1. The exposures are reported as 8-hour energy equivalent RMS accelerations for the component directed into the palm (approximately the z_h-axis of ISO 5349-1:2001). All exposures include break times and the exposure occurring after the engine was started and the operator walked through the underbrush and around trees with the engine idling. The results are shown for two frequency weightings: the weighting recommended by ISO 5349-1:2001, and an un-weighted frequency band from 4 to 1250 Hz. On average, the workers operated the brush cutter (BC) for 5.5 hours/day, and the chain saw (CS) for 5.8 hours/day. When expressed as an 8-hour energy equivalent RMS acceleration, it can be seen from Table 1 that the exposure of chain saw operators appears to be approximately twice that of brush cutter operators.

VASs for the chain saw and brush cutter were constructed from the backpack recorded time histories of the component accelerations at the tool handles. The results are expressed in Table 2 as the ratio of accelerations recorded separately at the handles held by the left and right hands, and assume that the z_h-component acceleration is closest to that monitored during data logging.

Estimates of the days per week, and months per year, the workers operated either a brush cutter or chain saw were obtained from the questionnaires completed by the men whose vibrotactile thresholds are described in the companion paper. In total, the men worked, on average (±SD), 105±12.5 days per year operating brush cutters and 72±37 days per year operating chain saws.

Table 2. Ratios of Component Accelerations and Vector Acceleration Sum to z_h-Component Acceleration

Tool & Hand	Acceleration Ratio		
	x_h/z_h	y_h/z_h	VAS/z_h
BC - L	0.87	1.31	1.86
BC - R	1.20	1.40	2.10
CS - L	0.85	0.95	1.62
CS - R	1.23	0.84	1.79

4. DISCUSSION

An estimate of the exposure for workers who operate only a brush cutter, or chain saw, throughout the year can be constructed from Table 1 if the data are converted to VASs. This has been done using the mean values of the accelerations ratios in Table 2. The daily 8-hour energy-equivalent VASs are labeled 100% BC and 100% CS in Table 3, and are shown for the two frequency "weightings". However, it has been established by questionnaire that the men operated either a chain saw or a brush cutter, and worked for at least a week before changing tools. Guidance for analyzing such exposures can be obtained by extending Annex B of ISO 5349-2 to a partial year's work, by energy averaging. The result is listed in Table 3 as 29% BC + 20% CS, where the percentages represent the number of days per year worked with each power tool. This last estimate is believed to represent best the workers' exposure. It is instructive to note that ISO 5349-1:2001 predicts a 10% group prevalence of finger blanching after about 11 years for this exposure. Since all our workers have been exposed to vibration for in excess of thirteen years, we would expect there to be vibration-induced white finger in the group. In fact, the prevalence of finger blanching at study inception was 5%. At follow up four years after the change in work practices, the prevalence of numbness was 29% and there were no new cases of finger blanching. The companion paper found little change in vibrotactile perception, suggesting the ISO procedure may slightly overestimate the health risk from the exposure constructed as described here.

Table 3. Estimated Exposure Expressed as 8-Hour Energy-Equivalent Vector Acceleration Sum ($m.s^{-2}$)

Exposure	Frequency Weighting	
Assumption	ISO	4-1250 Hz
100% BC	3.0	11.0
100% CS	5.3	18.7
29%BC+20%CS	2.9	10.2

REFERENCES

Peterson, D. R., Brammer, A. J., and Cherniack, M. G. (2008). "Exposure monitoring system for day-long vibration and grip force measurements," Int. J. Industr. Ergonomics, **38**, 676-686.

ISO 5349-1. (2001). *Mechanical Vibration - Measurement and Evaluation of Human Exposure to Hand-Transmitted Vibration - Part 1: General Guidelines* (International Organization for Standardization, Geneva).

ISO 5349-2. (2001). *Mechanical Vibration - Measurement and Evaluation of Human Exposure to Hand-Transmitted Vibration - Part 2: Practical Guidance for Measurement at the Workplace* (International Organization for Standardization, Geneva).

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