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TWELFTH INTERNATIONAL CONFERENCE ON HAND-ARM VIBRATION

13 – 17 JUNE, 2011 OTTAWA, CANADA

Scientific Organizing Committee

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13 – 17 June, 2011 Ottawa, Canada

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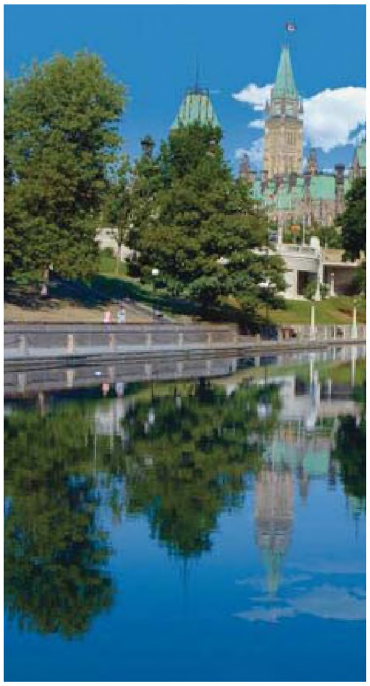

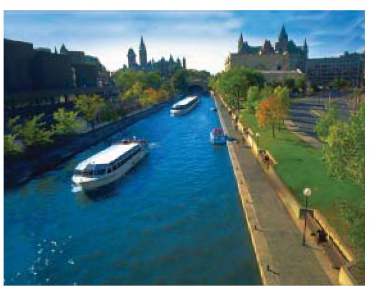

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EDITORIAL

"Exposure of the hand to vibration, leading to 'white fingers' and 'dead hand' is rapidly becoming recognized as an important occupational health hazard. It commonly occurs in industries that are essential to the economies of developing and industrialized countries - mining, forestry, metal working and others in which hand-held power tools, such as pneumatic hammers, chain saws and grinders, are used. Methods for quantifying exposures and their effects on man are still being developed. The mechanisms whereby vibration affects the nerves, blood vessels, and musculo-skeletal system are still being explored. As a result, there is no generally accepted limit for exposure, nor method for assessing impairment."*

These words were written thirty years ago in the Preface to the Proceedings when this conference was first held in Ottawa. Many of them are still applicable today.

Now, the International Conference on Hand-Arm Vibration comes to Canada for a second time. We acknowledge this by our logo of a hand pierced by 'vibration', which adorned the cover of the 1982 Proceedings book. While, unfortunately, a lack of recognition of the health hazard persists, exposure limits have been introduced in some jurisdictions and procedures for identifying affected persons have been refined. A series of international standards has been promulgated to codify methods for measuring and assessing exposure, for testing for symptoms of disease, and for characterizing the response of the hand and arm to vibration. A procedure to evaluate the potential for gloves to reduce vibration has also been developed. Overall, progress in knowledge building has been impressive, but less so in knowledge uptake.

The 12th International Conference on Hand-Arm Vibration attempts to build on this solid foundation, and to supplement it with a concerted effort to improve outreach and to contribute to knowledge implementation. To achieve this, the papers in this volume are augmented by a half-day Round Table on strategies for medical surveillance, a full-day Workshop on the most contentious issue (frequency weighting), and brainstorming on ways to encourage knowledge uptake by stakeholders. We invite you to attend.

Anthony J. Brammer and Marilyn J. Eaman

*Extract from the Preface to Vibration Effects on the Hand and Arm in Industry, edited by A.J. Brammer and W. Taylor (John Wiley & Sons, New York, 1982).

« L'exposition de la main aux vibrations menant aux 'doigts blancs' et à la 'main morte' devient rapidement reconnue comme étant un risque important de santé au travail. Il se produit généralement dans des secteurs d'activité qui sont essentiels à l'économie des pays en développement et des pays industrialisés – les mines, la forêt, la transformation du métal et d'autres secteurs dans lesquels des outils tenus par la main, tels que les marteaux pneumatiques, les tronçonneuses et les rectifieuses, sont utilisés. Des méthodes pour mesurer l'exposition et leurs effets sur l'homme sont toujours en cours de développement. Les mécanismes par lesquels la vibration affecte les nerfs, des vaisseaux sanguins, et le système musculo-squelettique sont toujours en train d'être explorés. En conséquence, il n'y a aucune limite courante pour l'exposition, ni méthode pour évaluer les atteintes à la santé. »*

Ces mots ont été écrits il y a trente ans dans la préface des actes de la conférence quand elle a été tenue pour la première fois à Ottawa. Bon nombre d'entre eux s'appliquent encore aujourd'hui.

Maintenant, la Conférence internationale sur les vibrations main-bras vient à Canada pour la deuxième fois. Nous reconnaissons ceci par notre logo d'une main percée par une 'vibration', qui a orné la couverture du livre des actes de 1982. Même si, malheureusement, un manque de reconnaissance du risque sanitaire persiste, des limites d'exposition ont été présentées dans quelques juridictions et des procédures pour identifier les personnes affectées ont été raffinées. Une série de normes internationales a été promulguée pour codifier des méthodes pour mesurer et évaluer l'exposition, pour déterminer des symptômes de la maladie, et pour caractériser la réponse de la main et du bras aux vibrations. Une procédure pour évaluer le potentiel de gants pour réduire les vibrations a été également élaborée. De façon générale, le progrès dans le développement des connaissances a été impressionnant, mais moins dans le transfert des connaissances.

La 12e Conférence internationale sur la vibration main-bras essaye de construire sur ces fondations solides, et de les compléter avec un effort concerté d'améliorer le transfert et de contribuer à l'application des connaissances. Pour réaliser ceci, les articles dans ce volume sont augmentés par une table ronde d'une demi-journée sur des stratégies pour la surveillance médicale, d'un atelier d'un jour complet sur la question la plus controversée (la pondération en fréquence), et de réflexions sur des manières d'encourager le transfert de ces connaissances aux intervenants œuvrant en santé et en sécurité du travail. Nous vous invitons à y être présent.

Anthony J. Brammer et Marilyn J. Eaman

*Extrait de la préface de Vibration Effects on the Hand and Arm in Industry, édité par A.J. Brammer et W. Taylor (John Wiley & Sons, New York, 1982).

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ASSESSING IMPACT-TOOL VIBRATION DAMAGE OF TISSUES IN A RAT-TAIL MODEL

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1. INTRODUCTION

The risk of Hand Arm Vibration Syndrome (HAVS) has been linked to years of using vibrating powered tools with dominant frequencies in the 30-250 Hz range. The current International Standard ISO 5349 defines vibration risk exposure in the workplace based on frequency-weighted acceleration which diminishes risk for frequencies above 16 Hz. Impact tools, like riveting and chipping hammers, deliver shock waves with kHz frequency power superimposed on the 30 to 90 Hz duty cycles [1]. The high frequency content of the shock waves is nullified by frequency weighting, but are these shock waves harmful? McKenna etal. reported that the worker holding the metal bucking bar against the rivet is 4 times more likely to develop vibration white finger than the worker operating the rivet gun [2]. This suggests that tissue damage is occurring because the hands of the bucking bar worker are exposed to transmitted shock wave vibration. Previously, we developed a rat-tail vibration injury model to test the effects of sinusoidal vibration in the 30 to 800 Hz range [3]. The sinusoidal vibration was delivered by a B&K 4809 motor. In the present study, an Atlas Copco riveting hammer (RRH04P) accelerated a fan-shaped, steel tool bit that served as the vibration platform (Fig. 1). The rat tail is taped to the impact platform to model the worker's hand in contact with the bucking bar. We predicted that the degree of functional and structure damage following shock wave vibration would be much greater than that generated by the lower frequency content of sinusoidal acceleration.

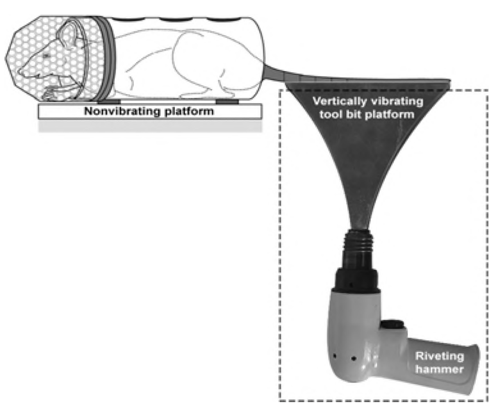

Figure 1. Rat-tail impact vibration model. The tail is taped to the fan-shaped, steel tool bit to simulate vibration from a bucking bar. The bit is accelerated vertically by the riveting hammer enclosed within a sound dampening box (dotted line).

2. METHODS

Male Sprague-Dawley rats (275-300 g) were divided into 4 groups (n=8/group): 1) impact vibration immediate (0-day recovery), 2) vibration 4-day recovery, 3) immediate sham control and 4) 4-day sham control. These procedures were approved by the Institutional Animal Care and Use Committee of the Medical College of Wisconsin.

Awake rats were restrained in tubes mounted to a non-vibrating platform, and the tail was taped to the riveting hammer tool bit (Figure 1). The riveting hammer was activated by 20 psi air, and the duty cycle was 33 Hz. Vibration exposure was 12 minutes continuous to simulate an intense period of using a bucking bar. The sham control rats were restrained in tubes, and the tails were taped to nonvibrating platforms. After vibration, the immediate 0 day groups were tail flick tested by measuring the tail withdrawal response time to noxious heat exposure. The rats were then deeply anesthetized and euthanized. The ventral nerve trunks and proximal tail skin were removed and processed for light and electron microscopy. The innervation of the skin was visualized by PGP9.5 immunoreactivity. Mast cells were stained with avidin-fluorophore conjugate.

The 4-day recovery, vibrated rats and the sham controls were returned to their cages. Tail flick testing was performed on days 2 and 4. On day 4, the recovery rats were euthanized, and the tail tissues were processed as described for the immediate groups. Tail flick responses were compared by a two-way repeated measures analysis of variance for treatment times day. Significance was accepted at $p < 0.05$.

3. RESULTS

Tail flick response times, measured before vibration treatment, were similar for the vibration and sham groups. Tail flick times for the vibration immediate rats were 34% shorter than the pre-vibration values ($p < 0.01$). The sham controls were unchanged from the pre-vibration values. By day 4 of recovery, the vibration groups exhibited a 32% prolongation of tail flick withdrawal time ($p < 0.001$).

Electron microscopy of the nerve trunks revealed the presence of axons with disrupted myelin in the immediate and 4-day vibration recovery groups (Figure 2). Evidence for loss of myelinated and nonmyelinated axons was not observed in the vibrated groups.

Figure 2. Vibration causes myelin delamination (arrows). White bar equals 1 micron for both panels.

Compared to the sham control, the terminal nerve fibers revealed by PGP9.5 immunoreactivity in the dermis of the skin were fragmented immediately and 4 days after vibration (Figure 3).

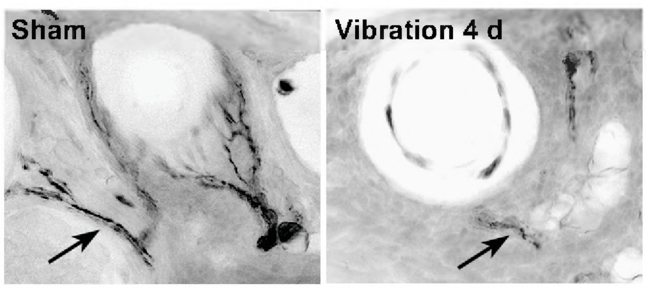

Figure 3. Intact PGP9.5 immunoreactive nerve fibers (left arrow) in the dermis of the sham. Vibration causes fragmentation and loss of nerve fibers (right arrow).

Mast cells are numerous in the dermis of the skin. Degranulation of mast cells was uncommon in the sham. Immediately after vibration (0 d), mast cell degranulation was pronounced (Figure 4). By 4 days, mast cell degranulation was similar to that in the sham control.

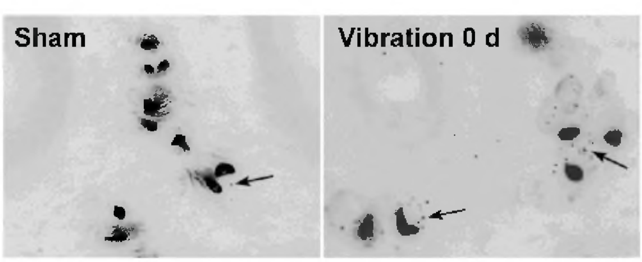

Figure 4. Mast cells in the dermis of the Sham exhibit occasional secretory granules (arrow). Immediately following vibration (0 d), many mast cells have released secretory granules (arrows).

4. DISCUSSION AND CONCLUSIONS

Exposure of the rat tail to a single period of impact shock vibration produces profound changes in the function and structure of the innervation. Immediately after vibration, the tail skin is hyper sensitive to noxious heat stimulation. By 4 days after vibration, the prolonged response to heat shows hypo sensitivity. The shift from hyper to hypo sensitivity does not correlate with the occurrence of axons with disrupted myelin in the nerve trunks. There is also no loss of axons in the nerve trunks to explain the altered responses to noxious heat. However, the fragmentation of PGP9.5 immunoreactive nerve fibers in the skin suggests that the immediate damage to nerve fibers renders them hyper sensitive to sensory stimuli. Nerve fiber hyper sensitivity is exacerbated by mast cell secretion of histamine and other inflammatory factors [4]. By 4 days, the damaged nerve fibers appear as discontinuous clumps, indicating necrosis and phagocytosis. The loss of terminal nerve fibers accounts for the hypo sensitivity to heat stimulation.

The intact parent axons in the nerve trunks can regenerate nerve endings. Regeneration was observed at 2 weeks after shock wave damage of skin with a lithotripsy machine [5]. Failed regeneration from repeated vibration injury may explain the persistent neuropathy in HAVS.

Further studies are necessary to determine the causes of nerve damage and mast cell degranulation. The major factors are the high frequency content and high acceleration levels of the impact shock vibration. The present findings indicate that frequency weighting under-estimates the risk of nerve damage in workers using impact hand tools.

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ACKNOWLEDGEMENTS

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RECOVERY OF VASCULAR FUNCTION AFTER EXPOSURE TO A SINGLE BOUT OF VIBRATION

Kristine Krajnak[1], Stacy Waugh[1], Claud Johnson[1], Roger Miller[1], Shengqiao Li[2], and Michael Andrew[2]

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1. INTRODUCTION

Job rotation has been used to reduce worker exposure to hand-transmitted vibration and the risk of developing hand-arm vibration syndrome (HAVS). However, there are no studies indicating what the best rotation schedule is. Immediately following a single exposure to vibration, transient changes in finger blood flow (1) and shifts in vibrotactile sensitivity (2) can be measured in humans. In rats, exposure to a single bout of vibration also results in immediate changes in blood flow, transient shifts in the sensitivity of large myelinated fibers to electrical stimulation (3), and changes in vascular responsiveness to vasoconstriction agents (4). However, it is not known if there are longer-term effects of a single vibration exposure that may affect vascular or sensorineural responsiveness to subsequent exposures. The goal of this study was to use a model of vibration-induced dysfunction to determine if there are residual effects of a single exposure to vibration on peripheral vascular function, and if there are residual effects, the number of days of rest needed for vascular function to recover after a single exposure.

2. METHODS

2.1. Exposure

Male Sprague-Dawley rats [Hla:(SD) CVF rats; 6 weeks of age at arrival; Hilltop Lab Animals, Inc, Scottdale, PA;] were used in this study. Animals were maintained in an AALAC accredited vivarium under a 12:12 LD cycle(lights on 0700 h) with food and water available *ad libitum.* Rats were acclimated to the laboratory for 1 week prior to the beginning of the experiment. On the first day of the experiment, rats were restrained in Broome style restrainers. Each rat had their tail secured to a platform as previously described. Half of the rats were exposed to a single 4h bout of vibration (125 Hz, 49 m/sec^2 rms). The remaining rats served as controls. Control rats had their tails secured to a platform mounted on isolation blocks. Rats were anesthetized using pentobarbital (100 mg/kg, i.p.) and euthanized by exsanguination 1, 2 or 7 days following the exposure. All procedures were approved by the NIOSH Animal Care and Use Committee and were in compliance with CDC and NIH guidelines for the care and use of laboratory animals.

2.2. Vascular Physiology

After dissection, each ventral tail artery was mounted and pressurized (60 mmHg) in a micro-vessel chamber (Living Systems, Burlington VT). Vasoconstriction in response to the α2C-adrenoreceptor agonist UK14304 and the α1-adrenoreceptor agonist phenylephrine (PE) were assessed in separate artery segments. To assess endothelial-mediated vasodilation, phenylephrine, constricted arteries were re-dilated with acetylcholine (ACh). All vaso-modulating factors were added in half-log increments and the internal diameter of the artery was measured after each application of the drug.

2.3. Data Analyses

All data are expressed as a percent change from baseline. Data were analyzed using 2-way repeated measures ANOVAs. Differences were considered significant if $p < 0.05$.

3. RESULTS

One day following exposure to vibration, vasoconstriction in response to UK-14304 was enhanced in vibrated arteries as compared to controls (Figure 1). ACh-mediated vasodilation was not different between the two groups (Figure 2).

Figure 1. One day after exposure, arteries from vibrated rats displayed increased responsiveness to UK14304-mediated constriction (* greater than vibrated arteries, p <0.05).

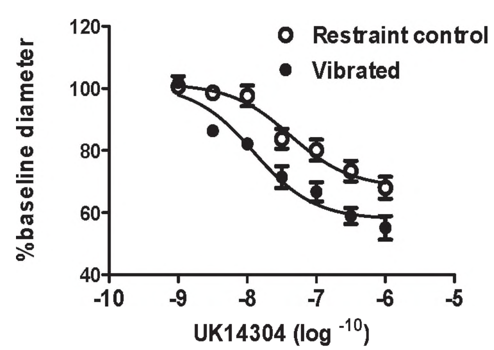
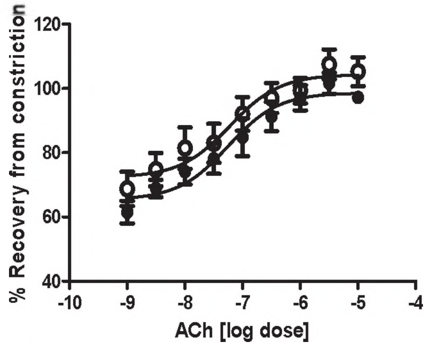
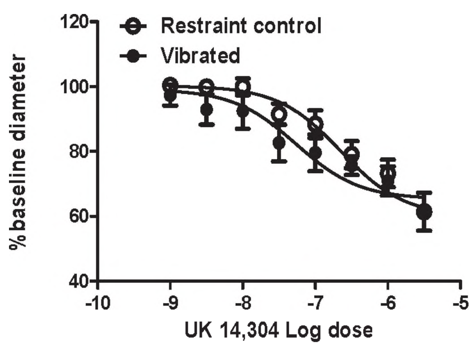


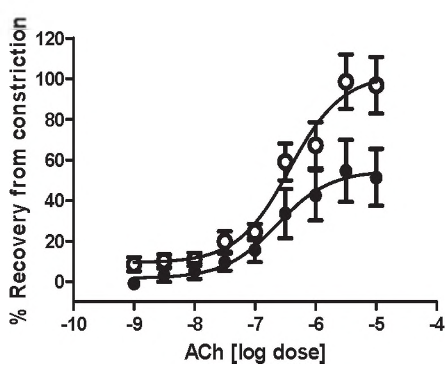
Figure 2. One day after exposure, arteries from vibrated rats displayed unaffected ACh-mediated vasodilation.



After two days of recovery, UK14304-mediated vaso-constriction had returned to control levels (Figure 3, top), but ACh-mediated vasodilation was significantly reduced in arteries collected from vibrated rats (Figure 3, bottom). Responses to vasoconstricting and vasodilating factors were back to control levels after 7 days of recovery (data not shown).

Figure 3. Two days following vibration exposure, vascular responsiveness to UK14304 was similar in control and exposed rats (Top). However, ACh-mediated vasodilation was reduced in vibrated arteries (Bottom;* greater than vibrated arteries, p <0.05).





4. DISCUSSION AND CONCLUSIONS

- Changes in adrenoreceptor-mediated vasoconstriction are apparent for the first 24 h following a single exposure to vibration.
- Endothelial-mediated vasodilation is not affected until 48 h after vibration exposure.
- Changes in responsiveness to vasoconstricting and vasodilating factors may affect vascular responses to subsequent vibration exposures.
- Vascular responsiveness returns to control levels after a 7-day recovery period.
- Additional time-points need to be assessed, but these findings suggest that it may take up to seven days for vascular function to recover after exposure to a single bout of vibration.
- The acute responses of the human peripheral vascular system to vibration are similar to the responses of rats. Thus, it is likely that finger vascular function may also be altered for at least two days following exposure to vibration.
- Work rotation schedules that allow more than two days of recovery between subsequent bouts of vibration exposure may help reduce the risk of developing the vascular dysfunction that is characteristic of HAVS.

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ANALYSIS OF SPATIAL RESONANCE IN A SMALL VESSEL TO STUDY VIBRATION-INDUCED DIGITAL VASCULAR DISORDER

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1. INTRODUCTION

Numerous construction, forest workers and miners are exposed to hand-arm vibration from tools. Prolonged exposures to hand-vibration have been identified to cause hand-arm vibration syndrome (HAVS). HAVS is a collective term, which consists of disorders of a musculoskeletal, vascular and neurological nature. But the exact pathophysiology is still unknown. One of the HAVS components is Vibration White Finger (VWF) that causes severe blanching due to loss of blood, followed by episodic and painful return of blood circulation.

A number of experimental studies performed to understand the relationship between the damage in the arterial wall and vibration (Bovenzi et al., 2006), but most of these studies are non-invasive or on various animals like rat-tail or rabbit. According to Curry et al., (2005), the ultrastructural appearance of the internal elastic membrane (IEM) was most modified by 800 Hz vibration and the pattern of damage above 800 Hz suggests that the IEM is destroyed because it resonates and absorbs vibration energy at this frequency. In this paper, the vibration response of small arteries is studied by modeling the system as an elastic tube filled with incompressible fluid embedded in an elastic foundation.

2. METHODS AND RESULTS

The blood flow through the artery is represented in Figure 1.

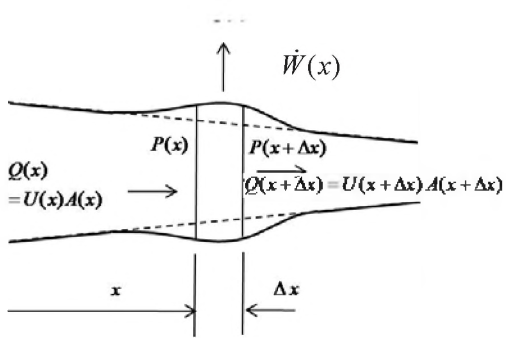

Figure 1. Schematic of flow through artery

Using the volume velocity Q(x)=U(x) A(x), where U(x) is particle velocity and W(x) is wall distension:

$$Q(x) - Q(x+\Delta x) = \dot{W}(x) 2\pi R(x) \Delta x \cong P(x) Y_w(x) \Delta x$$

$$P(x) - P(x+\Delta x) = Z_f(x) \Delta x Q(x)$$

$Y_w(x)$ is the admittance of the artery wall and Z_f (x) the impedance of the flow. They are defined as:

$$Y_w = \left(j\omega L_w + R_w + \frac{1}{j\omega C_w} \right)^{-1}, \quad Z_f(x) = \frac{j\omega\rho_f}{A(x)} \text{ where}$$

$$L_w = \frac{\phi \rho_w h}{2\pi R(x)}, R_w = \frac{r_w}{2\pi R(x)}, \frac{1}{C_w} = \frac{Eh}{2\pi R^3(x)}$$

We assume that the radius changes linearly. The equations can be represented by the circuit diagram shown in Figure 3.

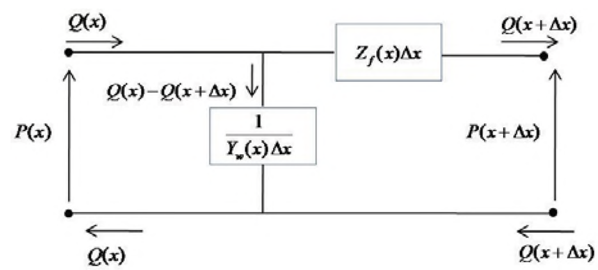

Figure 2. Equivalent Circuit for a small section of artery.

The entire artery system can be represented by a series of circuits shown in Figure 2, as it is shown in Figure 3. In the figure, $Z_{ni} = 1/Y_{ni}(x)$ is the structural impedance of ith section of the artery wall. Looking at Figure 3 and the system equations, it is recognized that the wave problem in an artery of varying diameter is represented by exactly the same equations as those of waves in the cochlea (Zweig, 1976). The cochlea is a wave guide that has fluid-structure interaction, which is comprised of the basilar membrane whose admittance varies as a function of the distance from the oval window and is loaded by the cochlea fluid. The derivation in this paper follows the work by Zweig on the motion of the cochlea in response to a sound input.

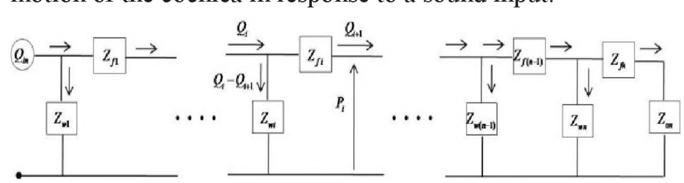

Figure 3. Long artery with linearly changing radius.

2.1. Local Resonance Frequency

As can be seen in Figure 3, segments of the artery system can be considered to be small oscillatory dynamic systems connected serially by the fluid impedance.

Therefore, it is expected that the vibration input (Q) coming from the left end will keep leaking through the circuit branch with Z_{ni}. The “resonance frequency” $\omega_r(x)$ and damping ratio $\delta(x)$ of each segment of the system are –

$$\omega_r(x) = \left(L_w C_w\right)^{-1/2}, \quad \delta(x) = \omega_r(x) R_w(x) C_w$$

These properties are functions of the axial position. The resonance frequency of the digital artery is calculated with 0.1mm thickness, 0.49 Poisson’s ratio, 15 MPa Young’s modulus and 50mm length of the vessel (Kuwabara et al., 2008; Langewouters et al., 1986). The diameter linearly increases from 0.52 mm to 1.06mm over the length of 50mm. Figure 4 shows the resonance frequency calculated as a function of the length of the vessel. The resonance frequency decreases with distance from the left end.

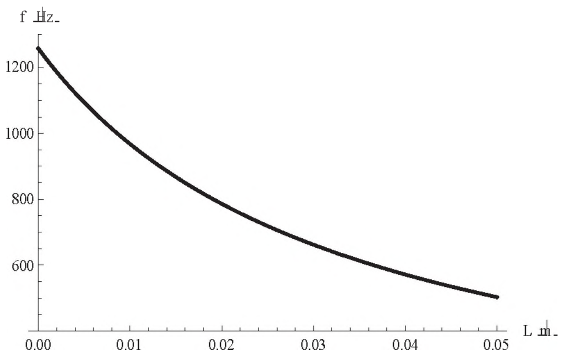

Figure 4. Resonance frequencies in Hz versus length in m.

2.2. Spatial Resonance Phenomenon

When the cochlea are subjected to sound of a given frequency, the basilar membrane vibrates with large amplitude at a particular position, and the position depends on the frequency of the sound. This is called spatial resonance (Zweig, 1976), which explains how frequency can be sensed by the ear. Because the equation of motion of the artery system is the same as that of the cochlea, the spatial resonance phenomenon is expected also in the artery system. Figure 5 shows the displacement amplitude at two different frequencies with input from smaller and larger diameter sides. A very interesting observation is that when the input is from the large diameter side, the same artery system does not show any spatial resonance. This phenomenon can be explained qualitatively by the circuit diagram shown in Figure 3. When the input is from the large diameter side, artery impedances are small in the input side. Therefore, the flow (current) through these impedances is large in the beginning. Thus the vibration energy flowing downstream decreases very quickly, making only a very small amount of the flow reach the resonance location.

3. DISCUSSIONS AND CONCLUSION

It has been shown that the frequency of local resonance of an artery whose diameter changes is a function of the axial position. The equations of motion as well as the circuit description of the motion are recognized as the same as those of the motion of the cochlea. As it is expected from the similarity with the cochlea, spatial resonance is observed, however only when the vibration input is from the small diameter (stiffer) side. It is noted that cochlea input is always from the stiffer side.

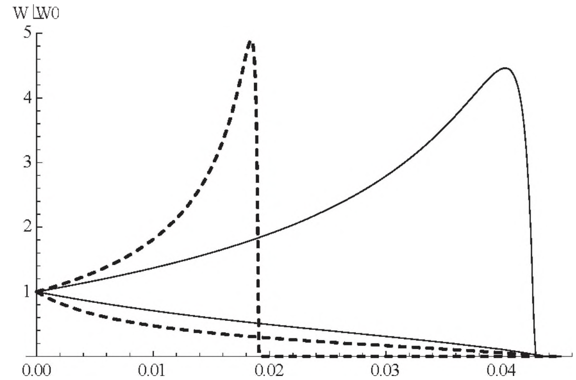

Figure 5. Displacement of the artery wall as a function of the axial distance in meters. Solid: 550 Hz, dashed: 800 Hz. Curves with peaks are when the input is from the small diameter side and curves that decrease without any peak are when the input is from the large diameter side.

This spatial resonance phenomenon may explain the pathophysiology of the circulation system disorder that causes white finger disease. If a worker uses a specific type of tool for a prolonged period, he/she will be subjected to vibration of high amplitudes with the same dominant frequency components. Therefore, the finger will be subjected to vibration of large amplitude always at same locations, which will cause hardening of the artery wall and surrounding tissue. Further work is underway to verify the behaviour at various other frequencies using bench-top tests and other equivalent models.

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FOLLOW-UP STUDY OF VASCULAR AND SENSORY FUNCTIONS IN VIBRATION-EXPOSED SHIPYARD WORKERS

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1. INTRODUCTION

Workers exposed to hand-transmitted vibration may complain of vascular and sensory disturbances in their fingers and hands, such as white finger, tingling, and numbness. Clinical and epidemiological studies have reported an association between exposure to hand-transmitted vibration and deterioration of vascular and sensory functions, but no well defined exposure-response relationship could be determined mainly because of the cross-sectional design of these studies (Bovenzi, 1998). The aim of this study was to investigate prospectively vibration induced vascular and sensory dysfunctions in shipyard workers who operated vibratory tools.

2. SUBJECTS AND METHODS

A cohort of 63 vibration-exposed shipyard workers was investigated by means of a medical interview, physical examination and laboratory methods for assessing peripheral vascular and sensory functions. Clinical and laboratory investigations were carried out at the initial survey and over a follow up period of 2 to 4 years, in connection with compulsory occupational health surveillance procedures established by Italian legislation. Thirteen subjects were lost to the follow up because of retirement (n=6) or change of job (n=7). All subjects continued to work with vibratory tools during the follow up. They wore ordinary, non-antivibration gloves. The diagnosis of vibration induced white finger (VWF) was made according to the criteria of the Stockholm Workshop '94, supplemented with administration of colour charts.

Finger systolic blood pressures (FSBP) at 10°C in a test finger as a percentage of FSBP at 30°C in the same finger, corrected for the change in FSBP at 30° and 10°C in a control finger ($FSBP\%_{10°}$), were measured by means of an *HVLab* multichannel strain-gauge plethysmograph according to the procedure recommended by the international standard ISO 14835-2 (2005).

An *HVLab* thermal aesthesiometer and an *HVLab* tactile vibrometer were used to measure hot and cold thresholds and vibrotactile thresholds, respectively. The thermal thresholds were measured before the vibrotactile thresholds. All subjects were tested by a single examiner who used the same apparatus and the same measurement protocol at both the cross-sectional and the follow up surveys. To avoid temporary loss of tactile sensation, on the day of the tests the subjects did not operate vibratory tools prior to the measurements of perception thresholds.

Thermal perception thresholds (TPT in °C) were measured at the palmar surface of the distal phalanx of digit II (innervated by the median nerve) and digit V (innervated by the ulnar nerve) of both hands using the method of limits. The thermograms (six cycles of warm and cold thresholds) were displayed on a computer screen and output to a printer. The software computed the means of the warm and cold thresholds, as well as of the neutral zone (the difference between the warm and cold thresholds), ignoring the first two cycles.

Vibrotactile perception thresholds (VPT) were measured at the fingertips of digit II and digit V of both hands using the up-and-down method of limits according to the recommendations of international standard ISO 13091-1 (2001). VPT were determined at the frequencies of 31.5 and 125 Hz to reflect the response of Meissner's corpuscles and Pacini's corpuscles, respectively. The vibrograms were displayed on a computer screen and output to a printer. The software computed the mean VPT at each frequency by averaging the peaks and troughs of the acceleration time history (six consistent vibration reversals). VPTs were expressed in decibels (dB) relative to a reference r.m.s. acceleration of 10^{-6} $m.s^{-2}$.

Vibration generated by the tools used by the shipyard workers (grinders, wrenches, drills, nut runners, and pistol-grip screwdrivers) was measured according to ISO 5349-1 (2001).

Duration of exposure to hand-transmitted vibration during a typical workday was estimated by a supervisor who used a stopwatch method. Daily vibration exposure was expressed in terms of 8-h energy-equivalent frequency-weighted acceleration ($A(8)$ in $m.s^{-2}$ r.m.s.).

The prevalence and cumulative incidence of vascular and sensory disorders were estimated by conventional epidemiological methods. The relations of vascular and sensory outcomes to measures of vibration exposure were assessed by random-intercept linear regression to account for the within-subject dependency of the observations over time. Data analysis was performed with a transition model to 'capture' the longitudinal part of the relationship between outcomes and predictor variables (Twisk, 2003).

3. RESULTS

At the initial survey, the mean (SD) age of the 50 surveyed workers was 37.5 (10.5) yr; BMI averaged 26.6 (3.8) kg.m^{-2}. Smoking and drinking habits were reported by 56% and 60% of the subjects, respectively. Daily vibration exposure did not differ significantly between the initial survey and the end of the follow up ($A(8)$ about 3.1 ms^{-2}).

Table 1. FSBP%$_{10°}$, hot and cold perception thresholds, and thermal neutral zone (hot threshold – cold threshold) in the vibration exposed workers (n=50) at the initial survey and the end of the follow up. Data are given as means (SD).

Outcome	Digit (r/l)	Initial survey	End of follow-up	P
FSBP%$_{10}$	III r	69.9 (28.9)	64.3 (32.1)	0.025
Hot threshold (°C)	II r	39.4 (3.7)	40.4 (3.6)	0.027
	II l	39.1 (5.0)	39.9 (4.2)	0.18
	V r	40.1 (3.8)	41.2 (3.7)	0.023
	V l	38.7 (3.9)	39.9 (3.3)	0.026
Cold threshold (°C)	II r	25.7 (3.0)	24.9 (3.1)	0.06
	II l	25.3 (3.4)	25.1 (3.1)	0.63
	V r	24.7 (3.3)	23.9 (3.2)	0.10
	V l	25.1 (3.0)	24.2 (3.7)	0.09
Neutral zone (°C)	II r	13.7 (6.3)	15.5 (6.3)	0.029
	II l	13.7 (7.9)	14.8 (6.4)	0.29
	V r	15.4 (6.6)	17.3 (6.5)	0.036
	V l	13.6 (6.4)	15.7 (6.4)	0.030

Table 2. Relation of the changes in FSBP%$_{10°}$ and thermal neutral zone (mean of the right and left digits (D)) to measures of vibration exposure over the follow-up period. The coefficients and robust 95% CI for the change in FSBP%$_{10°}$ or neutral zone per unit of increase in $A(8)$ and follow-up time are estimated by random-intercept linear regression, while adjusting by age, BMI, smoking, drinking, and FSBP%$_{10°}$ or neutral zone measured at one time-point earlier (t – 1).

Outcome	D	Factors	Coeff	95% CI
FSBP%$_{10}$ (%)	III	$A(8)$ (ms^{-2})	-5.0	-9.0 to -1.1*
		Follow-up (yr)	0.3	-9.4 to 9.9
		FSBP%$_{10°(t-1)}$	0.2	-0.2 to 0.5
Neutral zone (°C)	II	$A(8)$ (ms^{-2})	-0.25	-0.81 to 0.30
		Follow-up (yr)	2.97	0.65 to 5.28*
		NZ$_{(t-1)}$ (°C)	0.43	0.18 to 0.67H
	V	$A(8)$ (ms^{-2})	-0.07	-0.64 to 0.49
		Follow-up (yr)	3.06	1.16 to 4.96*
		NZ$_{(t-1)}$ (°C)	0.48	0.24 to 0.71H

*p<0.01; Hp<0.001

At the cross-sectional study, the point prevalence of symptoms was 36% for tingling, 32% for numbness, and 8% for VWF. Over the follow-up period, there were 5 new cases of tingling, 2 new cases of numbness, and 2 new cases of VWF, giving rise to cumulative incidences of 15.6%, 5.9% and 4.3% respectively. In the study population, FSBP%$_{10°}$ and TPT (Table 1), but not VPT (results not shown), deteriorated significantly over the follow-up period. After adjustment for several confounders, data analysis with a random-effects transition model showed that the changes over time in FSBP%$_{10°}$ and TPT were significantly related to either $A(8)$ or the follow-up time. Table 2 reports the relations of the change in FSBP%$_{10°}$ and thermal neutral zone (hot threshold – cold threshold) to measures of vibration exposure. Changes over time in VPT were found to be related to vibration exposure only for digit V at 125 Hz (results not shown).

4. DISCUSSION

This follow up study of shipyard workers showed that exposure to hand-transmitted vibration can deteriorate finger circulation over time. This finding is consistent with those of previous experimental investigations and epidemiological studies with either cross-sectional or longitudinal design (Bovenzi et al., 2000; Bovenzi, 2010). Peripheral sensory dysfunction over time in the digits innervated by the median nerve (index finger) and the ulnar nerve (little finger) was limited to deterioration of thermal thresholds, while no significant differences were observed for vibrotactile perception thresholds. These findings suggest that in the vibration exposed workers of this study sensory nerve damage was at an early stage and occurred primarily in the small-calibre nerve fibres of the fingers which conduct thermal sensation (myelinated Aδ fibres, unmyelinated C fibres), rather than in the large-diameter fibres which are sensitive to tactile, pressure and vibration stimuli (myelinated Aβ fibres), (Nilsson and Lundström, 2001). After adjusting for potential confounders, longitudinal data analysis with a transition model showed that there were significant exposure-response relationships between measures of vibration exposure and impairment to vascular function and thermal acuity.

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NEUROPHYSIOLOGIC SYMPTOMS AND VIBRATION PERCEPTION THRESHOLDS IN YOUNG VIBRATION-EXPOSED WORKERS – A FOLLOW-UP STUDY

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1. INTRODUCTION

Vibration exposure may cause the hand-arm vibration syndrome (HAVS), including digital vasospasms (vibration white fingers; VWF), sensorineural symptoms and/or muscular weakness and fatigue (Gemne, 1997). Neurophysiologic symptoms include numbness and/or tingling, impaired touch sensitivity, impaired manual dexterity and reduced grip strength in the hands. The Stockholm Workshop Scale is commonly used for sensorineural (SN) staging (0SN – 3 SN). Sensorineural symptoms of this in combination with difficulties in handling small objects may interfere both with the workers social- and work-related activities (Sakakibara et al., 2005).

2. OBJECTIVE

The objective of this work was to study the development of neurophysiologic symptoms and vibration perception thresholds in a cohort of young vibration-exposed workers.

3. METHODS

The follow-up study in 2006/2007 comprised 108 young male vibration-exposed workers (mean-age was 22.6 ± 1.0 y) from the machine shop and construction industries, who had been followed since they finished school. They were compared with 21 male non-exposed referents (mean-age 22.4 ± 0.9 y). All participants completed several questionnaires related to working and medical history, smoking, alcohol consumption, previous and on-going vibration exposure and symptoms of sensorineural disturbances. The neurophysiologic function was checked by the determination of vibration perception thresholds (VPTs) at 31.5 and 125 Hz and by Semmes Weinstein's Monofilament tests. Measurements of vibrotactile thresholds were performed by delivering sinusoidal vibrations to the pulp of digits II and V, bilaterally (the up-and-down method of limits; von Békésy method), and registering the subjects response, using the HVLab Tactile Vibrometer system (HVLab, United Kingdom).

The results were compared with the findings from the baseline study in 2004/2005. Parametric statistics were used for comparison of elements that showed a normal distribution (checked by Normal Probability Plots, Levene's test). For elements with a skewed distribution, nonparametric statistical processing was applied (Mann-Whitney's U-test; r_s = Spearman's rho). P-values < 0.0: were regarded as statistically significant (2-tailed tests).

Multiple regression analysis was performed with VPT as th dependent variable, and with age, height, examiner an different vibration dose calculations as predictor variable (total hours of vibration exposure (h), a*t weighted tota dose, a^2*t weighted total dose, current weighted vibratio exposure A(8) and total a^2*t weighted total dose for worl and leisure time). Model fits were checked by means o residual analysis (Altman, 1991)

4. RESULTS

Among the exposed workers, 18 subjects (17 % reported tingling sensations, 9 reported numbness (8 %) an 5 reported both tingling and numbness in their fingers. Thi is a doubling of reported tingling sensations compared to th baseline study (8 %), while reported numbness was more o less unchanged (10 % at baseline study).

The exposed workers showed significantly raised VPTs fo 32 Hz in digit II (p=0.036) and for 125 Hz in digit V, lef hand (p=0.045). The other VPTs didn't differ significantl between workers and referents. The exposed worker showed approximately the same median values of vibratio perception thresholds (m/s^2) in the follow-up study (31. Hz, digit II, left hand 0.11, digit II, right hand 0.13; 125 Hz digit II, left hand 0.16, right hand 0.17) as in the baselin study (31.5 Hz, digit II, left hand 0.13, digit II, right han 0.15; 125 Hz, digit II, left hand 0.17, right hand 0.24).

A multiple regression analysis (VPTs as dependen variables; age, height, examiner and vibration doses a predictor variables) showed the strongest associations fo the models including two of five calculated doses (curren weighted A(8), r^2=0.38; work+leisure a^2*t weighted tota dose, r^2=0.29) in the highest exposed quartile (Table 1).

DISCUSSION

This is a fairly young cohort of machine shop an construction workers who have been followed since th participants finished school. The follow-up study showed a increase of reported neurophysiologic symptoms (tingling in vibration exposed workers as compared to the result from the baseline study. The vibration perceptio thresholds, however, were approximately at the same leve at baseline and follow-up and no apparent deterioration was observed during the study period. A multiple regression analysis with VPTs as the dependent variable showed the strongest associations with two of five calculated vibration doses, A(8) and work leisure a^2*t weighted total dose, respectively.

In conclusion, neurophysiologic symptoms and vibration perception thresholds seem to appear after short-term exposure in this cohort of young vibration exposed workers, who will be followed up prospectively.

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Table 1. Multiple regression analysis, digit II, left hand, 32 Hz, highest exposed quartile. Parameter estimates and p-values. NS = non significant.

Vibration dose definition	Intercept	Age	Height	Examiner	Vibration dose	R-squared significance of model
Total hours exposure (h)	0.78 (NS)	-0.026 (NS)	-2.9×10^{-5} (NS)	-0.05 (NS)	-1.1×10^{-6} (NS)	$R^2 = 0.07$ NS
A*t weighted total dose	0.84 (0.039)	-0.026 (0.036)	- 0.001 (NS)	-0.05 (NS)	5.8×10^{-7} (NS)	$R^2 = 0.22$ NS
a^2*t weighted total dose	0.75 (NS)	-0.023 (0.04)	-0.001 (NS)	- 0.022 (NS)	9.9×10^{-9} (NS)	$R^2 = 0.17$ NS
Current weighted A(8)	0.98 (0.025)	-0.036 (0.006)	0.00 (NS)	-0.08 (0.045)	0.02 (NS)	$R^2 = 0.38$ $p = 0.042$
Work+leisure a^2*t weighted total dose	1.30 (0.008)	-0.03 (0.035)	-0.003 (NS)	-0.062 (NS)	7.5×10^{-7} (NS)	$R^2 = 0.29$ (NS)

POSITION OPEN - Assistant Editor, Canadian Acoustics Journal

The current Editor-in-Chief, Ramani Ramakrishnan, will be stepping down in 2012. A new Editor will be elected during the Annual General Meeting (AGM) in October 2012 and will become the new Editor-in-Chief from 2013 onwards. CAA is looking for an Assistant Editor who will work with Ramani Ramakrishnan and will be trained to be the next Editor. He or she will be nominated during the 2012 AGM and it is hoped that the membership will vote him/her to be the Editor-in-Chief.

The current proposal is to aid in the smooth transition from Ramani Ramakrishnan to the new Editor.

Interested person should contact either the president, Christian Giguère or Ramani Ramakrishnan.

LONGITUDINAL STUDY OF SUOMUSSALMI FORESTRY WORKERS I - VIBROTACTILE THRESHOLDS

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1. INTRODUCTION

A thirteen-year prospective study has been conducted of an open cohort of forestry workers, who operate low-vibration power tools in the Suomussalmi region of Finland. The purpose of this paper is to report the changes in vibrotactile perception thresholds (VPTs) observed at the fingertips of a subgroup of workers who reported for a required annual medical examination on three occasions (in 1990, 1995, and 2003), when a sensitive tactometer was available to record their thresholds. The same apparatus was used for the first and third evaluation, and a production prototype with equivalent performance was used for the second. The apparatus has been described elsewhere (Brammer and Piercy, 1991; Brammer et al., 2007), and fulfills the requirements of ISO 13091-1:2001 (method A).

During the study, the work practices changed. In 1999, mechanized tree harvesting was introduced into the area, and brush saws were substituted for chain saws for much of the manual work. The change resulted in a reduction in vibration exposure. In this paper, the changes to the VPTs recorded before, and after, the reduction in exposure are examined. The vibration exposure in 2003 is described in a companion paper at this conference. A preliminary report of some aspects of this work was presented at the second North American Conference on Human Vibration.

2. APPARATUS AND METHOD

2.1. Apparatus

Vibrotactile thresholds were recorded at the fingertips with the subject seated, and with his forearm supported horizontally in a comfortable position. The hand and wrist were rotated so that the volar skin could be stimulated by a vertically-mounted probe. As a psycho-physical measurement procedure is employed, an effort was made to ensure the subject was sitting with back and arm fully supported before positioning the stimulator on the skin surface, to reduce discomfort. The stimulator consisted essentially of: 1) a vibration exciter suspended from a beam balance with an adjustable fulcrum, to permit the stimulator to be lowered onto a fingertip; 2) a 3 mm diameter cylindrical plastic probe, to apply the stimulus to a fingertip with a controlled contact force (0.05 N), and; 3) an accelerometer and conditioning electronic circuits, to record skin motion.

2.2. Method

The psychophysical algorithm was generated by computer, as were the values of VPTs. Vibratory tone bursts separated by quiescent intervals were applied to the skin at amplitudes close to the threshold of perception. The change in stimulus intensity between bursts was 2 dB in the first study, and was automatically decreased from 3 dB to 2dB during the other studies depending on the subject's performance, to reduce the measurement time. With the accelerated procedure, VPTs could be obtained at one frequency in about 1 min. Stimulus frequencies were chosen to be little influenced by a subject's age, and were 4, 6.3, 20 and 32 Hz (Brammer et al., 2007).

The consistency of threshold tracking was monitored during the measurement process in 1995 and 2003, and employed to reduce errors in the VPTs. The procedure consisted of comparing either, or both, ascending and descending threshold reversals, and VPTs mediated by the same mechanoreceptor population (Brammer and Piercy, 1995).

The apparatus was calibrated daily before commencing measurements, using a built-in reference stimulus that produced a known acceleration at the probe tip. Long-term variations in calibration were less than 1 dB.

Skin temperature was recorded at the fingertips before the measurements commenced, and was maintained at ≥27 °C.

2.3. Subjects

The study group consisted of almost 20% of the workforce at baseline. Twenty-three forestry workers (23/124) were randomly assigned to the study when attending the annual compulsory medical examination in 1990. Eighteen of these workers (18/109) returned for re-examination in 1995, and ten (10/59) in 2003, who are the subject of the present analysis. The workers' 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.

The forest workers felled and de-branched softwood trees, and were paid by their production (piecework) prior to 1999. After this date the workers were paid an hourly rate, and either cleared brush around immature trees, or cut trees.

Table 1. Mean VPTs for LH3 (10 Subjects)

Frequency	VPT (dB re 10^{-6} m.s^{-2})		
(Hz)	1990	1995	2003
4	80.7	87.7	84.4
6.3	85.1	90.9	87.7
20	97.1	102.4	98.7
32	103.9	107.3	107.0

None of the subjects had operated vibrating power tools on the day of the health examination, and so the vibrotactile thresholds are believed to be free of any temporary loss in sensation resulting from acute exposure of the hand to intense vibration.

Symptom reports were obtained during a physical examination conducted by a physician, who also performed a neurological examination to exclude polyneuropathies.

3. RESULTS

Twenty-eight percent of the study group reported numbness in the hands at study inception, at which time the prevalence reported by the complete cohort was also 28%. The mean age of the study group at inception was 39 years (range 25 - 52 years) while that of the cohort was somewhat greater (mean 43, range 24 - 60 years). Of the ten subjects who attended all examinations, two reported hand numbness in 1995, but only one reported hand numbness in 2003.

VPTs were obtained at the fingertips of digits 3 and 5 for both hands on each occasion. For the 10 subjects, the trend was for increasing VPTs (i.e., less sensitive) from 1990-1995, and constant or decreasing VPTs (i.e., more sensitive) from 1995 to 2003. The mean VPTs are shown for digit 3 of the left hand (LH3) in Table 1. The mean VPTs in the other digits replicated those for LH3 from 1990 to 1995, but there was less improvement from 1995 to 2003. It can be seen from Table 2 that the changes in mean VPTs for digit 3 of the left hand reached statistical significance ($p<0.05$) at some frequencies (t-test). The deterioration of acuity from 1990 to 1995 was very significant at frequencies of 4, 6.3, and 20 Hz, but less so at 32 Hz. The changes in acuity of this finger from 1995 to 2003 were not statistically significant, except at 4 Hz. The statistical tests conducted on the changes in VPTs recorded from the other fingers were less definitive, suggesting that a more complex metric of threshold change may be required (Brammer et al., 2007).

4. DISCUSSION

When stimulated in the manner described, thresholds at 4 and 6.3 Hz are believed to be mediated by the same mechanoreceptor population, the Merkel disks, while those at 20 and 32 Hz are believed to be mediated by the Meissner corpuscles (ISO 13091-1, 2001).

Table 2. Statistical Significance of Changes in VPTs for LH3

Frequency	p-value (t-test)	
(Hz)	1990-1995	1995-2003
4	6×10^{-4}	0.03
6.3	2×10^{-6}	0.28
20	0.001	0.31
32	0.02	0.86

An analysis of the change in VPT with time at frequencies mediated by the same receptor population has shown that the *same* change in threshold is to be expected at each stimulation frequency, provided the threshold changes associated with aging are removed (Brammer et al., 2007). For our study, the change in threshold due to aging is, on average, +0.03 dB/year at 4 Hz, and +0.07 dB/year at other frequencies. Thus, the changes in VPTs from year to year are slightly less than those in Table 1. Taken together, the statistical tests for the VPTs of LH3 at 4 and 6.3 Hz provide a conflicting picture for the acuity of the Merkel disks from 1995 to 2003. The tendency towards a lack of improvement in acuity from 1995 to 2003 in the other digits suggests the threshold improvements recorded in LH3 during this period may be fortuitous. However, it does appear that the deterioration in acuity observed in these workers from 1990 to 1995 has subsequently been arrested. The stability of VPTs from 1995 to 2003, coincident with the change in work, suggests that the present vibration exposure is producing no additional sensorineural health effect.

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DETECTION OF SENSORY DISTURBANCES IN 23 HAVS CASES WITH TYPICAL ARTERIAL DISORDERS: 15 HYPOTHENAR HAMMER SYNDROME, 3 THROMBOANGIITIS OBLITERANS AND 5 ARTERIOSCLEROSIS OBLITERANS

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1. INTRODUCTION

We have been engaged in the diagnosis and treatment of HAVS, especially from the standpoint of peripheral circulation and peripheral sensorineural disorders (Kaji, 1992, 1993, 1998, 2007; Honma, 2000, 2003). In our daily practice, evaluation of the complaints in HAVS, such as numbness, tingling and pain in hands and fingers, is one of the most important and difficult diagnostic problems in the clinical management of patients and the workers' accident compensation. In our previous studies, sensory nerve conduction velocities such as anti-dromic sensory nerve conduction velocity and N9 latency of short-latency somatosensory-evoked potentials (SSEPs) were significantly prolonged in vibration-exposed workers with cervical spondylosis, both in HAVS and in non-HAVS subjects (Kaji, 1998, 2007). In this study, we reinvestigated the peripheral sensorineural disturbances in vibration-exposed HAVS subjects accompanied with arteriographically typical peripheral arterial disorders, such as hypothenar hammer syndrome (HHS), thromboangiitis obliterans (TAO), and arteriosclerosis obliterans (ASO). This study may provide evidence of whether peripheral circulation disorders of HAVS are always accompanied with peripheral sensorineural abnormalities.

2. SUBJECTS and METHODS

All the HAVS subjects were male with mean ages: HHS 57.7 ± 6.3, TAO 54.0 ± 10.0, and ASO 60.8 ± 5.0years. Mean vibration-exposures were in HHS 18.9 ± 7.3, TAO 14.7 ± 1.5 and ASO 22.6 ± 10.5 years, respectively. Clinical diagnoses had been made by arteriography of upper and/or lower extremities, in addition to the routine clinical examinations for HAVS.

Since diabetes mellitus and cervical spondylosis (CSP) are the most common confounding disorders in adults over the age 40 years in Japan, diabetes mellitus was checked by blood HbA1c levels, and CSP was also diagnosed radiographically (Kaji, 2007). In the present study, subjects with clinical carpal tunnel syndrome were not found in these three clinical entities.

Following the electric supra-maximal square pulse stimulations at the wrist of the right median nerve, the anti-dromic sensory nerve conduction velocity (SCV) and the SSEPs (N9, N13, N20) were obtained. The SSEPs parameters (the N9 latency and the interpeak conduction times N9/13 & N13/20) were corrected by body height (msec/mBody height). The apparatus and the test conditions have been described elsewhere (Kaji, 1992).

Normal limit values of each electrophysiological parameter (M±2SD) had been determined prior to the present study in 43 healthy males with ages between 40 and 69 years (Table 1). In these healthy controls, the subjects with both diabetes and CSP had been carefully excluded beforehand.

Table 1. Normal limits of sensorineural parameters (N=43)

SCV	M−2SD	46.1	m/sec
N9	M+2SD	6.29	Msec/mBody height
N9/13	M+2SD	2.80	Msec/mBody height
N13/20	M+2SD	4.33	Msec/mBody height

The severity of neurological disorders, based on SCV and SSEP measurements, were graded as follows –

SCV	Symbol	SSEP
M-3SD < x ≤ M-2SD	+	M+2SD ≤ x < M+3SD
M-4SD < x ≤ M-3SD	++	M+3SD ≤ x < M+4SD
x < M-4SD	+++	M+4SD ≤ x

3. RESULTS

Among 23 HAVS subjects with typical arterial disorders, nine cases had delayed or prolonged electrophysiological parameters as listed in Table 2.

Table 2. Nine HAVS cases with prolonged sensory nerve conduction, with grades of severity, in a group of 23 HAVS cases with and without cervical spondylosis (CSP) and with typical arterial disorders: HHS, TAO and ASO

	Case/Age	SCV	N9	N9/13	N13/20
WITH CSP	HHS/62	++	++	−	−
	HHS/63	n.d.	+	+	++
	HHS/58	+++	−	−	−
	ASO/64	++	+	−	−
WITHOUT CSP	HHS/46	−	+	−	−
	HHS/66	−	−	+	−
	TAO/44	+++	++	−	++
	TAO/54	−	++	+++	−
	ASO/68	+	−	−	−

These 23 HAVS subjects were divided into two groups WITH and WITHOUT CSP (Table 3). Among 16 HAVS cases WITH CSP, only 25% of cases (3/12) had prolonged SCV ++ ~ +++. Prolonged N9 latency + ~ ++ was observed in 25% of these cases (4/16); however, the other 12 (of 16) subjects (75%) had no sensorineural abnormalities.

On the other hand, in the 7 HAVS cases WITHOUT CSP (Table 3), 5 of them (as shown in Table 2) had prolonged SCV and SSEPs, (71.4%). In total, as shown in Table 3, disordered SCV was observed in 5 out of 18 cases (27.8%), prolonged N9 latency in 6/23 cases (26.1%), prolonged interpeak conduction times N9/13 in 3/23 cases (13.0%), and N13/20 in 1/23 cases (4.3%) (Table 3).

Table 3. Frequency of prolonged sensory nerve conduction in 23 HAVS cases with and without cervical spondylosis (CSP) and with typical arterial disorders: HHS, TAO and ASO

	SCV	N9	N9/13	N13/20
WITH CSP	3/12	4/16	1/16	0/16
N=16	(25.0%)	(25.0%)	(6.25%)	(0%)
WITHOUT	2/6	2/7	2/7	1/7
CSP N=7	(33.3%)	(28.6%)	(28.6%)	(14.3%)
TOTAL	5/18	6/23	3/23	1/23
N=23	(27.8%)	(26.1%)	(13.0%)	(4.3%)

4. DISCUSSION AND CONCLUSION

HAVS is characterized by peripheral circulation, neurological, and musculoskeletal disturbances (Pelmear, 1992). However, one important problem of great concern is whether peripheral circulation disorders in HAVS always accompany peripheral neurological disturbances. In this investigation, sensorineural examinations were conducted after arteriographical diagnoses of HHS, TAO and ASO.

Previously, SCV and N9 latency in vibration-exposed workers WITH CSP have been observed to be significantly prolonged in HAVS, non-HAVS, diabetes, and healthy subjects when compared with those of healthy subjects WITHOUT CSP (Kaji, 1998, 2007). In this work, peripheral parameters (SCV and N9 latency) in HAVS subjects with typical peripheral arterial diseases (HHS, TAO and ASO) were not always disordered even in subjects WITH CSP, as 75% of cases had normal sensory nerve function (Table 3). When the normal limit values were lowered from M±2SD to M±1SD, the increase in number of cases in SCV group was only one WITH CSP. But in the N9 latency group, 5 cases WITH CSP and one case in WITHOUT CSP were added as subjects with sensory abnormalities. As a result, peripheral and/or distal sensorineural disorders were observed in 12/23 cases (52.2%). In other words, 47.8% of HAVS cases with typical arterial diseases had no detectable electrophysiological abnormalities. This frequency corresponded well to those of the work by House et al (2007), where nerve conduction studies in almost 1000 patients showed 47% of workers assessed for HAVS had no measurable abnormalities in peripheral nerve function in the upper extremities. Their most common neuropathies were mild carpal tunnel syndrome and ulnar neuropathy. Since the ulnar nerve is known to be easily injured from trauma or osteoarthrotic changes of the elbow joint, especially at the cubital tunnel, our clinical studies were conducted on the median nerve (Kaji, 1992).

Although the mechanism of how CSP affects sensorineural disorders in HAVS has not yet been elucidated, the double-crush hypothesis (Upton, 1973; Yu, 1985) seems to explain our present observations. It suggests that periodic medical examination for early detection of peripheral neuropathy in vibration-exposed workers and/or for diagnosing HAVS for workers' compensation, several tests of peripheral circulation disorders would be preferred, rather than electrophysiological determinations for sensorineural disorders. The presence CSP should always be taken into consideration as a prerequisite, when highly sensitive neurophysiological examinations are applied.

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HYPOTHENAR HAMMER SYNDROME: AN UNDERDIAGNOSED CAUSE IN WORKERS EXPOSED TO HAND-ARM VIBRATION

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1. INTRODUCTION

Hand-arm vibration syndrome (HAVS) may contribute to various disorders of the vascular, neurological and musculoskeletal systems. Vibration-induced white finger (VWF) is characterised by episodic constriction of digital arteries. VWF without permanent trophic changes is most often a purely vasospastic disorder without organic arterial obliterations (Olsen, 2002). In severe cases, structural lesions have been reported in biopsies (Takeuchi et al., 1986). In advanced cases, peripheral circulation becomes sluggish, giving a cyanotic appearance to the fingers, whereas in very rare cases (1%), trophic skin changes (gangrene) will occur at the fingertips (Taylor & Brammer, 1982). In vibration exposed workers, underlying secondary causes of Raynaud's phenomenon or ischemia can be present such as hypothenar hammer syndrome (HHS), thoracic outlet syndrome, Buerger's disease or connective tissue disorders. Given that working with vibrating tools involves repetitive trauma to the hands, the aim of this presentation is to review the literature reporting structural lesions such as HHS among HAVS patients and present further cases of thrombosis of the radial and cubital arteries that could account for the poor prognosis of HAVS patients.

2. METHODS

We searched Medline for articles published between 1970 and 2010, in French and English, using the keywords "hypothenar hammer syndrome" and "ulnar artery thrombosis". Abstracts were excluded. A total of 86 articles for HHS were retrieved and analysed. In addition, from a study of 355 compensation files submitted to the Quebec Workers Compensation Board (CSST) for HAVS claims between 1993 and 2002 (Turcot et al., 2007), 33 files of workers with digital thrombosis and/or ulcers were identified. One case was rejected for further analysis because of a diagnosis of severe primary ischemic Raynaud's disease. Descriptive analysis of the remaining 32 cases was carried out with respect to personal, medical and occupational characteristics, prescribed treatments and recommendations about return to work. Among the 32 files, one case and 2 other cases of confirmed HHS referred to us in 2009-2010 will also be presented.

3. PRELIMINARY RESULTS

The preliminary literature review on HHS found few studies on HHS, mainly case reports and a few small cohort studies. Thompson et al. (2006), Noël (1998) and Kaji et al. (1993) reported cases of HHS and Youakim (2006) reported one case of thenar hammer syndrome. These arterial lesions were described alone or in combination with HAVS. HHS is a rare disease, first described by Conn et al. (1970). True incidence and natural history are unknown. Among 1300 individuals presenting with hand ischemia, the prevalence of HHS was 1.6% and has been reported as high as 7% in 333 vibration-exposed workers (Ferris et al., 2000; Kaji et al., 1993). Depending on frequency or severity of the traumatizing event, repetitive trauma can cause arterial vasospasm but, over time, damage to the intima occurs with subsequent thrombus formation and, less frequently, aneurysmal dilatation (Friedrich et al., 2010). The condition may be complicated by embolization of thrombi to intermetacarpal or digital arteries, or both. HHS has been described in a number of industries in which the workers use their hands to pound or push, including carpenters, automobile mechanics, metal workers, coal miners, rock drillers, forestry workers, construction workers, water well drillers, and factory workers (Marie et al., 2007; Thompson & House, 2006; Kaji et al., 1993). Mean duration of occupational exposure to repetitive palmar trauma at HHS diagnosis was 21 years in one study and 19 years in another (Marie et al., 2007; Kaji et al., 1993). Signs and symptoms due to vascular insufficiency include discoloration of the fingertips, cold sensitivity, pain, cyanosis, and subungual hemorrhage or ischemic ulcers. Other features suggestive of HHS include asymmetrical distribution of Raynaud's phenomenon (RP), usually in the dominant hand, and absence of the hyperemic phase of RP. A hypothenar mass or callus may be palpable (Spencer-Green et al., 1987). Any finger may be involved, except the thumb, due to anatomic variability of the superficial palmar arch. Paresthesia, pain and numbness are due to ulnar nerve irritation or compression (Taj et al., 2010). Diagnosis can be made by clinical investigation: Allen's test, or doppler ultrasound, while arteriography is the gold standard for establishing the treatment plan. Noninvasive investigations include multi-detector computed tomography (CT) angiography, magnetic resonance angiography (Taj et al., 2010). The optimal strategy for therapy remains unclear and controversial (Friedrich et al., 2010).

The preliminary results of the analysis of the 32 files reveal that the diagnoses were made in different ways. Ten were based solely on an abnormal Allen test by one clinician while arteriography was performed and positive in 9 cases. Results from 25 Allen's tests were retrieved from the 32 files and results varied from one clinician to another. Two

Doppler ultrasound tests for 2 workers carried out in these 32 patients were positive. The diagnosis of HHS was rejected for compensation by the CSST in 4 cases. One case of thrombosis of the radial artery was confirmed by angiography. Twelve workers presented digital ulcers, and one case of gangrene was described. These workers were mainly from mining (n=12), automobile mechanics (n=9), construction (n=2), forestry (n=3), heavy equipment operators (n=1), pressure hose operators (n=1), seamstress (n=1), factory workers (n=1), skidder operators (n=1), sandblaster operators and loggers (n=1). Vibrating tools included high pressure hose, grinder, zip gun, sledgehammer, ratchets, impact wrench, jack leg drill, stoper, plugger, road drill, sewing machine, chain saw, compressed-air cutting machine, skidder, and brush cutter.

Analysis of the files shows confusion in the diagnosis established by different clinicians for the same file, the use of non-standardized clinical tests for Raynaud's phenomenon, incomplete clinical investigation of HHS, incomplete examination of occupational "hammering" tasks, and differences in impairment and in functional limitation rating. Medical and surgical follow-up differs among the workers. Three clinical cases were presented to us: one mechanic and two road workers. The HHS diagnosis was delayed and recognition of the disease questioned. One of the workers underwent amputation of digits 4 and 5.

4. DISCUSSION

Workers who operate vibrating tools are at risk of HHS due to the nature of their tasks, which require that they push and grasp the tools tightly in the palms of their hands. The impacts generated by certain tools, such as air hammers, weaken the hypothenar eminence. It is difficult to differentiate the contribution to repeated hand trauma from impact activities versus the trauma related to the transmission of vibration by the tools (Thompson & House, 2006). It is surprising to note the low prevalence of HHS, considering the frequency of palm impacts and trauma in manual workers using vibrating tools. Very few studies exist on the exact prevalence of disease in workers exposed to vibration. According to Little & Ferguson (1972), the syndrome might go undetected in its early stages, which suggests the need for increased surveillance. Preliminary analysis of the files shows that clinicians do not understand the syndrome very well. In fact, faced with documented cases of acute ischemia, other etiologies are often reported by clinicians, such as Buerger's disease or connective tissue disease, thus ruling out a diagnosis of HHS. Patients are often misdiagnosed or diagnosed too late (Liskutin et al., 2000). Confusion exists in the diagnoses reported in the analysis of cases, in the lack of consensus regarding medical investigation and inadequate occupational histories, and in the investigation of the tasks and use of tools that could cause HHS. HAVS and HHS can produce similar symptoms; however, the presence of hand cyanosis and pain, ulcers and necrosis with or without Raynaud's phenomenon, and the presence of neurological symptoms secondary to ulnar nerve compression, as reported in the cases, should have led to suspected HHS. Could the 1% of cases with necrosis reported in the HAVS literature be due to HHS and incorrectly attributed to microangiopathy of HAVS or other causes of secondary Raynaud's syndrome? It is important to recognize the possibility of HHS in vibration-exposed workers, to conduct a systematic occupational history on work methods and vibrating tools used, to perform an appropriate physical examination and follow a rigorous medical investigation protocol to diagnose HHS. Clear recommendations regarding follow-up of these patients is essential. A consensus on the treatment of cases is essential to avoid complications, including amputation.

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QUALITATIVE AND QUANTITATIVE CHARACTERISTICS OF PAIN SYNDROME IN HAND-ARM VIBRATION SYNDROME

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1. INTRODUCTION

Among all chronic occupational diseases in Russia, Hand-Arm Vibration Syndrome (HAVS) makes up 25. 8 %. Now a classification of syndrome for vibration-induced hand disorders is used in Russia in which the leading syndromes are peripheral, vascular and neurologic disorders. The musculoskeletal pathology is included in this classification [1, 2]. The diagnosis confirmation requires some investigative methods of analyzing all three components of HAVS: vascular, sensory, neurological and musculoskeletal.

For patients with HAVS, the most common complaints are pain, tingling or numbness of fingers, chillness of hands (heightened sensibility to cold) and fingers albication (white fingers). The perception of pain is always subjective. For specification of sensory symptoms in hands, several electro-physiological methods are used: electroneuromyography (ENMG) and quantitative sensory testing (QST). Study of the relationship between qualitative and quantitative indicators of pain may contribute to the study of mechanisms of pain perception [3]. In clinical medicine, neuropathic and nociceptive pain mechanisms are distinguished for determining adequate analgesia methods. Neuropathic and nociceptive mechanisms were determined in the development of pain syndrome in various diseases of the peripheral nervous system. Researching the character and neurophysiologic mechanisms of pain syndrome in occupational diseases is an actual problem nowadays [4, 5].

The aim of this study was to investigate the correlation between electrophysiological methods and pain questionnaires in patients with vibration-induced hand disorders.

2. APPARATUS AND METHOD

For qualitative and quantitative characteristics of pain, all the patients were investigated with a clinical bedside examination, electrophysiological methods and pain questionnaires. The questionnaires (pain scales) consisted of several validated instruments which were used to examine intensity of pain, quality of pain and neuropathic pain: Visual Analog Scale (VAS) [6], specialized questionnaires screening for neuropathic pain - Douleur Neuropathique in 4 questions (DN4) [7] and Pain Detect (PD) [8]. DN4 questionnaire: If the patients score is equal to or greater than 4, the test is positive (sensitivity: 82.9%; specificity: 89.9%). Pain Detect: If the patient score is equal to or less than 12, a neuropathic pain component is unlikely (<15%); 13-18 points, the result is ambiguous, although a neuropathic pain component can be present; and equal to or greater than 19, a neuropathic pain component is likely (>90%). The questionnaire tool correctly classified 83% of patients to their diagnostic group with a sensitivity of 85% and a specificity of 80%.

ENMG was carried out using an electromyograph (Neurosoft, Russia), and nerve conduction velocity (NCV), latency, and the amplitude of the M-wave were determined. QST was carried out using a neurosensory analyzer, Model TSAII (Medoc, Israel), and thermal thresholds (WS), vibration sensitivity , cold sensitivity (CS), thermal pain (HP) and cold pain (CP) were determined. Statistical processing of the results was done by Statistica 6.0. Parametrical and nonparametric methods of the statistical analysis were used, depending on character of distribution of the data (age, length of service, results of questionnaire and electrophysiological methods). Quantitative variables are presented as M± m.

A group of 26 miners at a bauxite mine (from workers in the Sverdlovsk region, Russia) aged from 35 to 57 (mean age 48.3±0.9 y) with upper limb disorders were examined. Their participation was voluntary, and the subjects gave their informed consent. Major specific risk factors were: use of vibrating equipment and tools (110-120 decibel), intensive manual work, air temperatures of about 6-12°C and high use of watering. The durations of exposures were between 10 and 33 years (24±1.1 y).

Patient symptoms were obtained during physical examinations conducted by a physician, who also conducted a neurological examination to detect polyneuropathies. Among this group of workers, 15/26 (57%) were with HAVS, and 7/26 (9%) had occupational musculoskeletal disorders. Among the 15 patients with HAVS: 5 had vascular disorders, 3 had neurological disorders, 7 had an expressed degree of illness-the combination of vascular and neurological disorders with a musculoskeletal pathology.

3. RESULTS

From the results of the VAS, the intensity of pain syndrome was characterized by high point scores, and was therefore interpreted as "strong". High values from the questionnaires screening for neuropathic pain (DN4 and PD) point to a high probability of presence of neuropathic pain component. On the PD, the average score among all was more than 13 points. On the DN4, all got more than 4 points. The results of ENMG were: 24/26 patients had symptoms of axonal-demyelization process (multifocal neuropathy), 1/26 patients had decrease of the medianus nerves conductivity, 1/26 patients had normal indicators and 3/26 patients (with occupational musculoskeletal disorder) had combination of multifocal polyneuropathy with the syndrome of the cubital canal. Signs of carpal tunnel syndrome in this group of patients ware not found. Temperature threshold c vib hanges (all thermal sensitivity tests and ration sensitivity) occurred in all patients.

Table 1.

Details of Symptoms	n=26	%
Painful cold	26	100%
Pain in articulations of hand	26	100%
Numbness	25	96%
Pins and needles	24	92%
Neck pain	24	92%
Tingling	21	80%
Electric shocks	11	42,3%
Angiospasm (blanching)	10	38,4%
Burning	4	15%
Itching	4	15%

There was a statistically significant correlation (Spearman Correlation) between the level of pain on the VAS and the questionnaire results on neuropathic pain. There was a direct correlation between the level of pain on the VAS and the PD ($r=0.603$; $p=0.001$), and between the inverse between the VAS and the DN4 ($r=-0.554$; $p=0.003$). All 26 patients responded positively to DN4 (6.4 ± 0.2), but the number of patients with points in the PD over 13 was 19 (73.1%). The levels of pain on the VAS ($r=0.543$; $p=0.004$) and the PD ($r=0.479$; $p=0.013$) were directly correlated with sleep disorders. However, no significant correlation was observed between the questionnaires on neuropathic pain and the duration of service. There was a direct correlation between positive results on the neuropathic component of pain (PD) and parameters of the QST: such as Ws ($r = 0,631$; $p = 0.001$), Cs ($r =- 0,406$; $p = 0.040$) (Table.2). Statistically significant correlation was revealed between the indices ENMG (NCV-nerve conduction velocity) and DN4 ($r = 0,406$; $p = 0.040$), NCV and QST (vibration sensitivity $r = 0,447$; $p = 0.022$).

Table 2.

	CS	WS	CP	HP
Pain Detect	r = -0.406 p= 0.044*	r =0.63 p= 0.001**		
M-amp			r =0.406 p= 0.044*	r =-0.614 p= 0.001**

4. DISCUSSION

The analysis of pain and patient complaints indicates suspected presence of both the neuropathic and nociceptive pain components (Table.1). The results suggest there may be correlations between the QST and pain questionnaire results, that subjective perceptions of pain might be represented by a certain pattern in the QST results. These connections could help clarify the pathophysiologic mechanisms leading to the perception of pain. Lack of correlation between the data of DN4 and the duration of work exposures is probably connected to the fact that only long-service miners having a work-related disease were involved in the investigation. That is why correlation was done between questionnaires results and the neuro-physiological methods. During the analysis of QST and ENMG data, we found correlation only between NCV and VS. It may indicate damage to A-beta fibers. The observed changes of WS and CS are of some interest. The results confirm the difficult structure of a chronic pain syndrome in vibration-induced hand disorders. Extensive use of pain questionnaires and quantitative sensory testing allow components of a chronic pain syndrome to be specified, and can contribute to optimizing therapeutic tactics. All the received data need to be further studied and analyzed.

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COMBINATIONS OF EXPOSURE TO VIBRATION, NOISE AND ERGONOMIC STRESSORS IN THE SWEDISH WORK FORCE AFFECT MUSCULOSKELETAL HEALTH OUTCOMES

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1. INTRODUCTION

Exposure to vibration both hand-arm vibration (HAV) and whole-body vibration (WBV) involves mechanical energy transferred to the human body. These mechanical oscillations also cause noise. Thus workers exposed to vibrations are also exposed to noise. Furthermore workers exposed to WBV and HAV are often simultaneously exposed to other ergonomic stressors, such as awkward postures and manual material handling (lifting) [1].

In a study of the Swedish workforce from a survey conducted in 1999, 2001 and 2003 by Statistics Sweden, we found that when the exposure factors lifting and frequent bending were added to a multivariate analysis, there was surprisingly a low magnitude of association between low back symptoms and whole body vibration exposure [2]. Interestingly, the relation between whole body vibration exposure and symptoms in the neck, shoulder/arm and hand had the same or higher magnitude of association even when the possible confounders were in the model. For the neck, low back and shoulder/arm there was an increase in prevalence ratio (as high as 5 times) when combined exposures of whole body vibration, lifting, frequent bending, twisted posture and noise were included in the analysis [2].

There are few studies of combination of exposure to noise and vibration on possible health effects such as musculoskeletal disorders and hearing problems. It has been proposed that sympathetic vasoconstriction causes hearing impairment as an explanation to the finding of an association between hearing problems and Raynaud's disease [3]. If so, there would also be a possibility of an association between ergonomic stressor and hearing problems since it has been hypothesized that chronic muscle pain conditions are associated an increased sympathetic activity.

1.1. Aim

To study the combinations of exposure to vibration, noise and ergonomic stressors in the Swedish workforce, and the effect on self-reported health outcomes such as musculoskeletal symptoms and hearing problems.

2. METHODS

The occurrence of exposure to noise in the working environment was considered for surveys conducted in 1997, 1999, 2005, 2007 and 2009 by Statistics Sweden (SCB), by order of the National Board of Occupational Safety and Health. Exposure to noise in these surveys is defined as "Exposed at least 1/4 of the time to noise so that you cannot speak in a normal tone". All together, the sample for these surveys is over 44,000 employed persons.

This cross-sectional working environmental study is based on material from a survey conducted in 1999 by Statistics Sweden (SCB), by order of the National Board of Occupational Safety and Health. Data concerning the working environment was collected by phone interview and questionnaire. The response rate for the phone interview was 88% (12,546 employed persons) and for questionnaire there was a 69% response rate (9,798 employed persons). These responders were the study population for the analytical study of risk factors for musculoskeletal and hearing disorders. For individual questions the level of non-response was between 1% and 3%.

2.1. Vibration and Noise Exposure

The definition of exposure to whole body vibration (WBV), hand transmitted vibration (HAV) and noise was based on three different questions, "Are you at work exposed to vibrations that make your whole body vibrate (e.g. tractor, truck or other working machines)?" "Are you at work exposed to vibration from hand held machines (e.g. compressed air machines, jigsaw or similar)?" "Are you at work exposed to noise that is so high that you cannot talk in a normal tone?" All questions had the same six response alternatives, "Almost all the time", "About 3/4 of the time", "At least half the time", "About 1/4 of the time", "Slightly (maybe 1/10 of the time)", and "Not at all". Exposure cutoff was set to "At least half the time". The regions for musculoskeletal symptoms considered were low back, neck, shoulder/arm and hand.

2.2. Statistics

Descriptive statistics were constructed for symptoms, vibration exposure, noise exposure, other risk factors, and age stratified for gender. The effect measure used for all analyses was prevalence ratios (PR) with 95% confidence intervals (CI). A proportional hazard model with time set to one was used to assess PR. All analyses were adjusted for gender and age. The relation between symptoms and noise exposure was examined. A multivariate model assessing the relation between risk factors, exposure and symptoms was analyzed. Risk factors included in the multivariate model were significant in a univariate model assessing the relation between factors and symptoms. The relationship between variables was considered with Spearman's rank correlation to avoid multicollinearity, and variables with a correlation >0.7 were not included in the same model. Risk combination factors were analyzed one at a time, adjusted for gender and age. Statistical significance was set to $p \leq 0.05$ or equivalent, and the 95% CI for PR not to include one. All analysis was performed with SAS 9.1. The multivariate analysis models used PROC PHREG.

3. RESULTS

In the sample of 12,546 persons representing the Swedish workforce, exposure to noise and ergonomic stressors such as lifting and bending was frequent among both men and women, whereas vibration exposure, both HAV and WBV, was frequent among men (around 6 percent) but less than one percent among women (Table 1).

Table 1. Descriptive statistics for symptoms and exposure stratified for gender. Data are given as numbers and percent (%). n=12,546.

Variable	Men	Women
Neck	640 (15%)	1417 (30%)
Low back	546 (13%)	867 (19%)
Shoulder/arm	635 (15%)	1265 (28%)
Hand	299 (7%)	631 (14%)
Hearing problems	128 (2%)	121 (2%)
Lifting (15-25 kg)	1277 (29%)	942 (20%)
Lifting (>25 kg)	773 (18%)	462 (10%)
Frequent bending	1528 (35%)	1878 (39%)
Twisted posture	635 (15%)	757 (16%)
Whole body vibration (WBV)	271 (6%)	35 (1%)
Hand-arm vibration (HAV)	295 (7%)	47 (1%)
Noise	834 (19%)	483 (10%)
WBV and Noise	189 (4%)	23 (0.5%)
WBV and no Noise	81 (2%)	12 (0.3%)
WBV and HAV	91 (2%)	9 (0.2%)
WBV and no HAV	175 (4%)	25 (0.5%)
HAV and Noise	211 (5%)	20 (0.4%)
HAV and no Noise	82 (2%)	27 (0.6%)

In a multivariate analysis, hand-arm vibration had a significant prevalence ratio of 1.5 for hand pain, even when controlling for whole body vibration, noise, frequent bending, lifting and twisted posture (Table 2).

The combination of ergonomic stressors gave a prevalence ratio of 14.2 (95% CI 8.6-23.6) for hand pain.

Table 2. Multivariate analysis of musculoskeletal symptoms and hearing symptoms in relation to ergonomic stressors and individual factors. Data are given as prevalence ratios (PR) with 95% confidence interval (CI).

Variables	Hand symptoms		
	PR	95% CI	
Gender (women/men)	2. 3	2.0	2.7
Age	1.03	1.03	1.04
Whole body vibration	1.4	1.0	1.8
Lifting (15-25 kg)	1.4	1.2	1.6
Frequent bending	2.3	2.0	2.7
Twisted posture	1.3	1.1	1.6
Noise	1.6	1.3	1.9
Hand-arm vibration	1.5	1.1	1.9

4. DISCUSSION AND CONCLUSIONS

This study clearly describes the complex nature of physical exposure relation with hand symptoms. We need to consider multiple exposures when preventing musculo-skeletal disorders. The importance of considering ergonomic confounders when evaluating the health effects of HAV exposure is fundamental.

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VIBRATION-WHITE FOOT IN A WORKER WITH DIRECT VIBRATION EXPOSURE TO THE FEET

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1. INTRODUCTION

The acute and chronic effects of segmental vibration exposure to the hands are well documented (Noel, 2000). Chronic exposure to hand-transmitted vibration results in hand-arm vibration syndrome (HAVS), a disorder consisting of vascular, neurological and musculoskeletal pathology in the upper extremities. That a condition analogous to HAVS might occur in the feet after segmental lower-extremity vibration exposure is biologically plausible though not well studied; the presented case (Thompson et al., 2010) represents the first published report on this topic in the English language literature, with only one other case report in a non English journal (Tingsgard et al., 1994).

2. CASE REPORT

A 54-year-old retired miner presented with a 2-3 year history of cold intolerance in his feet and cold-induced blanching in his toes. The worker denied any significant symptoms suggestive of HAVS such as finger blanching, cold intolerance in the hands or numbness and tingling in the fingers. He had worked in the mining industry for 35 years and was exposed to foot-transmitted vibration primarily via the use of underground bolters at least 4 hours per day, 3 days a week in the 4 years immediately preceding assessment. The main control console of underground bolters is located on a platform mounted on the machine. When the machine is in operation the platform vibrates, which exposes the worker standing on the platform to continuous foot-transmitted vibration.

The worker had a past history of hypertension and hypercholesterolemia, and was an ex-smoker with a 35-pack year history of smoking. He stopped smoking 6 years prior to the assessment. Doppler imaging at the time of assessment showed no peripheral artery insufficiency in the arms or legs. The worker had no history of connective tissue disease, diabetes mellitus, gout, arthritis, neurological problems, or thyroid disease. There was no reported history of frostbite to the fingers or toes. The only medication at the time of assessment was rosuvastatin. Physical examination showed blood pressure of 160/90. Heart rhythm was regular. There was no evidence of vessel occlusion on Adson's or Allen's testing. Vascular, neurological and musculoskeletal examination of the lower limbs was unremarkable.

Blood tests for systemic causes of secondary Raynaud's phenomenon, including complete blood count, erythrocyte sedimentation rate, thyroid-stimulating hormone, cryoglobulins, rheumatoid factor, antinuclear antibody and serum immunoelectrophoresis were all normal. Standard testing for HAVS was performed. All results were normal, with the exception of cold provocation plethysmography, which showed normal plethysmographic toe waveforms at room temperature, with significant dampening of the waveforms post cold stress. The results in the fingers were normal. These results were consistent with a vasomotor disturbance in the toes associated with cold sensitivity, but not in the fingers. The worker was diagnosed with vibration white foot. He was advised to avoid cold exposure as much as possible, to dress warmly whenever exposed to cold ambient conditions, and to minimize future vibration exposure to the feet. A trial with a calcium blocking agent was suggested for treatment of his cold-induced vasospastic symptoms. At four months follow-up, the worker reported no change in his symptoms, though he had not yet attempted pharmacological therapy as a treatment option.

3. EXPOSURE ASSESSMENT

Vibration measurements from the platforms of bolting machines and similar platforms upon which miners work indicate vibration exposure at the feet; however, a full description of the conditions under which the measurements have been taken are often not reported. Hedlund (1989) reported that vertical vibration exposure measurements at the feet during the operation of two drills on a metal raise platform exceeded the International Organization for Standardization (ISO) 2631-1 health guidelines after 2.5 hrs of exposure (Hedlund, 1989). Hedlund did not report the frequency weighted vibration acceleration values, though did report the dominant frequency as being 40 Hz. Foot transmitted vibration from bolting off a scissor lift and a bolting platform were reported to be below the International Organization for Standardization (ISO) 2631-1 health guidelines for whole body vibration (WBV) for 8-hrs of exposure (Eger et al., 2006). The dominant frequency was not reported in this study but was confirmed with the author to be 40 Hz [Personal communication; Eger, T.].

4. DISCUSSION

This case demonstrates vasospastic disease in the feet of a worker with a history of foot-transmitted vibration exposure. The diagnosis was based on history of segmental vibration exposure to the feet, compatible symptoms, a negative work-up for other secondary causes of Raynaud's phenomenon, and documentation of cold-induced vasospasm in the toes by plethysmography. Unremarkable Doppler investigation argued against significant peripheral arterial insufficiency, while Buerger's disease was deemed unlikely given the worker's current non-smoking status, lack of findings in the hands, normal laboratory investigations, and normal baseline plethysmography.

Postulated vascular pathophysiological mechanisms of vibration syndrome (local and systemic) include: 1) vasospasm resulting from centrally mediated increased sympathetic tone; 2) increased circulating systemic vasoactive mediators such as endothelin-1; 3) vasospasm due to local selective loss of calcitonin-gene-related peptide (CGRP) fibers in the digits, resulting in an imbalance between endothelin-1 (vasodilator) and CGRP nerve fibers (vasoconstrictor); 4) hypertrophy of smooth muscle cells due to repetitive episodes of vasoconstriction; 5) microangiopathy as a result of direct trauma from segmental vibration exposure, and 6) arterial thrombosis due to traumatic shear stress to the vascular endothelium, triggering a coagulation cascade. These postulated mechanisms help to explain why symptoms are usually most severe in the extremities directly exposed to vibration (in this case the feet), while non-exposed extremities tend to have less severe symptoms best attributed to central mechanisms and circulating systemic vasospastic mediators.

The literature provides some insight into the characteristics of vibration levels from mining machines applicable to foot-transmitted vibration. While reported acceleration values vary, the dominant frequency appears to be in the 40 Hz range (Hedlund, 1989; Eger et al., 2006). The current guideline used for assessing health risks from vibrating platforms in mining is the ISO 2631-1 health guideline for whole body vibration (WBV). However, the frequency weighted acceleration values in ISO 2631-1 are focused on frequencies between 1 and 20 Hz (resonant frequencies for the pelvis and spine), while the relevant anatomic factors of the feet and toes might be expected to be more analogous to the finger-hand-arm system which is more susceptible to vibration at higher frequencies (40-100 Hz for the hand-arm system, and > 100 Hz for the fingers) (Dong et al., 2004). If this is the case, workers exposed to foot-transmitted vibration through platforms, drills and bolters, where the dominant frequency is 40-50 Hz, may not be protected by the ISO health risk guidelines, and may be at risk of developing vascular dysfunction in the feet. Additional research is needed to characterize foot exposures and to determine which workers are at greatest risk for developing vibration-white foot.

A population-based prevalence estimate for the number of workers exposed to foot-transmitted vibration is not available. The United States Bureau of Labor Statistics 2009 estimates 4,950 workers roof bolters in mining (BLS 2009). While not all of these workers would use vehicle-mounted underground bolters (as in this case), the prevalence of foot exposure to vibration in the mining sector may increase as greater use is made of mechanized equipment for drilling, bolting and moving materials (McPhee B, 2004). Foot-transmitted vibration may also occur in the use of other equipment and locations, such as forklifts operated from a standing position, jacklegs in construction, and crusher plant operations (the platform the operator stands on may not be isolated from the crusher).

No exposure limits exist for prevention of foot vascular effects from direct vibration exposure to the feet. The ISO provides guidelines for whole body and hand-arm vibration exposure assessment and risk evaluation, but as noted in this report, vibration white foot may not be adequately prevented by use of the whole body guideline. Legislation in the European Union controls occupational exposure to hand-arm vibration. The U.S. American Conference of Governmental Industrial Hygienists has exposure limits for whole body and hand-transmitted vibration. In Ontario, where this case was seen, there are no regulations for hand-arm or whole body vibration, though the general duty of employers to protect workers might be interpreted as requiring them to observe the exposure limits of other jurisdictions. In the future, foot transmitted vibration may be considered as an additional hazard requiring attention.

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NEW STANDARD CRITERIA FOR COLD PROVOCATION TEST WITH HAND IMMERSION FOR CASES OF HAVS IN JAPAN

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1. INTRODUCTION

In Japan, physicians diagnose hand-arm vibration syndrome (HAVS), a peripheral circulatory disorder, with a cold provocation test (Harada et al., 1999). However, there are no standard protocols for the performance of this test, although several standards have been proposed and used for diagnosis of HAVS. The inconsistencies have led to confusion among practitioners who treat patients with HAVS, and there is demand for a national standard. ISO 14835-1:2005 recommends that the cold provocation test be performed with 12°C water and immersion of the hands for 5 min. However, there is extensive data in Japan where the cold-water provocation test is performed in 10°C water for 10 min. This study aimed to establish a national standard for cold-water provocation tests based on an analysis of Japanese multi-institutional data.

2. METHODS

We collected data from 872 individuals (667 patients, 205 controls) who underwent cold-water provocation testing (10°C for 10 min) at 7 institutions. Data from 340 individuals (280 patients 280, 60 controls) met the selection criteria for analysis (Table 1).

Table 1. Subject selection criteria

Items	Conditions
Age (yrs)	40-69
Sex	Male only
Vibration Exposure and Diagnoses	
Controls	None or < 500 h
Patients	More than 500 h
VWF	+ve within 1 yr of cold provocation test
Complication	No complications of collagen diseases and arteriosclerosis obliterans (ASO)
Testing Conditions	
Season of year	Autumn to winter
Test room T (°C)	20 – 23

2.1. Analysis Index

Three (3) indices were used for the analysis of finger skin temperature:
1) finger skin temperature before immersion,
2) finger skin temperature 5 min after immersion, and
3) finger skin temperature 10 min after immersion.

2.2. Evaluation System

We incorporated the scores from the above 3 indices into an evaluation system that logically combined them. We used the cut-off values for evaluation of the 3 indices. The 5th and 30th percentile cut-off values in the control group were applied (Table 2).

Table 2. The cut-off values for each evaluation systems

Cut-off value	5th percentile	30th percentile
Before immersion (°C)	24.5	30.0
5 min. after immersion (°C)	14.0	15.5
10 min. after immersion (°C)	15.5	18.0

Scored method

If the skin temperature at each time point (the 3 indices) was lower than the value of 5th percentile value, the score was 2 points. If the skin temperature was higher than the 30th percentile value, the score was zero. The score was 1 point in all other cases. The total scores were classified as, "highly abnormal" (total score ≥ 4 points), "slightly abnormal" (2 points ≤ total score ≤ 3 points), and "normal" (total score ≤ 1 point).

Logical method

First, we assigned the skin temperature for each index to 3 ranges based on the cut-off values, "normal range" (≥ 30th percentile)", "abnormal range" (5th percentile ≤ value ≤ 30th percentile)" and "highly abnormal range" (≤ 5th percentile)" for each index. According to the logical combination of these levels, we judged subjects "normal" when all 3 indices were within "normal range". When 1 or more indices were in the “highly abnormal range”, the case was judged “highly abnormal”. All other cases were judged “slightly abnormal”.

3. RESULTS

The mean ages of the patients and control groups were 59.4 and 51.1 years, respectively. The mean exposure duration to vibration was 22.5 years in the patient group. The most frequently used vibrating tools were chain saws (34%) and chipping hammer (25%) in the patient group. In contrast, bush cutters were used only by members of the control group. When compared to the control group, members of the patient group with vibration white finger (VWF) had significantly lower average values for the 3 indices (Table 3).

Table 3. The comparison of skin temperature at 3 points during cold provocation test between two groups.

Finger skin temperature (℃)	Patient Group (n = 280)	Control group (n = 60)	Statistics
Before immersion	27.4	30.6	P<0.001
5 min. after immersion	15.3	18.0	P<0.001
10 min. after immersion	17.6	21.9	P<0.001

According to the scored method, 28.3% and 71.7% of patients were designated normal and abnormal, respectively. The control group was 72.0% normal and 28.0% abnormal. The logical method designated 29.4% and 70.6% of patients as normal and abnormal.

The sensitivity and specificity of the scored method were 71.7% and 72.0%, while the logical combination evaluation system yielded sensitivity and specificity values of 70.6% and 74.0% (Table 4).

Table 4. Sensitivity and specificity of diagnosis by two evaluation methods.

Evaluation system	Sensitivity (%)	Specificity (%)
Scored method	71.7	72.0
Logical method	70.6	74.0

4. DISCUSSION

We propose two standard criteria after performing an analysis of data from seven Japanese institutions. This study provides new standard criteria for the evaluation of peripheral circulatory disorders, and for the diagnosis of HAVS.

Several Japanese groups have proposed standard criteria for evaluation of cold provocation test with hand immersion for 10 min in 10°C water. However, the choice of which criteria to apply remains at the physician’s discretion. Variations in criteria lead to variations in the evaluation of peripheral circulatory function. Many measurement parameters have been used in the evaluation of the cold provocation test, such as rewarming time to room temperature, and rewarming rate at 5 and 10 min after immersion, but skin temperature has not been used (Harada, 2008). We used three skin temperature measurements in this study. We did not apply the common Japanese parameters of rewarming rate. There is some possibility of underestimation in the cases of low skin temperature before immersion.

In this study, we applied two methods for evaluation. There was little difference between the methods’ sensitivity and specificity. However, while it was easy to convert the data to scores by weighting according to the scoring method, the logical method was practical and easy to perform. We believe it to be the better choice for defining standard criteria.

When we use these criteria, we should consider several points. Firstly, we could not strictly apply these criteria to patients without VWF. We examined the application of the criteria only in patients with VWF. This problem still remains to be solved in a future study. Second, the provocation test should be performed under the measurement conditions recommended by ISO. In recent years, there has been growing controversy regarding the diagnostic ability of the cold provocation test in distinguishing patients with VWF. These standard criteria are only one evaluation method for diagnosing peripheral circulatory disorder in patients with HAVS. Diagnosis of HAVS should involve a comprehensive evaluation including occupational history, subjective symptoms, physical examinations, and laboratory examinations.

5. CONCLUSION

New national standard criteria are expected to facilitate the diagnostic ability for the cold provocation test used in Japan.

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EXAMINATION OF THE ADAPTOR APPROACH FOR THE MEASUREMENT OF HAND-TRANSMITTED VIBRATION EXPOSURE

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1. INTRODUCTION

According to the current ISO 5349-2 (2001) [1], hand-transmitted vibration (HTV) exposure should be measured using accelerometers rigidly fixed on the vibrating surface in the hand contact areas. If it is difficult to apply this approach, HTV can be alternatively measured using an adaptor held in the hand (ISO 5349-2, 2001) [2]. Compared with the direct approach, the adaptor approach has several advantages if applied appropriately. For example, it could be more efficient for the measurement and less intrusive to the tool operation; hence, it may be suitable for a long-term monitoring measurement. Probably for this reason, the adaptor approach has been considered in the development of some convenient or direct-reading devices for HTV measurement. However, it is not the preferred option in the standardized methodology, primarily because the adaptor vibration could be affected by the inconsistency of the hand-applied forces and the biodynamic response of the hand. The objectives of this study are to find the specific mechanisms of the biodynamic effects and to identify the optimized design of the adaptor and/or its hand-holding strategy so that the undesired effects could be minimized.

Palm adapter

Finger adapter

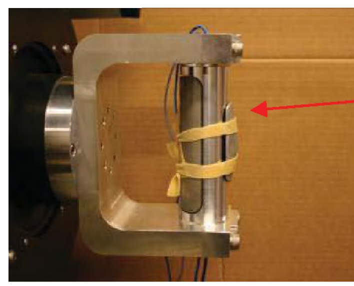
Miniature adapter held in the palm of a glove

Figure 1: A pictorial view of three adapters

2. METHOD

Three typical adapters were considered in this study, as shown in Figure 1. The first one is a palm adapter designed based on the requirements of ISO 10819 (1996) [3], and it was built in house. The second one is a finger adapter similar to a commercially available model [4], and the third one is a miniature adapter held in the palm of a glove [5]. All three adapters were equipped with tri-axial accelerometers. The experiment was carried out on a hand-arm vibration test system equipped with an instrumented handle that can measure the tri-axial vibration excitations and the applied grip force. A force plate was used to measure the applied push force on the handle.

To establish the baseline measurement, each adapter was attached to the handle along the vibration direction, as shown in Figure 2. The vibrations in three orthogonal directions on both the adapter and handle were simultaneously measured.



Palm adapter attached to the hand with rubber bands

Figure 2: Test setup for measuring the baseline value of the palm adapter. The other two adapters were separately attached to the handle in a similar manner.

In the subject test, each of the adapters was held at its designed position at the fingers or palm of the hand, as shown in Figure 3. Three subjects participated in the test of the palm adapter and two of them participated in the tests of the other two adapters. Each of the subjects applied 30 N grip force and 50 N push force on the handle in the tests.

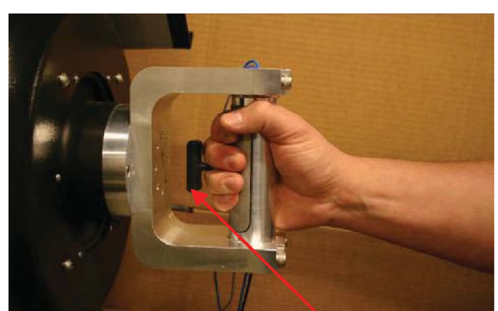


Figure 3: Subject test of the finger adapter

3. RESULTS AND DISCUSSIONS

The vector sums of the three axes accelerations (root-mean-square values) at each one-third octave band frequency were calculated and used to evaluate the adapters.

Figure 4 shows the vibration transmissibility functions of the palm adapter under different test conditions. Large drifts from the baseline values were observed at the low and middle frequencies (<100 Hz). The variations were also subject- and test trial-dependent. It is thus difficult to correct the potential errors in the post-data analyses. The drifts primarily resulted from the rocking movements of the adapter that is largely influenced by the biodynamic response of the hand. This principle suggests that the potential measurement errors could also be adapter-specific.

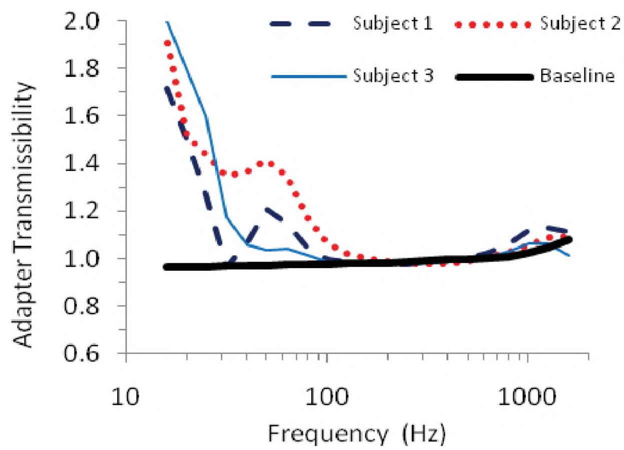


Figure 4: Comparison of baseline transmissibility of the palm adapter with those measured with three subjects.

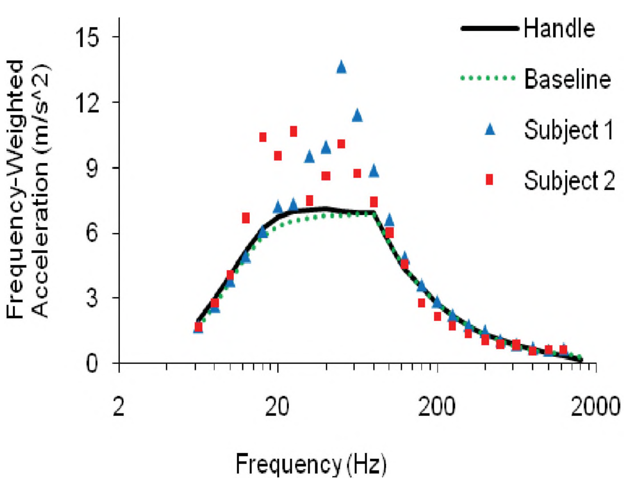


Figure 5: Comparisons of excitation/handle accelerations, baseline values of the finger adapter, and test results.

Figure 5 shows the results of the finger adapter tests. The vibration of a finger adapter could be greatly affected in the frequency range from 25 to 80 Hz, especially in the range (30 to 50 Hz) of the fundamental resonance of the hand-arm system. The rotational vibration was also identified as one of the major sources affecting the translational vibration measurement required in the risk assessment of HTV exposure.

Figure 6 shows the results measured with the miniature adapter held in the palm of the glove. This adapter approach provided with the most reliable measurement of the frequency-weighted acceleration [1].

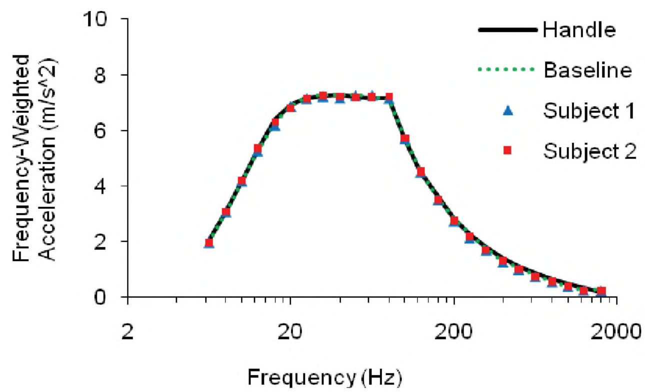


Figure 6: Comparisons of excitation/handle accelerations, baseline values of the miniature adapter held at the palm of a glove, and its subject test results.

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METHOD TO EVALUATE THE RUNNING TIME OF PNEUMATIC TOOLS IN A CAR WORKSHOP

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1. INTRODUCTION

In Finland, there are about 2 million cars. Approximately 50,000 cars are serviced every day. Although the new European Vibration Directive (2002/44/EC) has been implemented in the Finnish legislation since 2005, the adverse effects of hand-arm vibration are poorly identified in workplaces and in occupational health care.

In car workshops, several pneumatic tools are used. The most common tools are impact wrenches, grinders and sanders.

According to Palmer at al (1998), the self-evaluation of exposure time is not a reliable method to estimate worker exposures. Even immediately after the end of a work shift, the self-evaluation results are inaccurate when using questionnaires or interviews. Several potential sources for errors can be found, including -

- time estimations – for example, rounding the results to the nearest 5 or 10 minutes, or rounding up to the next full minute, when the exposure time is less than one minute;
- repeated short exposure times;
- workers tend to estimate the length of task instead of the trigger time;
- the number of tasks using vibrating tools;
- the number of vibrating tools in use;
- variations in daily usage times; and,
- the varying names of tasks and tools.

All these errors are present in evaluations of vibration exposures in car workshops. According to Palmer et al (2001) and Åkesson (1998), the average trigger time in car workshops is 14 minutes and weighted average levels during that time is 3.55 m/s^2. These results do not correspond to the observed prevalence of Vibration White Finger (VWF) symptoms.

The purpose of the study is to develop a measuring device capable of measuring the actual trigger times of several working points simultaneously.

2. APPARATUS AND METHOD

2.1. Apparatus

The system consists of several (1-16) high precision digital pressure switches (SMS ZSE30A) capable of fast detection of pressure (Figure 1). The switches have a common power supply delivering 12 V DC. The pressure signal was directed to a A/D-converter (Agilent 3481A), and was sampled two times per second. The readings were data logged to the hard disk of a computer with software developed with Agilent VEE-Pro 6.0. The software displayed the pressure and stored the data on the disk (Figure 2).

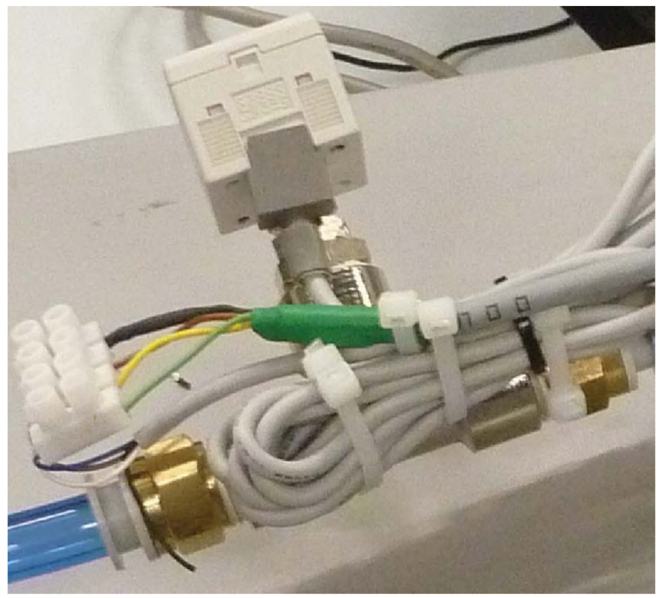


Figure 1. The pressure switch and its connection to air supply.

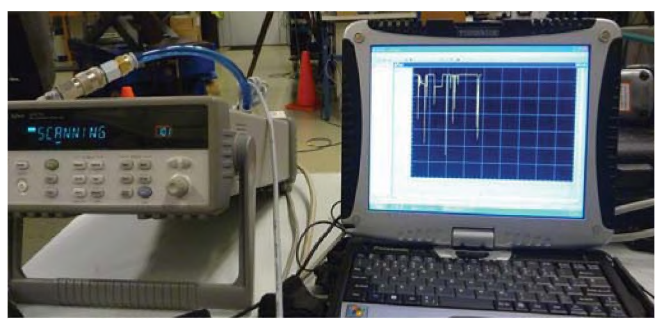
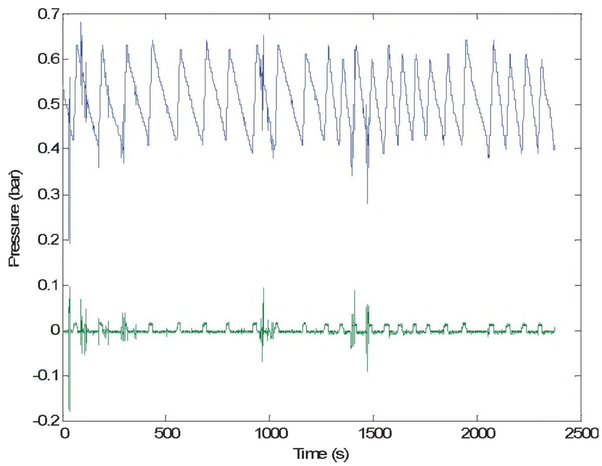


Figure 2. Data logger and display with one channel logging.

3. RESULTS

A typical measurement result is shown in Figure 3 – the upper curve. The pressure curve shows pressure changes caused by the use of tools and the slow variation caused by the relay control of the air compressor.

Figure 3. Typical pressure reading from one channel. Upper curve is the measurement curve. (The curve is brought down by 3 bar for better resolution.) Lower curve is the high-pass filtered upper curve.



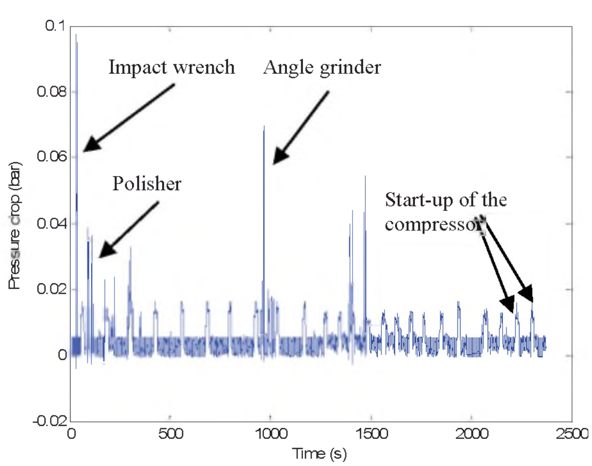
By using a simple high pass filter -

```
y(i)=a*y(i-1)+b*(x(i)-x(i-1))/(a+b)
```

where y is (i) the filtered curve at point I, and x is the measured curve at point (i), the lower curve is created presenting only the tool use. Pressure drops at measuring point are tool dependent (Figure 4).

Simple mathematics can be used to recognize the running time. In Figure 4, the absolute value of high-pass filtered signal has been smoothed using the Savitsky-Golay smoothing. The height of the peak gives the air consumption and the width gives the trigger time. As the power consumption varies, different tools may be identified from the signal. In Figure 4, the start-up of the compressor is also visible as short peaks, which is easy to detect.

Figure 4. Running time of tools recognized by squaring and smoothing the data



4. DISCUSSION

With this equipment, it is easy to monitor up to 16 working points simultaneously. The system is easy to mount in any car workshop, simply by changing the plugs. Of course, installing the cables in such way that they do not disturb the work takes some time.

The system has been tested in one car shop where a pressure regulator did not exist, as well as in a laboratory workshop where a pressure regulator was in all outputs. The results were similar. The equipment does not recognize the tool in use, but tools can often be identified by the height of peak.

Of course, if several tools are in use, the accuracy of the recognition decreases. In the car workshops, 70-80 % of exposure is due to the use of one or two tools. This is reasonable accuracy.

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DEVELOPMENT OF A LOW-COST SYSTEM TO EVALUATE COUPLING FORCES ON REAL POWER TOOL HANDLES

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1. INTRODUCTION

Risk assessment of hand-arm vibration is currently performed following the guidelines of the ISO 5349-1 (2001) standard, by applying a frequency weighting on the measured tool handle acceleration. However, it is known that the health risks associated to hand-arm vibration also depend on the static coupling forces such as the push and grip forces applied on the handle. Indeed, several studies have shown that vibration absorbed and/or transmitted to the hand-arm system depends upon the static coupling forces exerted between the hand and tool handle (Adewusi et al., 2010; Burstrom, 1997; Dong et al., 2004; Kihlberg, 1995; Marcotte et al., 2005). To take into account the effect of the coupling forces when assessing hand-arm vibration exposure, it has been suggested to add a coupling factor to the frequency weighted acceleration (Reidel, 1995). Lemerle et al. (2008) have proposed a system based on a pressure mat to measure the pressure distribution at the hand-handle interface. From the pressure distribution, the static push/pull and grip forces are calculated as defined in the ISO 15230 (2007) standard. In this paper, it is proposed to use a low cost system based on two rigid thin film pressure sensors located on two sections of the handle between the operator hand and the tool handle. It is hypothesized that the grip and push forces can be estimated using two single distributed force sensor elements: one positioned between the palm and the handle and the other between the finger and the handle. The preliminary design and validation for such a system will be presented.

2. METHODS

The proposed system is made of two custom *FlexiForce®* sensors from *Tekscan Inc*. These sensors act as single distributed force sensors and can be trimmed to the desired shape and size. Each sensor is connected through a signal conditioner/amplifier. The sensors are positioned to partially cover the finger and palm sides of the handle, as shown in Figure 1. The coverage of the handle can be optimized in order to maximize the force measured in the axial direction (z_h-axis in this case) while minimizing the force measured in the tangential direction (x_h-axis). Let us define F_1, the force measured by the finger sensor (Sensor 1), and F_2, the force measured by the palm sensor (Sensor 2) It can be shown that the grip (F_g) and push forces (F_p) can be estimated using the following equations:

$$F_p = F_2 - F_1 \qquad (1)$$

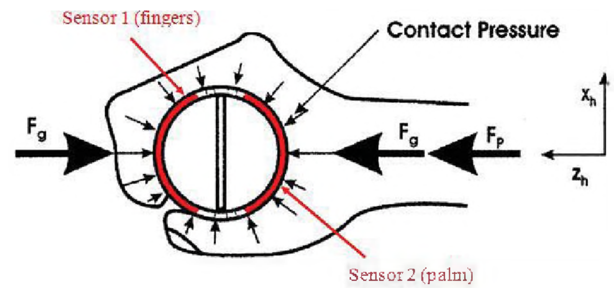

Figure 1. Schematic of the proposed system to measured the grip and push forces.

$$F_g = ½ (F_1 + F_2 - | F_2 - F_1 |) \qquad (2)$$

Where | A | denotes the absolute value of A. A negative value for F_p indicates a pulling rather than a pushing force.

2.1. Calibration of the Sensor on a Flat Surface

The sensors with its amplifier were first calibrated on a flat surface by applying a force distributed over its entire area. The static forces were applied with a digital force gauge to values between 20 and 200 N with increment of 10 N. Three loading and unloadings were performed in order to evaluate the linearity and repeatability of the sensor.

2.2. Validation of the Sensor on an Instrumented Handle

The second test was performed on a split cylindrical handle having a diameter of 40mm. The handle is mounted on a shaker and is instrumented to measure the grip and push forces (Marcotte et al., 2005). Two *Flexiforce* sensors were attached to the handle with double sided tape as in the configuration shown in Figure 1. Four male subjects were asked to apply grip force to the handle from 10 to 80 N, with increment of 10 N. Each subject repeated the measurements three times. The process was then repeated for push forces applied to the handle from 10 to 80 N, with increment of 10 N. The grip and push forces were measured by the force sensors integrated in the instrumented handle.

3. RESULTS

3.1. Calibration of the Sensor on a Flat Surface

The outputs of the sensor, as a function of the force applied on the pressure sensor on a flat surface, are shown in Figure 2 for three trials in loading conditions (applied force is gradually increased). Linear correlation coefficients

(R^2) slightly above 0.99 were obtained for each of the three trials, confirming the linearity of the sensor. Similar results were obtained while unloading the sensor (not shown here) suggesting minimal hysteresis.

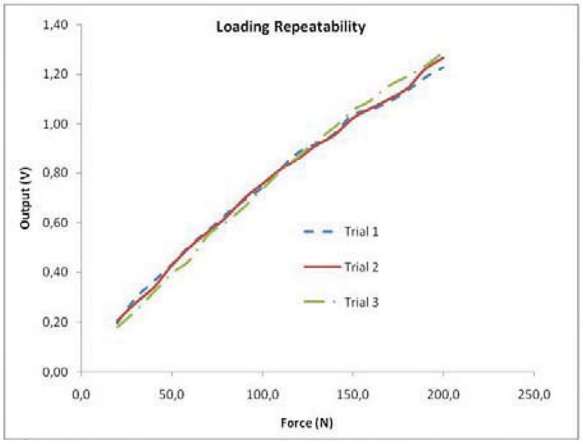

Figure 2. Output signal from the sensor as a function of the applied force: loading on a flat surface.

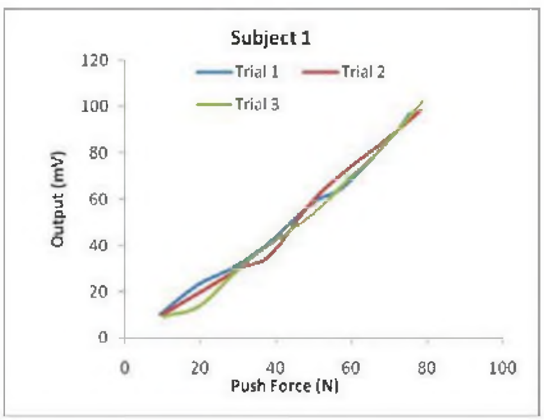

Figure 3. Output signal from the sensor on the palm side as a function of the measured push force on the handle.

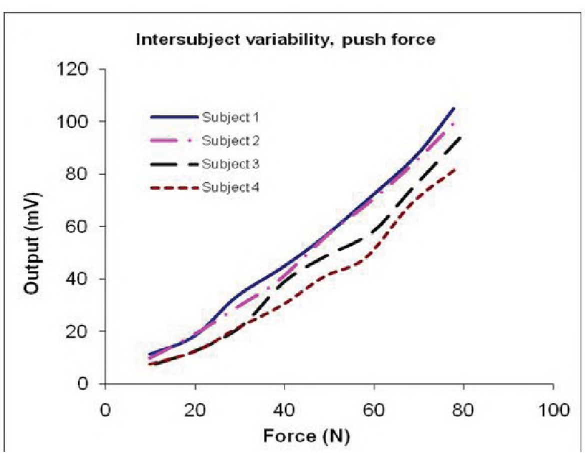

Figure 4. Intersubject variability for the push force measurement.

3.2. Validation of the Sensor on an Instrumented Handle

Figure 3 shows the palm sensor responses, as a function of push force applied by one of the subjects for three different trials. Linear correlation coefficients slightly above 0.98 were achieved for all three trials. However, some subjects have achieved lower linear correlation coefficients (0.93 and above). Similar results were obtained for the grip force (not shown here), using the finger sensor.

For each subject, the data of the three trials were averaged and are shown in Figure 4 for the push force. The Figure shows limited inter-subject variability for the push force. Similar results were obtained for the grip force (not shown here). These results suggest the proposed sensor could be of interest to estimate the grip and push forces on real handles.

4. DISCUSSION AND CONCLUSIONS

A low cost sensor based on thin *FlexiForce*® sensors has been proposed and validated. Preliminary results suggest that the new sensor is suitable to estimate the grip and push force on a cylindrical handle.

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Laboratory Assessment of Vibration Emissions from Vibrating Forks used in Simulated Beach Cleaning

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1. INTRODUCTION

As part of NIOSH's response to the BP Deepwater Horizon oil spill, representatives traveled to the gulf coast to observe and assess workers involved in beach cleaning operations, to identify potential hazards and to provide guidance for protecting response workers. One beach cleaning operation involved the use of lightweight, battery-powered, motorized vibrating manure forks to remove tar balls and patties from beach sand. To investigate the vibration exposures associated with these operations, we performed a laboratory study on the vibrations produced by the forks operated during simulated beach cleaning. The objectives of this study were to characterize the vibrations associated with the use of vibrating manure forks and to estimate vibration exposure time limits based on the recommendations of ANSI S2.70-2006.

2. METHODS

The test apparatus for the laboratory study consisted of a mortar-mixing tub filled with a fairly homogenous mixture of moist sand and debris (pine bark mulch and golf balls). The vibrating forks evaluated in this study were Shake'n Fork™ models (Equi-Tee Manufacturing, Oregon, USA). Two fork models were evaluated in the study. One featured a variable-speed motor with a top speed of 980 rpm; the second fork had a top speed of 1400 rpm. There were two different basket arrangements evaluated. Both baskets featured plastic tines with 1/2-inch spacing. One basket featured a section of wire screen (1/4-inch mesh) attached to its tines. With two motors and two baskets, there were four different tool configurations evaluated in the experiment.

Eight adults (four male, four female) were recruited to operate the forks. To complete the simulated work task, the operator used a fork to scoop sand and debris out of the mortar-mixing tub. As shown in Figure 1, the subject stood on a platform-mounted force plate and used a two-handed posture to control the tool. The subject placed their dominant hand on the upper handle, while their non-dominant hand supported the fork handle near its midpoint. The operator inserted the fork into the tub, scooped a load of sand and debris, and lifted the loaded fork 12 to 18 inches directly above the tub. Once the basket load was weighed and adjusted to within 50±5 N, the operator was signaled to start the fork's shaker motor by fully depressing the tool's handle-mounted trigger.

The four tool configurations were presented to the subjects in random fashion. Each tool configuration was subjected to a measurement sequence of eight consecutive trials. The first five trials in the sequence were completed with the basket loaded; the next three trials were completed with an empty basket. Vibration data were collected for eight seconds per trial. Once eight trials were completed with a particular motor/basket combination, the next motor/basket configuration was presented to the operator and the sequence was repeated.

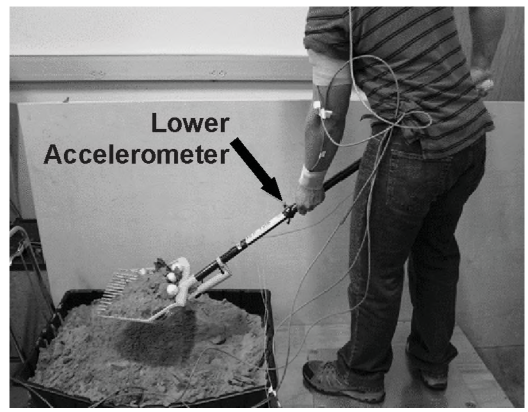

Figure 1. Simulated beach cleaning operation.

Two piezoelectric triaxial accelerometers were used to measure the vibration emissions. The lower accelerometer was affixed near the midpoint of the tool handle just below the operator's non-dominant hand (see Figure 1). The upper accelerometer was affixed near the handle-mounted trigger. The root-sum-of-squares (total) values of the r.m.s. accelerations were weighted according to the frequency-weighting factors given in ISO 5349-1, 2001.

Estimated daily vibration exposure values, A(8), were calculated using the methods outlined in ISO 5349-2, 2001 and ANSI S2.70-2006. The vibration measurements were used to estimate the maximum amount of vibration exposure time per eight-hour work shift that a user could operate a particular fork configuration without exceeding the ANSI Daily Exposure Action Value (DEAV=2.5m/s^2) and the Daily Exposure Limit Value (DELV=5.0m/s^2).

3. RESULTS

The frequency-weighted acceleration means for the upper and lower accelerometers are presented in Figure 2. ANOVA results indicate that the mean acceleration for the fast fork was significantly higher than that for the slow fork. The tines-only basket produced higher accelerations than the basket with the wire mesh screen. Acceleration was higher for the unloaded forks as compared to the loaded forks. The accelerometer mounted lower on the fork measured higher vibrations than the upper accelerometer.

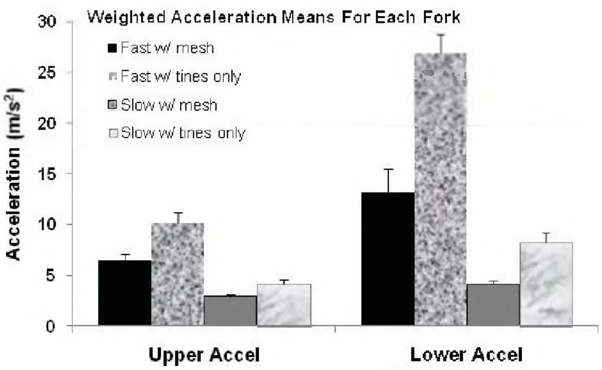

Figure 2. Weighted acceleration means for each fork with the baskets in the loaded condition. (Error bars equal +1 SD).

As indicated in Table 1, the tines-only fast fork could be operated for only four minutes at maximum speed before reaching the ANSI DEAV. On the other hand, the slow fork with the mesh basket could be operated at full throttle for almost three hours before reaching the action value.

Table 1. Operation time limits for each configuration to remain below the ANSI S2.70-2006 DEAV and DELV.

Motor	Basket	a_{hv} (m/s^2)	T_{DEAV} (min)	T_{DELV} (min)
Fast	Wire mesh	13.10	17	70
Fast	Tines only	26.89	4	17
Slow	Wire mesh	4.14	175	702
Slow	Tines only	8.27	44	175

4. DISCUSSION & RECOMMENDATIONS

The frequency-weighted accelerations in this study were found to be substantial, especially those for the non-dominant hand. It should be noted that all of the measurements were collected with the fork motors operating at maximum speed. In actual beach cleaning operations during the BP Deepwater Horizon oil spill cleanup, these tools were not always operated at full speed. Furthermore, the forks were seldom operated without a load. Thus, actual hand-arm vibration exposures in the field may be lower than the values reported here.

The dominant frequency of these tools is about 20 Hz. There is little to no epidemiological evidence to indicate that tools with dominant frequencies below 25 Hz can be associated with vibration-induced white finger (Griffin, 1990). And while low-frequency percussive tools have been linked to bone and joint disorders (Gemne and Saraste, 1987), non-percussive tools have not been implicated in the causation of such disorders. These observations have led to much debate about the appropriateness of the frequency weighting presented in the ISO standard, especially at lower frequencies (Bovenzi, 1998). Therefore, it remains debatable whether or not the ANSI DEAV and DELV limits are applicable to low-frequency, non-percussive tools, such as the vibrating forks evaluated in the present study. Even if the ANSI action and limit values are too conservative for this tool type, the high levels of vibration observed could cause considerable discomfort in the arms, shoulders, neck, and head, because low-frequency vibration can be effectively transmitted to these substructures. Recommendations based on this study are as follows:

Limit run time – Operators of these forks should reduce the amount of "trigger time" to short bursts that are just sufficient to separate the debris from the beach sand.
Operate the forks at the lowest possible speed – The forks are equipped with variable-speed motors. Faster operating speeds results in higher vibration exposures. These forks should be operated with just enough speed to get the job done; it is usually not necessary to fully depress the trigger.
Do not operate the forks unloaded – The loaded basket helps to dampen the vibration. These forks should not be operated in the unloaded condition.
Do not use anti-vibration gloves with these tools – Anti-vibration gloves are not effective at attenuating low-frequency vibrations, and may even amplify certain frequencies below 150 Hz (ISO 10819:1996). The dominant frequency for these vibrating forks is around 20 Hz, therefore use of anti-vibration gloves is not appropriate

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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

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GUNSHOT POWER ABSORPTION FIELD MEASUREMENT

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1. INTRODUCTION

Risk assessment and evaluation of impulsive vibration is an unfinished task with many unknown aspects. One of the questions that arises in the literature is whether the absorbed power is a suitable indicator of exposure. In order to contribute to the acquisition of a wider data collection on the topic, a measurement chain dedicated to impulsive vibration has been designed and tested for acquiring absorbed power in the field. The apparatus has been field tested on a firing range, while acquiring data on gunshots. The goals of the testing were to establish the reliability of the measurements and compare the acquired data with other available absorbed power data. The main difficulty is to capture the extreme dynamics of the gunshot and the subsequent difficulty of absorbed power post processing.

The selection of the accelerometer is crucial: it needs a fast response and wide dynamic range to follow the rapid rise in acceleration. Early measurements showed high acceleration on a time basis of some tenths of a second. This is very relevant because the acceleration will be integrated to give velocity for the computation of absorbed power. The acquisition of force is performed with a load cell at the same point of accelerometer. Absorbed power is evaluated in post processing. The high frequencies elicited by the shot require an adaptor that is non resonant even at those frequencies and a rigid attachment to the butt.

2. METHODS

The aim of present work is to measure acceleration and force on the butt of a gun (Beretta 92 FSB) with a triaxial accelerometer (PCB SEN026, USA; sensitivity 10mV/g) and a load cell (FGP Sensor & Instruments, FGPXFL212R, France) both mounted in an adaptor. That made the instrumentation portable. Numerical integration of acceleration gives velocity and its product with force gives absorbed power. The experimental setup has been shown in detail in another communication at this conference. The gun is the standard ordnance side weapon of the NATO Treaty. The bore is 9 mm, the caliber is 9 x 19 NATO; the magazine holds 15 rounds, and the unloaded weight is 975 g. Measurements have been done with the magazine always fully loaded. The distance between target and firing position was 10 m (training range). The firing position was with the arm fully extended. Subjects were asked to fire single shots, and three shots sequences. The force level was not shown to the subject, but it was recorded. Both signals (acceleration and force) were acquired by an OROS OR 38. The sampling frequency was 5.12 kHz. Analysis was done with MatLab software. Signals have been processed in a time windows of three seconds. We evaluated VPA on single and three shots. In addition we computed the crest factor and the root mean square (r.m.s) value of the weighted acceleration following the UNI EN ISO 5349 [1].

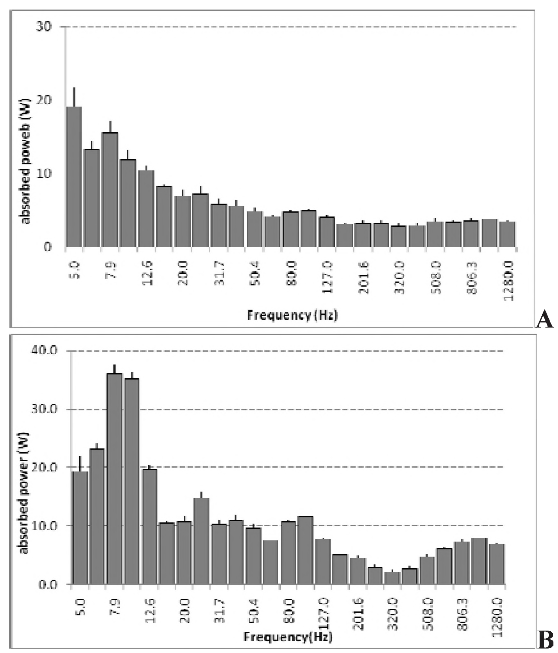

Figure 1. A: Frequency absorbed power for single shot; B: Frequency absorbed power for three shots.

3. RESULTS

Figure 1A shows a 1/3 octave band analysis for single shots, and Figure 1B for three shots. Figure 2 shows the time profile of the acceleration and its frequency-weighted value. Evaluation of the crest factor requires the signals to be weighted; weighting curve W_h has been used, [1] and leads to an attenuation of the extreme acceleration magnitudes. Finally, different levels of absorbed power for single and multiple shots are shown in Figure 3, from which was calculated the energy absorption. Power and energy absorbed, acceleration and crest factor values are listed in Table 1, either for single and multiple shots. The higher standard deviation of the crest factor is probably due to the variability of different subjects holding the gun.

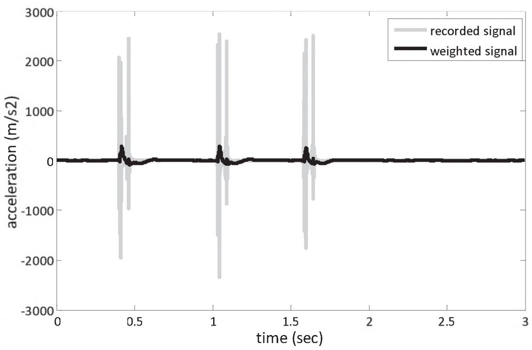

Figure 2. Acceleration signal recorded and its shape after applying weighting curve W_h.

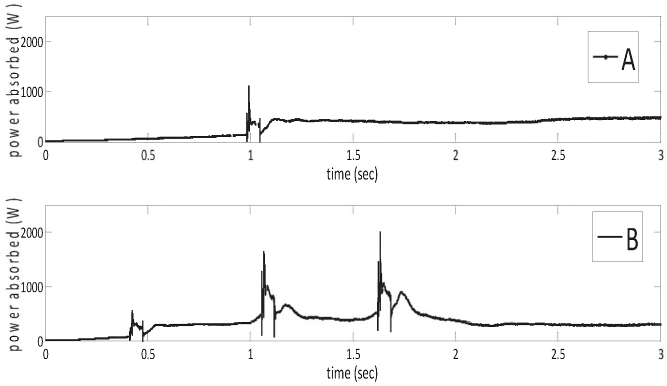

Figure 3. Power absorption for: A - single and, B - triple shots.

Table 1. Absorbed power, energy, acceleration & crest factor

	1 shot	3 shots
Absorbed power rms (W)	38.9±1.3	72.4±1.7
Absorbed energy (J)	14.5±1.9	174±2.3
Weighted acceleration rms (m/s^2)	6.62±1.5	10.4±2.1
Crest factor	10.1±5.1	8.6±3.2

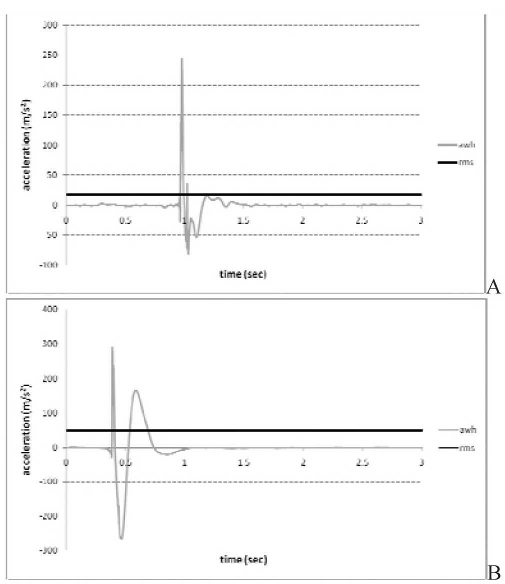

Figure 3. A: Maximum peak value of force - 425 N, B: Maximum peak value of force - 261 N.

Higher force values tend to increase the crest factor, while they reduce the r.m.s. value. Otherwise, there is the relative independence of absorbed power on the force exerted (38 W- 40W).

4. DISCUSSION AND CONCLUSIONS

Gunshot absorbed power has a rather high value, if compared with other working activity involving vibration exposure. The firing of a semi-automatic gun is a composite action. It can be divided in two phases: shooting and reloading. In both, there is an acceleration and a grip force, but the frequencies are different. As a matter of fact, the shot is a true impulsive vibration, while reloading is a mechanical movement. As illustrated in a companion paper at this conference, shooting has a wide frequency range while reloading is mainly concentrated at low frequencies (since it is essentially a motion). This difference can be seen in Figure 1 by comparing the spectra for one and three shots. Since both actions contribute to absorbed power, the three shots sequence produces an increase of both low and high frequency bands with respect to a single shot. This can also be seen in Table 1, where the crest factor for three shots is less than expected for a pure impulsive vibration with such energy. The increase of crest factor with higher grip force accounts for the stiffening of the gun motion while reloading. The absorbed power is, on the contrary, rather insensitive to increasing force because it is uncorrelated to the r.m.s. value.

The increase of absorbed power is not linear with the number of rounds shot, as can be seen from Figure 3 and from Table 1. This is probably due to the increment of grip force on subsequent shots. The hand is more relaxed when the shooter knows he/she will fire a single shot rather than a three shot sequence. The lower recoil (for the sequence) influences the absorbed power from the second phase (reloading).

Absorbed power measurement seems to be a promising parameter for the study of the risk assessment of gunshots and, more generally, impulsive vibration. This preliminary study will be followed by more extensive investigations, even with a revolving gun, to avoid the reloading phase and its consequences.

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INVESTIGATION OF THE 3-D VIBRATION TRANSMISSIBILITY ON THE HUMAN HAND-ARM SYSTEM USING A 3-D SCANNING LASER VIBROMETER

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1. INTRODUCTION

Vibration transmissibility on the hand-arm system is very important to understand and simulate the biodynamic response of the system. Such knowledge can be further used to help understand vibration-induced discomforts, injuries, and disorders. While the mass of the conventional accelerometers could significantly affect the measurement of the transmitted vibration, some single-axis laser vibrometers have been used to measure the transmitted vibration (Sörensson and Lundström, 1992; Deboli et al., 1999; Concettoni and Griffin, 2010). However, the transmitted vibrations excited from multi-axes vibrations have been far from sufficiently studied and understood. Further simulations of the system also require multi-axes transfer functions. Therefore, the objective of this study is to investigate the vibration transmissibility on the human hand-arm system subjected to vibrations in three orthogonal directions (x_h, y_h, and z_h). Some preliminary results and their interpretations are presented in this short paper.

2. METHOD

Seven healthy male subjects participated in the study. As shown in Figure 1, the experiment was carried out on a novel 3-D vibration test system (MB Dynamics, 3-D Hand-Arm Test System). The z_h direction is along the forearm, y_h direction is along the centerline of the instrumented handle in the vertical direction and x_h direction is in the horizontal plane normal to y_h-z_h plane. Each subject was instructed to maintain grip and push forces at 30±5 N and 50±8 N, respectively, with his dominant right hand with elbow angle between 90° and 120° and shoulder abduction between 0° and 30°. The vibration controller was programmed to generate broadband random vibration in the frequency range of 16 - 500 Hz along each direction. The overall rms acceleration in each direction was 19.6 m/s^2. The coherence of the three axial spectra was taken as 0.9. The three-axis accelerations on the handle were measured using a tri-axes accelerometer installed inside the handle, which provided the reference signals for deriving the vibration transfer functions in the three directions. The vibration transmitted to the top surfaces of the major substructures of the system (fingers, back of the hand, wrist, forearm, upper arm, and shoulder) was measured using a 3-D scanning laser vibrometer (Polytec PSV400-3D). To avoid the effect of hairs and to obtain a good reflection, a piece of retro-reflective tape was attached to a piece of first-aid tape that was firmly attached to the skin of the hand-arm system at the desired measuring locations, as also shown in Figure 1. Each transfer function was expressed in the frequency domain from 16 to 500 Hz, with an equal frequency interval of 0.5 Hz.

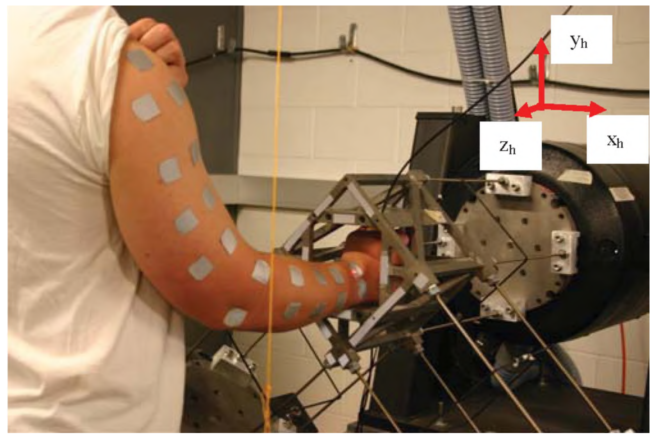

Figure 1: A pictorial view of the 3-D hand-arm test system, together with the posture of a test subject.

3. PRELIMINARY RESULTS AND DISCUSSIONS

The measured tri-axial transmissibility functions varied greatly among the subjects. However, their basic distributions of the transmitted vibration on the hand-arm system are similar. While it is difficult to clearly present the results of all the subjects in this short paper, the basic characteristics of the distributed vibration transmissions in the three orthogonal directions are demonstrated using the data measured with one of the subjects.

Figure 2 shows the magnitudes of the tri-axial transmissibility measured at six important locations on the hand-arm system of the subject. The transmissibility is generally a function of frequency, which varied greatly with measurement location and vibration direction. Each transmissibility function had at least one dominant peak or resonance. The dominant resonances at the wrist, elbow, and shoulder in the x_h- and y_h-directions were in a similar frequency range (30 to 50 Hz); in the z_h-direction, they were at marginally lower frequencies (20 to 40 Hz); on the fingers, they were at higher frequencies and varied in a wide frequency range (80 to 400 Hz). In some cases, two or more obvious resonances were observed in the finger responses. At the finger resonance frequencies, the transmitted vibration could be greatly amplified (Figure 2).

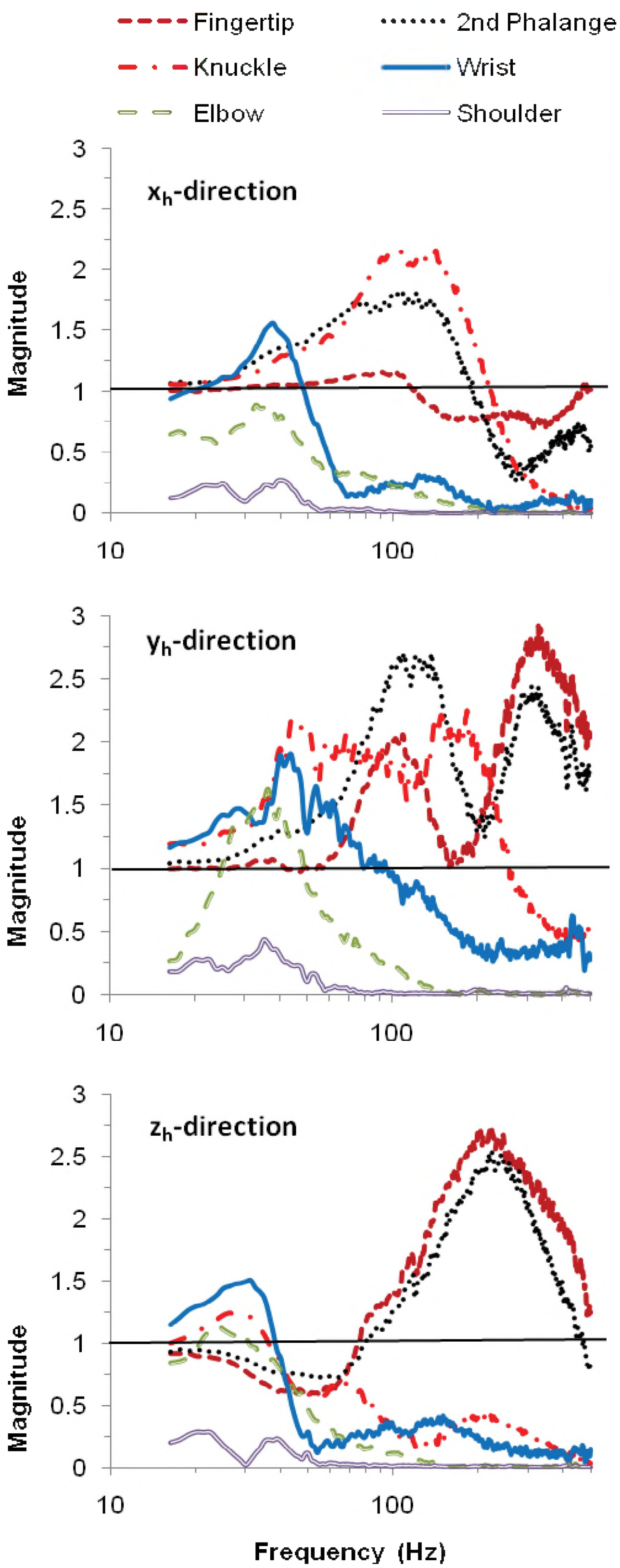

Figure 2: Magnitudes of the tri-axial vibration transmissibility at the fingertip, second phalange and proximal knuckle of the middle finger, wrist, elbow, and shoulder of a subject.

The resonances observed at the wrist, elbow, and shoulder were fairly consistent with the first resonance observed in the driving-point biodynamic response in each corresponding direction (Dong et al., 2011). This suggests that the entire hand-arm system vibrates more or less in phase in this resonance frequency range. This also suggests that this resonance primarily depends on the biodynamic properties of the palm-wrist-arm substructures. The major finger resonance observed in the transmissibility in each direction was also well correlated to that observed in the corresponding driving-point response of the fingers (Dong et al., 2011). This suggests that the fingers' resonances primarily depend on the biodynamic properties of the fingers.

A reported study found that the frequency dependence of the vibration power absorption density (VPAD) of a finger is similar to that of the vibration transmissibility at frequencies higher than the first resonance of the hand-arm system (Wu et al., 2010). While the finger VPAD may be a good measure of the finger vibration exposure, the finger resonances observed in this study suggest that the frequency weighting defined in the current standard (ISO 5349-1, 2001) is unlikely to be suitable for assessing the risk of the finger vibration injuries and disorders.

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3-D MECHANICAL IMPEDANCES DISTRIBUTED AT THE FINGERS AND PALM OF THE HAND

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1. INTRODUCTION

Vibration biodynamics of the hand-arm system is one of the foundations for understanding vibration-induced discomfort, injuries, and disorders. One of the approaches to the study of biodynamics is to examine the driving-point biodynamic response of the system. The vast majority of reported studies assumed vibration excitation at a single point on the handle-hand interface. This assumption is acceptable for the analyses of many tools when the overall response is of concern. According to Saint-Venant's principle (Toupin, 1965), this assumption may also be acceptable for the analyses of the dynamic loads in the arms, but it is not acceptable when responses in the vicinity of contact substructures, especially in the fingers, are of concern. While some studies on responses distributed at the fingers and palm of the hand along the forearm direction have been reported (Dong et al., 2005), little information on the distributed responses in the other directions is available. Therefore, the objective of this study is to examine the driving-point biodynamic responses distributed at the fingers and palm of the hand in three orthogonal directions (x_h, y_h, and z_h).

2. METHOD

Seven healthy male subjects participated in the study. The experiment was carried out on a novel 3-D vibration test system (MB Dynamics, 3-D Hand-Arm Test System), shown in Figure 1. The z_h direction is along the forearm, y_h direction is along the centerline of the instrumented handle in the vertical direction and x_h direction is in the horizontal plane normal to y_h-z_h plane. In this study, each subject was instructed to maintain grip and push forces at 30±5 N and 50±8 N, respectively, with his dominant right hand with elbow angle between 90° and 120° and shoulder abduction between 0° and 30°. The vibration controller was programmed to generate broadband random vibration in the frequency range of 16 - 500 Hz along each direction. The overall rms acceleration in each direction was 19.6 m/s^2. The coherence of the three axial spectra was taken as 0.9. The three-axis force signals, together with the acceleration signals, were acquired in a multi-channel signal analyzer while the subject gripped the handle with desired hand forces. The measured signals were analyzed to evaluate the apparent mass of the human hand-arm at the palm and fingers interfaces using the H_1 function available in the Pulse software of the analyzer, which was used to derive the impedance. The results were expressed in the frequency domain, corresponding to the center frequencies of the one-third octave bands from 16 to 500 Hz

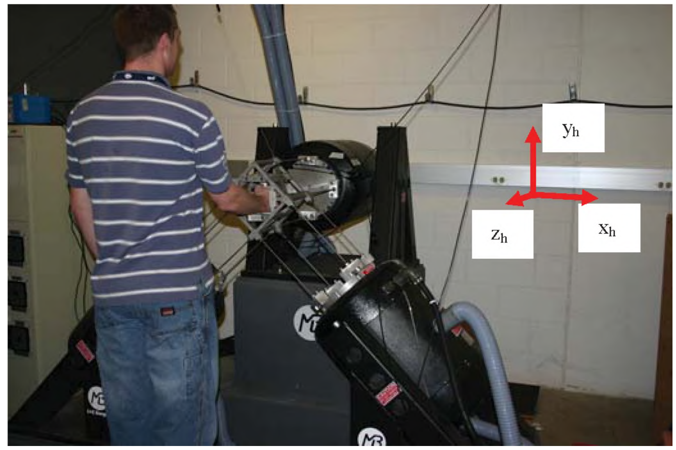

Figure 1. 3-D hand-arm test system, with test subject.

3. RESULTS AND DISCUSSIONS

Figure 2 depicts the mean magnitudes of the distributed impedance responses of the seven subjects in each of the three directions, together with their vector summation or the impedance of the entire hand-arm system. The experimental data indicate that the characteristics of the distributed biodynamic responses vary greatly with the specific location of the hand, the vibration direction, and the individual.

Despite the considerable inter-subject variability, the responses measured along each axis consistently exhibit two magnitude peaks in the frequency range considered, which can be approximately considered as dominant resonance frequencies of the hand-arm system. The first magnitude peak is observed in approximately 20 to 40 Hz frequency range, which varied considerably across the subjects but it did not vary greatly with the vibration direction for the same subject. This resonance was primarily reflected in the response at the palm in all the three measurement directions and was also evident from the response at the fingers in the z_h direction. The second resonant peak was clearly evident in the response at the fingers in each direction, although it could also be identified in the palm impedance responses in the x_h- and z_h- directions. The corresponding frequency varied greatly across the subjects and with vibration, and varied from approximately 100 to 200 Hz in the x_h-direction, from 60 to 120 Hz in the y_h-direction, and from 160 to 300 Hz in the z_h-direction.

Because the resonances are generally correlated with larger mechanical stimuli such as stresses, strains, and power absorption density, the vibration exposure of the hand and fingers should have more weighting in the resonance frequency range (20 to 300 Hz). This is inconsistent with the current frequency weighting defined in ISO 5349-1 (2001), which emphasizes the frequencies below 25 Hz. This observation casts doubt on the validity of the ISO weighting, especially for assessing the risk of the finger-transmitted vibration exposure.

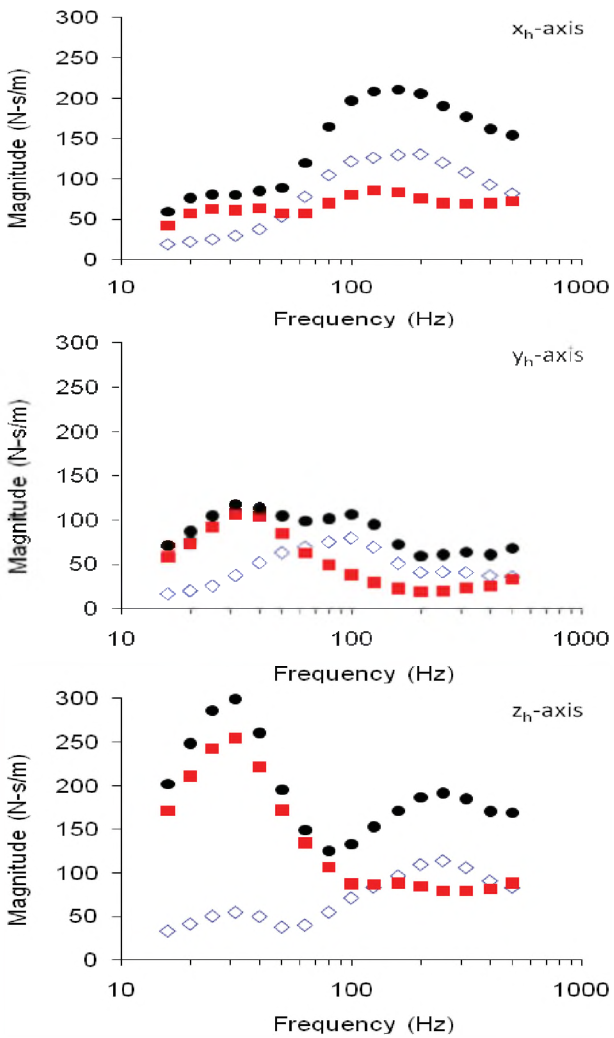

Figure 2: The distribution of the mechanical impedances in the three orthogonal directions (◇ fingers; ■ palm; ● hand).

The driving-point mechanical impedance of the hand is primarily distributed at the palm below a certain frequency in the range of 50 to 100 Hz, with the specific frequency transition depending on the vibration direction. However, the impedance at the fingers becomes comparable or higher than that at the palm at higher frequencies.

The characteristics of the distributed impedances also suggest that the vibration power is primarily transmitted to the hand-arm system through the palm in the vicinity of the first resonance frequency range (20-40 Hz). However, greater vibration power could transmit from the fingers to the hand around the second resonance frequency range (60-300 Hz). The percent power absorbed in the fingers also increases with the increase in frequency as the vibration becomes more concentrated in the hand and finger response becomes more independent to the remaining parts of the system. The non-proportional distribution as a function of frequency raises concerns on the validity of the use of total vibration power absorbed in the entire hand-arm system to represent the vibration exposure intensity at a specific location or in a specific substructure. This means that it is not appropriate to directly associate the total power absorption with the finger disorders.

On the other hand, the basic trends in the frequency dependencies of the vibration power absorption for the entire hand-arm system in the three directions are similar to that of the ISO weighting, which means that the total VPA in each direction is a vibration measure similar to the current ISO frequency-weighted acceleration. This relationship suggests that if the total vibration power absorption is not valid for quantifying the finger exposure intensity, as discussed above, the current ISO frequency-weighted acceleration is unlikely to be a good measure of the finger vibration exposure. This observation further suggests that the current frequency weighting is not suitable for quantifying the finger vibration exposure.

As also shown in Figure 2, the palm impedance in zh-axis is generally greater than that in any other direction and orientation. This implies that the transmissibility of a glove measured at the palm along the forearm direction specified in ISO 10819 (1996) could over-estimate the effectiveness of the glove for vibration reduction.

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DISCLAIMERS

Factors Influencing the Hand-Arm Mechanical Impedance

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1. INTRODUCTION

Several studies have focused on identification of the hand-arm driving point mechanical impedance (DPMI), pointing out how this quantity depends on the operator built, posture, grip and push forces, stimulus level and spectral content (Gurram et al. 1995; Gasparetto et al. 2004; Aldien et al. 2005; Marcotte et al. 2005; Aldien et al. 2006). The DPMI is commonly measured with instrumented handles, imposing a known vibration to the human limb and measuring the resulting forces. The measuring process is well consolidated, although errors may arise at high frequencies (Adewusi et al. 2008) because of handle dynamics. We describe here an experimental campaign whose aim is the evaluation of the factors affecting the DPMI at different frequencies, using the ANOVA technique. The first part describes the optimization of the method for DPMI measurements. The factorial design of experiments (DOE) was used to identify how the posture (elbow, shoulder and wrist angles), the grip and the push forces and the vibration level affect the DPMI at different frequencies.

2. METHOD

2.1. DPMI Measurement Set-up

An aluminum alloy handle was designed with finite elements methods so as to have a natural frequency above 3000 Hz. Two triaxial load cells PCB 260A11were used to measure the forces transmitted to the human limb. The acceleration generated by an electrodynamic shaker was measured with piezoelectric Bruel & Kjaer 4508B accelerometers. An image of the handle is shown in Figure 1. The vibration was imposed in a vertical direction; the handle axis has always been horizontal.

Figure 1. Instrumented handle for the hand-arm DPMI measurement.

The resonant frequency decrease due to the hand mass led to a systematic error (up to 10 %) not compensated by the handle idle mass subtraction. A correction procedure has been therefore developed creating a compensation function that accounts for the larger amplification when the resonant frequency decreases. The procedure can be summarized as follows - computation of the raw apparent mass, idle mass subtraction, and numerical (parabolic) compensation starting from the apparent mass at 1000 Hz.

With such a method, the apparent mass uncertainty in the frequency range 10 Hz – 1 kHz was lower than 5 % for masses ranging from 10 to 80 g. The DPMI has been eventually obtained multiplying the apparent mass by $j\omega$.

2.2. Posture Evaluation

Several bibliographical studies are based on subjective posture measurements; in this study six angles describing the upper limb configuration were measured with a vision-based system.

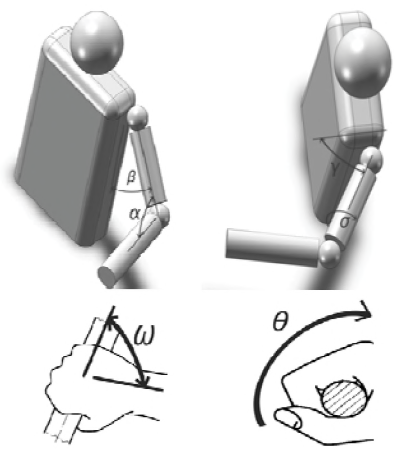

Figure 2. Six angles used to describe the upper limb posture.

Angles were measured starting from the position of adhesive markers attached to the testers' skin. The marker position was then identified with a pattern matching algorithm. Uncertainty of the measurement system was lower than 5°.

2.3. Force Measurements

The push force was evaluated with a dynamometric platform capable of measuring forces in the horizontal and vertical plane. The grip force has been measured before the tests with a pressure matrix manufactured by Novel GMBH. Testers were initially trained to produce a certain grip force and were required to reproduce such a condition during the shaker tests. Uncertainty deriving from this measurement method was quantified with purposely designed tests and was lower than 15 %.

2.4. Factorial DOE

A reduced factorial DOE was adopted; the nine factors included in the study were the six angles of Figure 2, the push and grip forces and the vibration amplitude. Factors levels were:

–	α	0→180°	1→90°
–	β	0→0°	1→90°
–	γ	0→90°	1→60°
–	σ	0→0°	1→30°
–	θ	0→0°	1→30°
–	ω	0→90°	1→60°
–	feed	0→0 N	1→70 N
–	grip	0→50 N	1→170 N
–	F	0→4.5m/s^2	1→9m/s^2

F is the w_h-weighted stimulus level. The reduced factorial design included 16 tests - 7 male subjects (age between 25 and 30 years, heights between 1.70 and 1.90 m, mass between 70 and 95 kg) performed the 16 tests on 4 different days. The response variables were the DPMI evaluated in third of octaves bands at the center frequencies of 16, 31.5, 63, 125, 250 and 500 Hz.

3. RESULTS

A first analysis was performed to identify the posture variability during the tests. The α and β angles standard deviations were between 7 and 15 ° depending on the arm configuration. The σ angle standard deviation was 11°.

Analyses were then performed to identify how the DPMI is influenced by the investigated factors. The DPMI boxplots in third of octave bands is shown in Figure 3. Tests include impedances measured along the Z_h and X_h directions (the vibration was always vertical but the forearm could be horizontal or vertical). Data presented here therefore have to be compared with the weighted average of the Z_h and X_h ISO 10068 curves.

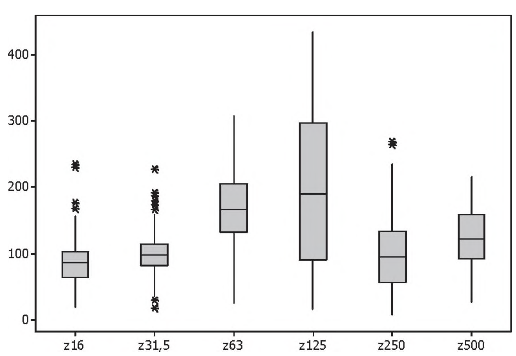

Figure 3. Boxplots of the DPMI (vertical axis) as a function of the frequency (horizontal axis)

ANOVA results are shown in Table 1. A factor influences the DPMI if the P-value is smaller than the type 1 risk (threshold in our case was set to 2 %).

Table 1. P values of the ANOVA tests. X non influencing factors, v influencing factors. ! a possibly influencing factor.

	Frequency [Hz]					
P-valu	16	31,5	63	125	250	500
α	✗ 0.08	✓ 0.00	✗ 0.11	✗ 0.08	! 0.03	✗ 0.09
β	✗ 0.27	✓ 0.02	✗ 0.37	✗ 0.48	✗ 1.00	✗ 0.59
γ	✗ 0.36	✗ 0.12	✗ 0.42	✗ 0.68	✗ 0.48	✗ 0.57
σ	✗ 0.71	✗ 0.83	✓ 0.02	✗ 0.94	✗ 0.66	✗ 0.07
θ	✗ 0.06	✗ 0.90	✗ 0.93	✗ 0.45	✗ 0.14	✓ 0.00
ω	✗ 0.06	✗ 0.34	✗ 0.97	✗ 0.48	✗ 0.65	✓ 0.01
feed	✓ 0.00	✓ 0.00	✓ 0.00	✓ 0.00	✗ 0.60	✗ 0.18
grip	✓ 0.01	✗ 0.71	✓ 0.00	✓ 0.00	✓ 0.00	✓ 0.00
F	✗ 0.70	✗ 0.59	✗ 0.73	✗ 0.25	✗ 0.97	✗ 0.67

4. DISCUSSION

In the investigated conditions, the DPMI depends from the grip force (all the bands but the 31.5 Hz one) and from the feed force (up to 125 Hz). A combined effect between these factors pointed out that the DPMI increases if one of these two factors is high; if both are simultaneously high the DPMI does not increase proportionally. The posture was important both at low frequencies (where DPMI is affected by the elbow and shoulder angles) and at high frequencies (where the wrist angles are important). The effect of the vibration level is limited; this leads to the conclusion that the adoption of a linear model is adequate.

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ANALYSES OF DISTRIBUTED ABSORBED POWER RESPONSES OF THE HUMAN HAND-ARM SYSTEM IN THE BENT- AND EXTENDED-ARM POSTURES

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1. INTRODUCTION

The absorbed power P within the hand-arm system relates to mechanical stimulus attributed to vibration exposure, and has been suggested as an important biodynamic measure for assessing the vibration exposure (Lindstrom, 1975). The majority of studies, however, have been limited to total power derived from the responses at the driving-point. In a recent study, the distributed power was estimated using lumped-mass models with a fixed shoulder condition (Dong et al., 2007), although relatively high magnitudes of vibration of the shoulder and the head have been reported, particularly in the extended-arm posture (Sakakibara et al., 1986).

The absorbed power derived from lumped-mass models based upon driving-point measure may not adequately characterize deformations and energy absorption associated with vibration modes of individual hand-arm substructures, and cannot reveal posture effects. In this study, biomechanical models of the hand-arm system in the bent- and extended-arm postures subject to z_h-axis vibration are applied to derive the energy distribution within different substructures of the hand-arm system. The validity of the model was established on the basis of multiple simultaneously measured biodynamic responses, namely the driving-point impedance, vibration transmitted to different hand-arm segments and the total power absorbed.

2. METHODS

The formulation and structures of the hand-arm models in the bent- and extended arm postures are similar to those reported by Adewusi et al. (2010). The models incorporate a clamp-like structure of the hand with two-driving points formed by the finger and palm sides of the hand (Dong et al., 2007), together with representations of the upper- and fore-arms, wrist, elbow and shoulder joints, and the torso. The torso facilitated the study of shoulder motion and coupling between the hand-arm and the whole-body vibrations. The parameters of the models were derived on the basis of both the driving-point impedance and vibration transmitted to different segments of the hand-arm measured, using six subjects under broadband random excitation. The vibration of a chipping hammer operated in an energy dissipater was also measured in the laboratory. The distributed power of the models is evaluated under broadband random and chipping hammer excitations for the two postures.

The distributed power absorbed in a substructure at joint k ($k = 1, \dots n$), P_k, is estimated from the power dissipated in the damping elements of the substructure, such that:

$$P_k(f) = c_k\left[\Delta v_k(f)\right]^2 + C_k\left[\Delta\Omega_k(f)\right]^2 \qquad (1)$$

where f is the frequency of vibration in Hz, Δv_k and $\Delta\Omega_k$ are relative translational and rotational rms velocities across the damping element at joint k, respectively, and c_k and C_k are the linear and rotational damping coefficients of joint k, respectively.

The total power, P, corresponding to frequency f is derived upon summation of the distributed power:

$$P(f) = \sum_{k=1}^{n} P_k(f) \qquad (2a)$$

$$P_m(f) = Re\left[MI(f)\right]\cdot\left|v(f)\right|^2 \qquad (2b)$$

where n is the number of damping elements in the model. The computed P was compared with the total power P_m estimated from the measured mechanical impedance MI and velocity v to further demonstrate the validity of the models.

Finally, the overall power of the models ($\overline{P}$) and that derived from the measured data over the entire frequency range of interest (with f_l and f_u as the lower and upper bounds) are derived from:

$$\overline{P} = \sum_{f_l}^{f_u} P(f_i) \qquad (3)$$

3. RESULTS AND DISCUSSION

Figure 1 shows the distributed and total power responses of the hand-arm system models under random excitations for both the postures, while Figure 2 presents the power due to chipping hammer excitation for the bent-arm posture only. Figure 1 shows that the total power of the models is comparable with that derived from the measured data, which further confirmed the validity of the models. The validation of models on the basis of MI and transmissibility responses had been previously presented (Adewusi et al., 2010).

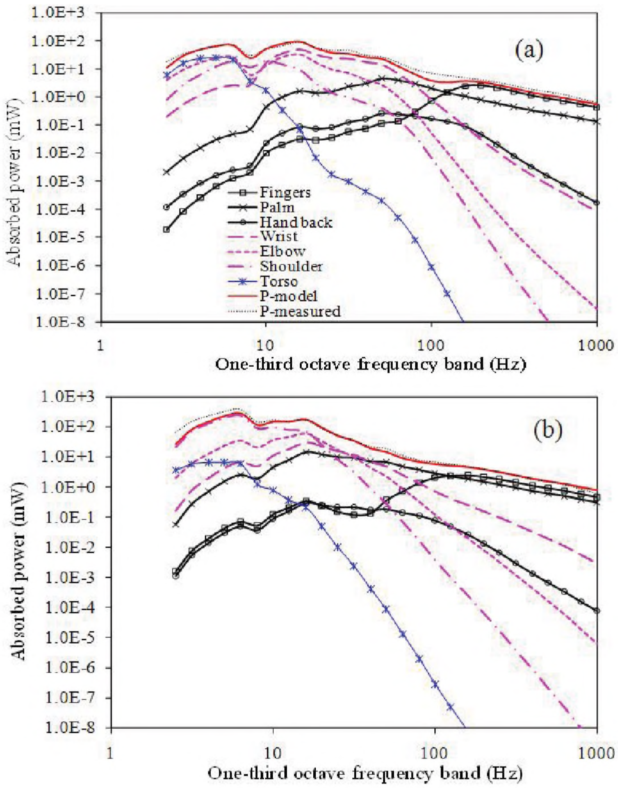

Figure 1. Distributed and total power absorbed in the human hand-arm due to broadband random excitation: (a) bent-arm posture; (b) extended-arm posture.

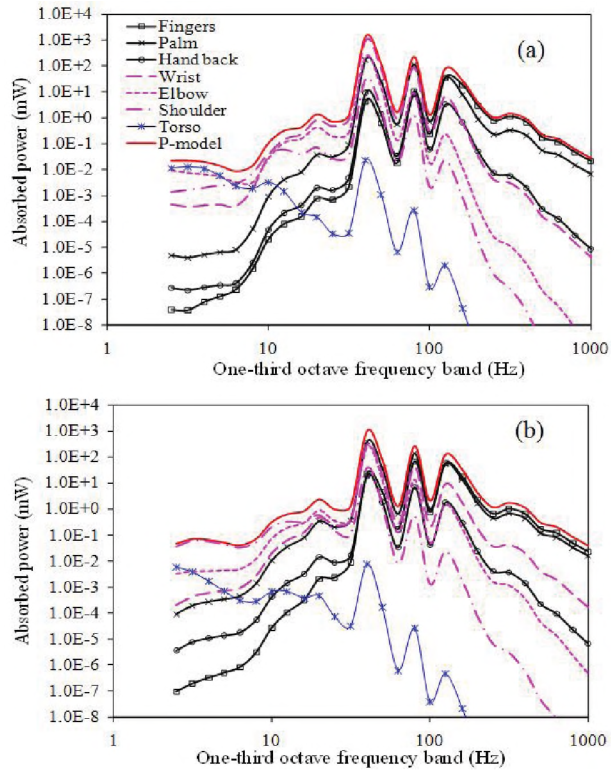

Figure 2. Distributed and total power absorbed in the human hand-arm due to chipping hammer excitation: (a) bent-arm posture; (b) extended-arm posture.

The figures show significant effect of excitation and posture on the absorbed power. Although Figure 2 shows that power is concentrated around the operating frequency (43.7 Hz) of the power tool, the trends shown by the power absorbed in different segments are similar for both excitations and postures. The results showed a general trend that the power absorbed in the arms (wrist, elbow and shoulder) was greater below 25 Hz than that in the hand (fingers, palm and hand back). The absorbed power of the hand structures was, however, greater above 100 Hz, except in the extended-arm posture, where the wrist power was greater than that of the hand back.

Despite similarities in trends shown by segmental absorbed power, the values of absorbed power in the extended arm posture were significantly greater than those in the bent-arm posture for the same overall frequency-weighted vibration. Under broadband random vibration with frequency weighted acceleration value of 5.25 m/s^2 (32.0 m/s^2 un weighted) in the 2.5 – 1000 Hz frequency range, the overall total power ($\overline{P}$) for the bent- and extended-arm postures were computed as 0.67 and 1.63 W, respectively. Furthermore, the frequencies of peak power under random excitation (Fig. 1) were close to resonance frequencies of the hand-arm system, while those due to chipping hammer excitation were dominated by the tool's operating frequency, its harmonics and resonant frequencies. The results showed that the power in different segments differed considerably, not only with posture but also in magnitudes and dominant frequencies, suggesting that different frequency-weightings may be needed to assess injury risks of different segments of the hand-arm system.

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STUDY OF VIBRATION TRANSMISSION ON A PAVER'S HAND HAMMER

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1. INTRODUCTION

Disorders caused by vibrating hand-held power tools and machines have long been known. By contrast, little is known about whether discrete shocks caused in particular by non-power tools lead to comparable exposure. The ISO 5349-1 [1] standard, for example, states in its scope that its application for repeated shocks is only provisional. A disorder suffered by a paver who, for decades, had made intensive use of a paving hammer (a special design of hammer) prompted a study of the vibration transmission from the hammer to the hand-arm system. The study was to examine whether the vibration exposure in this particular case was comparable with that of other power machines or tools. For this purpose, a realistic model workplace was set up in the laboratory, based upon field studies. This guaranteed reproducible test conditions for the subsequent study methods.

The interaction between hand and handle was determined during the discrete impact phases by synchronous measurement of the acceleration at the handle of the hammer and of the coupling forces. The coupling forces were determined by measurement of the pressure distribution on the surface of the handle. The measuring system from the VIBTOOL project [2] was used for this purpose. In addition, the phases of the impact cycle were recorded synchronously by means of a high-speed camera. For further validation of the data, the free vibration behaviour of the hammer handle and peen were determined by modal analysis.

2. STUDY METHODS

2.1 Preliminary studies

Based upon comprehensive studies of the working conditions on construction sites, the laying of paving setts with dimensions of 14 x 16 x 16 cm and a weight of 5.8 kg was selected as a typical work process. Six impacts per sett were measured as the average impact sequence.

2.2 Vibration measurements

Measurements were performed with the same paving hammer originally used by the individual who had suffered the disease. A work process involving an experienced paver was reconstructed in the laboratory for this purpose. The measurements were performed and analysed in accordance with ISO 5349 and the extended requirements of ISO/TS 15694 [3]. The direction of measurement was limited to the impact direction. This corresponds to the primary excitation and to the direction of measurement closest to the direction of the forearm in accordance with VDI 2057-2 [4].

2.3 Measurement of coupling forces

The coupling forces were measured in accordance with ISO 15230 [5] and DIN 45679 [6] synchronously with the vibration measurements. The system developed in the "VIBTOOL" EU project was employed as the measurement chain.

2.4 High-speed camera

A high-speed camera was used to record the work processes synchronously with the vibration and force measurements. The filming rate of 500 frames per second enabled the processes to be resolved at an interval of 2 ms. All signals were synchronized by means of an initial triggering pulse. For technical reasons, only the first few impacts of each work process could be recorded, owing to the limitation of the recording duration to 4 seconds.

3. RESULTS

3.1 Acceleration of the coupling forces

In order to prevent cable movements from causing contamination effects when the hammer was lifted, the vibration exposure was analysed separately for each impact. In order to permit comparison between the individual impacts, each impact was integrated over one second. Altogether, 12 series of measurements were conducted. The results for the energy-equivalent average values over one second were averaged arithmetically over the individual impacts. The resulting average frequency-weighted acceleration a_{hw} was 24.4 m/s². The unweighted acceleration measured at the hammer handle attained peak values of up to 30,000 m/s². The impact event was however very brief, and had already subsided after approximately 20 to 30 ms. The mean value for the push/pull force F_{pu} across all series of measurements was 22.3 ± 8.5 N, and for the grip force F_{gr} 32.8 ± 8.8 N. The coupling force F_{cp} averaged from the individual measurements was 55.1 ± 14.0 N. Since the vibration-free components during raising and lowering of the hammer were included in this average, the forces arising during the impact phase were determined separately.

The summary of all measured values (Figure 1) shows the coupling forces with the unweighted and weighted acceleration and the position of the hammer during the impact process. For technical reasons, the coupling forces were measured at intervals of 20 ms. The push force is decisive for the force acting outwardly. It acts in the direction of impact, and is oriented in the direction of action of the vibration/recoil. During the impact event, the push force is 17 N and the grip force 49 N. The recordings by the high-speed camera clearly show the transmission of the shock into the wrist, which is accompanied by a rotating/tilting motion.

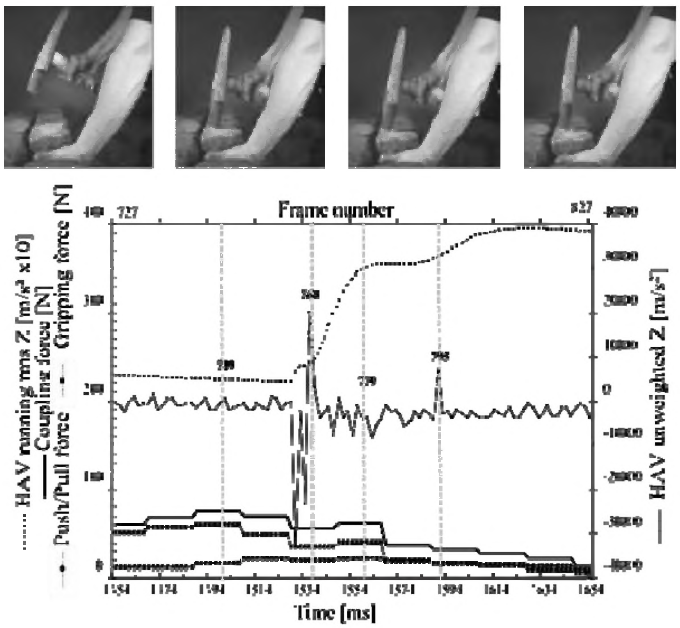

Figure 1: Summary of the measured values in the phases of the impact process (example)

3.2 Modal analysis

A modal analysis of the paving hammer was conducted to determine the free vibration behaviour of the hammer handle and peen. For the purpose of measurement, the direction of impact was defined as the x direction, and the axis parallel to the hammer handle as the z direction.

The entire hammer (peen and handle) exhibits a clear tilt movement in the x direction, i.e. in the direction of impact (forearm direction), with values of 9.4 to 17 Hz. The reason for this movement lies in the flexural vibration of the upper part of the hammer peen. This vibration movement is transferred directly to the hammer handle. At 20 Hz - 31 Hz, the movements of the hammer peen and hammer handle are out of phase with the steel body leading. At 31 Hz - 650 Hz, the two components of the hammer are back in phase. At over 650 Hz, the hammer handle is subject to a self-motion independent of the hammer peen. This is a flexural motion.

To summarize, the additional modal analysis confirms the exposure measurements, since free vibration of the paving hammer occurs within the relevant frequency range of the normal frequency of the hand-arm system.

4. ASSESSMENT AND DISCUSSION

The measurement and evaluation method in accordance with ISO 5349 applies in the first instance to periodic, random and non-periodic vibrations. Under what boundary conditions can the method also be applied to repeatedly occurring impacts? If the coupling force is considered to be an essential factor for the interaction between hand and handle in accordance with DIN 45679, the risk can be assessed as follows: If in addition, owing to the particular point of transmission, only the push force is considered, the frequency-weighted acceleration must be weighted (corrected) with the coupling factor c_p of 0.6. The coupling-force-weighted and frequency-weighted acceleration a_{hwF} is then 14.6 m/s². For the specific exposure case of 280 setts per day, the daily dose as a function of the coupling force $a_{hw(8)F}$ is then 3.5 m/s².

For the case under examination, the Social Court upheld the claim of occupational disease. The results also have implications for prevention. They show that consideration should be given in risk assessments to intensive paving work, even where power tools or machines are not also in use.

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NEW APPROACH TO MODEL THE HAND-ARM SYSTEM FOR ANALYSIS OF MUSCULOSKELETAL DISORDERS

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1. INTRODUCTION

Musculoskeletal disorder is a big part of the hand-arm vibration syndrome (HAVS) affecting millions of workers using hand-held tools. It is known that factors that cause HAVS are the magnitude and frequency of the vibration input as well as posture and gripping force (Griffin, 1990). The pathology of HAVS is still not well understood (Friden, 2001). A good hand-arm model is necessary to estimate the transmission of vibration forces through the human body, which will provide basic information to understand HAVS.

A human hand-arm system is composed of 31 different muscles has 24 degrees of freedom of motion. The system acts in combination of synergism and antagonism to generate forces required for motion. To create a higher force, muscles act synergistically along with increasing contribution of antagonistic muscles for stabilization and restoration of joint (Hatze, 1981; Prilutsky, 2000; Seireg and Arvikar, 1989). A musculo-tendon force transmission model is required to calculate forces and displacements transmitted through joints and muscle systems. Most dynamic models do not consider detailed muscle models (Rakheja et al., 2002). Such models are useful to calculate overall responses of the hand-arm system but not its internal responses. The purpose of this study is to develop a new analysis approach that takes all the above mentioned factors into account for hand-arm vibration analysis.

1.1. Muscle Model

Extrinsic muscles are actively controlled by motor neurons. A modified Hill's muscle model (Figure 1) is used to define the muscle force generation (Cheng et. al., 2000). The parameters are obtained from a similar model developed based on Simulink known as Virtual Muscle 4.0 (Song et. al., 2008). Each extrinsic muscle consists of a contractile element (CE) in parallel with passive elastic component (PE) connected to a muscle mass. The muscle mass and insertion location are connected by series elastic (SE) element which represents the tendon.

2. METHODS

Once the system parameters are found by a grip force analysis considering the active muscle force, the model of the hand-arm system can be developed which passively reacts to the tool vibration force. At a given equilibrium point, the musculo-tendon system can be interpreted as a spring damper system, as shown in Figure 2. M_1 and K_{CE1}

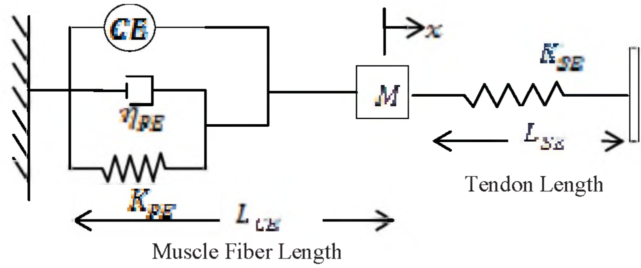

Figure 1: Modified Hill's lumped parameter based musculo-tendon system

are the mass and stiffness of the extrinsic muscle, which has bigger muscle belly. M_2 and K_{CE2} are the mass and stiffness of intrinsic muscle, which has smaller mass in comparison. Therefore, M_1 is bigger than M_2. K_{SE1} is the stiffness of the longer tendon of extrinsic muscle and K_{SE2} is the stiffness of the shorter tendon of intrinsic muscle. Therefore K_{SE1} is smaller in value than K_{SE2}. M is the mass of the segment of the finger driven by muscle and is in contact with tool, which is subjected to vibration.

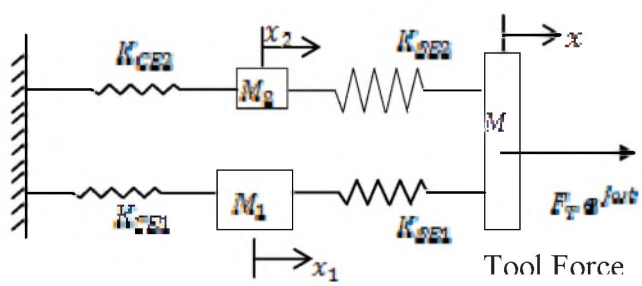

Figure 2: Schematic diagram of 3-DOF system of 2-muscles and vibrating tool

The response of the 3-DOF system can be written as in matrix form as:

$$[M]\{\ddot{x}\}+[C]\{\dot{x}\}+[K]\{x\}=\{F_T\} \quad (1)$$

The frequency response functions (FRF) for this system in the frequency domain are:

$$\frac{X(\omega)}{F(\omega)}=\frac{1}{-\omega^2[M]+j\omega[C]+[K]} \quad (2)$$

And the frequency response of the velocity with force, otherwise known as the mobility, is estimated as shown below. The mobility can be used to find the contraction velocity of the muscle.

$$\frac{V(\omega)}{F(\omega)}=\frac{j\omega}{-\omega^2[M]+j\omega[C]+[K]} \quad (3)$$

3. RESULTS

For the demonstration, a realistic human hand muscle set is used. We consider the Flexor Digitorum Profundus (FDP) and Lumbrical (LU) are participating in the response to the vibration force. Table 1 lists the properties of the muscle used in the study, where PCSA and TCSA are the muscle belly and tendon cross sectional areas. The mass of the distal finger segment in contact with tool is taken as 10g.

Table 1: Properties of the musculotendon system used (An et. al., 1979; Freivalds, 2004; Li et. al., 2001; Ward et. al., 2006)

Musculotendon	**1** - FDP	**2** – LU
Fiber length L_{CE} in mm	67.0±6.0	47.0±9.0
Tendon length L_{SE} in mm	292.6±7.1	65.76
PCSA in cm^2	4.10±2.40	0.30±0.10
F_{max} in N	130.38	9.54
Volume in cm^3	27.6±16.1	1.7±0.7
Mass in g	38.82±3.86	2.39
TCSA in mm^2	11.40±0.97	5.0
K_{SE} in N/m	1.7922×10^4	3.4975×10^4
K_{CE} in N/m	1.86×10^3	1.345×10^2

Figure 3 shows the frequency response (X/F) of the system. It is seen that the response of the smaller muscle (lumbrical) becomes higher in the high frequency range. This indicates that smaller muscles take up most of vibration excitation in the high frequency range.

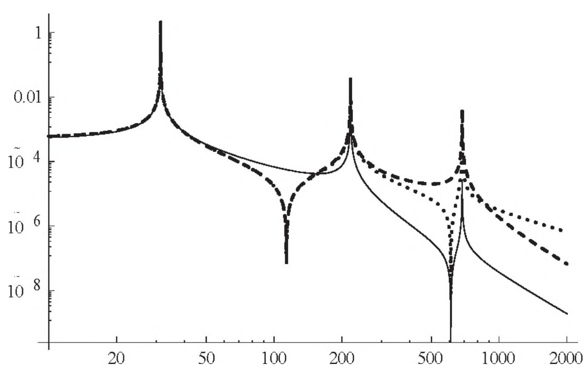

Figure 3: Frequency response functions of M (dotted line), M_1: FDP (dashed line) and M_2: LUM (solid line).

4. DISCUSSION AND CONCLUSIONS

This study shows that realistic muscle models should be included in the vibration analysis of the hand-arm exposed to tool vibration. The stiffness of extrinsic muscle has to be estimated by static analysis of grip modeling the muscle as an active element. In this study the modified Hill's model was used. Although not reported here, the hand-arm system has redundancy in muscles because it has many more muscles than the minimum number required to establish equilibrium in gripping. Therefore, the contribution of each muscle has to be determined by an optimization method.

The response of the hand-arm system to tool vibration can be considered as a passive vibration around the static equilibrium point that is set by the active muscle action. It has been demonstrated that detailed modeling of muscles is important in the response analysis. An important observation is that bigger extrinsic muscles carry most of the static load to generate the grip force: however, smaller muscles carry most tool vibration force at high frequencies.

Most experimental methods use various measurement techniques such as the electromyogram (EMG) of muscle activity to determine the muscle force generation under various dynamic conditions. But all such noninvasive measurements are only done on larger and extrinsic muscles. The current study suggests that small intrinsic muscles can be more prone to damage than simple models would predict if the vibration input has high frequency components. Thus current guidelines may underestimate the effect of high frequency vibration on possible injury.

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REDUCTIONS IN FINGER BLOOD FLOW INDUCED BY LOW MAGNITUDE HAND-TRANSMITTED VIBRATION

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1. INTRODUCTION

Experimental studies have shown that vibration applied to one hand can provoke digital vasoconstriction in fingers on both the exposed hand and the non-vibrated hand (Bovenzi *et al*., 1999, 2000, 2004, Griffin *et al*., 2006). It has been hypothesized that the vasoconstriction in fingers on the non-exposed hand indicates a central sympathetic vasomotor reflex.

The dependence of vibration-induced vasoconstriction on the magnitude of vibration has been investigated in several studies, but the magnitudes investigated have mostly been high (unweighted accelerations from 5.5 to 88 ms^{-2} r.m.s.).

This study was designed to investigate the effect on finger blood flow of lower magnitude vibration in healthy female subjects. The hypothesis is that vibration applied to a controlled area of the thenar eminence of one hand would reduce finger blood flow in fingers on both the exposed and the unexposed hand, and that there would be greater reductions in finger blood flow with a higher magnitude of vibration.

2. APPARATUS AND METHOD

2.1. Subjects

Twenty healthy females aged 18 to 30 years participated in the study. All subjects were university students with no history of regular use of hand-held vibrating tools in occupational or leisure activities. They were asked to avoid caffeine for 2 hours and alcohol for 12 hours prior to testing. The subjects read written instructions and gave informed consent before beginning the experiment that was approved by the Human Experimentation Safety and Ethics Committee of the ISVR at the University of Southampton.

2.2. Apparatus

Finger blood flow (FBF) was measured in the middle fingers of both hands using plethysmography. A mercury-in-silicone strain gauge was placed around the distal phalanx at the base of the nail, with a plastic cuff for air inflation around the proximal phalanx, of the right and left middle fingers, with soft plastic tubes from the cuffs connected to an *HVLab* Multi-channel Plethysmograph (*HVLab*, University of Southampton). Blood flow was measured using a strain gauge venous occlusion technique: the pressure cuffs were inflated to a pressure of 60 mm Hg, and the increase in finger volume was detected by means of the strain gauges according to the criteria given by Greenfield *et al*. (1963). Finger blood flow was expressed in ml/100 ml/s.

An *HVLab* Vibrotactile Perception Meter (VPM) generated sinusoidal vertical vibration at a frequency of 125 Hz at an unweighted acceleration of either 0.5 ms^{-2} r.m.s. or 1.5 ms^{-2} r.m.s., corresponding to frequency-weighted accelerations of 0.063 and 0.188 ms^{-2} r.m.s. according to International Standard 5349-1 (2001). The 6-mm diameter vibrating probe of the VPM was surrounded by a fixed circular surround. The gap between the probe and the surround was 2 mm. The vibration was measured using an accelerometer in the VPM, and was monitored using a digital meter and oscilloscope. Visual feedback of the downward force applied on the fixed surround (i.e. 2 N) was monitored on an electronic display of the VPM control unit.

2.3. Method

Subjects lay supine throughout the study, with both hands supported at heart level. After acclimatisation for 15 to 20 minutes, finger blood flow was measured simultaneously in the left and right hand at 30-second intervals for 28 minutes throughout seven successive 4-minute periods (with no break between the seven periods).

For the right hand, the seven periods were:

- (i) pre-exposure: no force,
- (ii) pre-exposure application of 2-N force,
- (iii) vibration 1: 2-N force with 125-Hz vibration at 0.5 ms^{-2} r.m.s. (unweighted),
- (iv) rest period with 2-N force,
- (v) vibration 2: 2-N force with 125-Hz vibration at 1.5 ms^{-2} r.m.s. (unweighted),
- (vi) post-exposure application of 2-N force, and
- (vii) recovery: no force.

The left hand remained motionless with no vibration and no force thoughout the 28-minute session. In each subject and on both hands, finger blood flow was expressed as the median of the eight measurements obtained during each 4-minute period. Statistical analysis with the non-parametric Wilcoxon test (for two-related samples) was conducted using SPSS (version 17.0) with a significance criterion of p=0.05.

3. RESULTS

The medians and inter-quartile ranges of the FBF in the middle fingers of the exposed and unexposed hands during each of the seven 4-minute periods are shown in Figure 1. During the pre-exposure period (i), the FBF did not differ between the exposed right hand and the unexposed left hand (p=0.16).

There was no significant change in FBF between period (i) and period (ii) on either hand, indicating the 2-N force applied by the right hand did not change finger blood flow on either hand.

During period (iii), on the exposed right hand there were significant reductions in the FBF compared to period (i) (p<0.001) and compared to period (ii) (p<0.001). On the unexposed left hand, there were no significant differences between period (iii) and either period (i) (p=0.28) or period (ii) (p=0.19). During period (iii), the FBF was less on the right hand than on the left hand (p=0.001). So, 0.5 ms^{-2} r.m.s. vibration applied to the thenar eminence of the right hand caused significant reductions in finger blood flow on the right hand but not on the left hand.

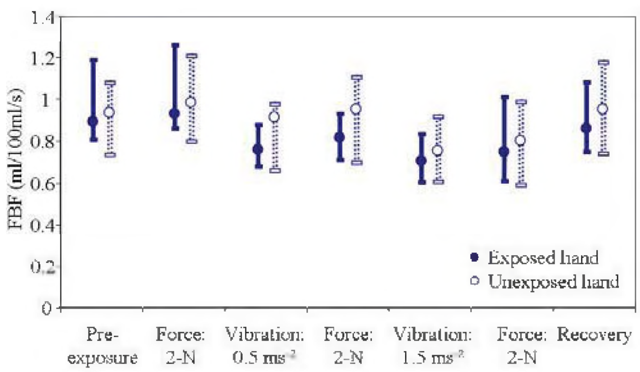

Figure 1. Medians and inter-quartile ranges of FBF in fingers on the exposed and unexposed hand during seven periods

During period (iv), on the exposed right hand there was a significant reduction in FBF compared to period (ii) (p=0.024), but a signficant increase in FBF compared to period (iii) (vibration exposure at 0.5 ms^{-2} r.m.s.; p<0.001). On the left hand, there was no significant difference in the FBF between period (ii) and period (iv) (p=0.37).

During period (v), on both the exposed right hand and the unexposed left hand there were reductions in the FBF compared to the previous four periods: period (i) (right: p<0.001, left: p<0.01), period (ii) (right: p<0.001, left: p<0.01), period (iii) (right: p=0.036, left: p=0.028), and period (iv) (right: p<0.001, left: p=0.041). During period (v), the FBF on the exposed right hand was significantly less than that on the unexposed left hand (p=0.001).

During period (vi), the FBF on both hands was less than during period (ii) (right: p=0.001, left: p=0.031). During period (vii), the FBF on the right hand was less than during period (i) (p=0.018) and less than during period (ii) (p=0.024), but greater than during period (vi) (p=0.045). On the left hand, the FBF during period (vii) did not differ from the FBF during period (i) (p>0.1) or period (ii) (p>0.1), but was greater than during period (vi) (p=0.025).

4. DISCUSSION AND CONCLUSIONS

Vibration of a small area of the thenar eminence of the right hand at 125-Hz at a magnitude of only 0.5 ms^{-2} r.m.s. caused signficant reductions in blood flow in the middle finger of the vibrated right hand, but not the middle finger of the unexposed left hand. Increasing the vibration magnitude to 1.5 ms^{-2} r.m.s. reduced finger blood flow in both hands, but most noticeably in the vibrated hand.

Stronger reductions in finger blood flow in both exposed and unexposed fingers have been reported, as the magnitude of 125-Hz vibration increased from 5.5 to 62 ms^{-2} r.m.s. (unweighted) (Bovenzi *et al.*, 1999) and from 16 to 64 ms^{-2} r.m.s. (unweighted) (Bovenzi *et al.*, 2004). Progressively greater reductions in FBF have been found with 16, 31.5, 63, 125, 250 and 315-Hz vibration and magnitude increasing continuously from 0 to 15 ms^{-2} r.m.s. (weighted) (Thompson and Griffin, 2009). With greater magnitudes of vibration, a larger area is vibrated, so it is unclear to what extent the effects of vibration magnitude found previously were due to increased magnitude of vibration or increased area of excitation. In the present study, the probe's static surround restricted vibration transmission to other locations, so the greater reductions in finger blood flow found here with the greater magnitude of vibration are probably not linked to vibration transmission to distant locations. Reflex control of skin blood flow is mediated through sympathetic vasoconstriction and vasodilation (Bovenzi *et al.*, 2001). The present results are consistent with some, but not all, of the vasoconstriction during and after exposure to vibration being mediated by central sympathetic vasomotor activity.

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PERCEPTION OF HAND-TRANSMITTED VIBRATION: CAN VIBRATION OF ONE HAND MASK PERCEPTION OF VIBRATION IN THE OTHER HAND?

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1. INTRODUCTION

Vibration is often transmitted to both hands (e.g. from tools, machinery, steering wheels), yet the effects of hand-transmitted vibration are mostly studied by vibrating only one hand. When vibrating two hands, the absolute threshold for the perception of vibration is determined by the sensitivity of the most sensitive hand (Morioka, 2006).

Increasing the area of contact with vibration on one hand can reduce thresholds for perceiving vibration, often explained by 'spatial summation' in the Pacinian channel, one of four tactile channels mediating vibration perception in the glabrous skin (Verrrillo, 1962). The perception of a vibration mediated by one tactile channel (either Pacinian or non-Pacinian) can be masked if another vibration excites the same channel (e.g., Gescheider *et al.*, 1982), but there has been little research on masking between the hands.

The objective of this study was to examine whether the perception of vibration at one hand can be masked by vibration presented to the contralateral hand.

2. METHODS

Thresholds for the perception of vibration at the right hand were determined while applying masking vibration to the left hand.

2.1. Subjects

Ten males aged between 21 and 28 years (mean 23.3 years) participated in the experiment. All subjects were right handed, healthy, and had not been exposed to severe hand-transmitted vibration. The experiment was approved by the Human Experimentation Safety and Ethics Committee of the ISVR at the University of Southampton.

2.2. Apparatus

Vertical vibration was presented using two rigid cylindrical handles (30-mm diameter, 10-mm length) connected to two identical electrodynamic vibrators (MB Dynamics). Cross-axis acceleration was less than 5% of the vertical acceleration. A piezoelectric accelerometer (DJ Birchall) was mounted on each handle. Vibration stimuli were generated and acquired using *HVLab* Data Acquisition and Analysis Software (version 3.81). A rigid, contoured wooden seat and stationary footrests (mounted on their own vibrator systems, but not used in this experiment) were provided as shown in Figure 1.

Figure 1. A subject with the experimental apparatus.

2.3. Procedure

The subjects participated in two sessions on different days. Each session consisted of two parts to determine:

Part A: Threshold for the masker
Part B: Threshold of the test stimulus with the masker

All thresholds were determined using a two-interval two-alternative forced-choice (2IFC) tracking method with the up-down transformed response procedure and a three-down one-up rule. The sinusoidal test motions (presented to the right hand) had a frequency of 125 Hz. The masking stimuli (presented to the left hand) were $^1/_3$-octave bandwidth random vibrations centered on either 16 Hz or 125 Hz and

The subjects were presented with two observation periods, each of 1.0 second duration, separated by a 1.0 second pause. In Part A: subjects judged whether the first or the second observation period contained a vibration stimulus. In Part B: subjects judged which observation period contained the test stimulus presented at the beginning of each trial (see Figure 2). In both Parts, subjects responded by saying, 'first' or 'second'. The masked threshold was defined as:

$$\text{Masked threshold (dB)} = 20 \cdot \log_{10}\left(\frac{A_{N\text{dB}}}{A_{0\text{dB}}}\right)$$

where $A_{N\text{dB}}$ is the threshold (r.m.s. acceleration) of the 125-Hz test vibration with the masker at N dBSL, and $A_{0\text{dB}}$ is the threshold (r.m.s. acceleration) of the 125-Hz test vibration with the masker at 0 dBSL (i.e. the threshold of the masker).

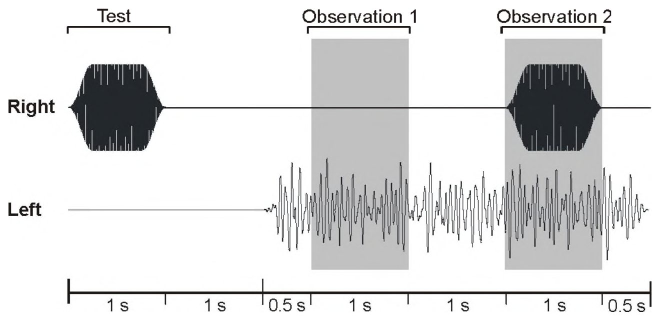

Figure 2. Example masked threshold test (Part B) with 16-Hz masker presented to the left hand and the 125-Hz stimulus to the right hand.

3. RESULTS

With the 125-Hz masker applied to the left hand, there were no significant differences in thresholds for the perception of 125-Hz vibration applied to the right hand (Friedman, p=0.766).

With the 16-Hz masker applied to the left hand, the threshold for perceiving 125-Hz vibration applied to the right hand differed over the six masker levels (0 to 30 dBSL) (Friedman, p=0.033). There was a slight decrease (1.6 dB) in the threshold when the masker increased from 18 to 24 dBSL (Wilcoxon, p=0.009) and a slight increase (1.4 dB) in the threshold when the masker increased from 24 to 30 dBSL (Wilcoxon, p=0.013) (Figure 3).

There were no significant differences in 125-Hz thresholds between the 16-Hz and 125-Hz maskers at any of the six masker levels (Wilcoxon, p>0.05).

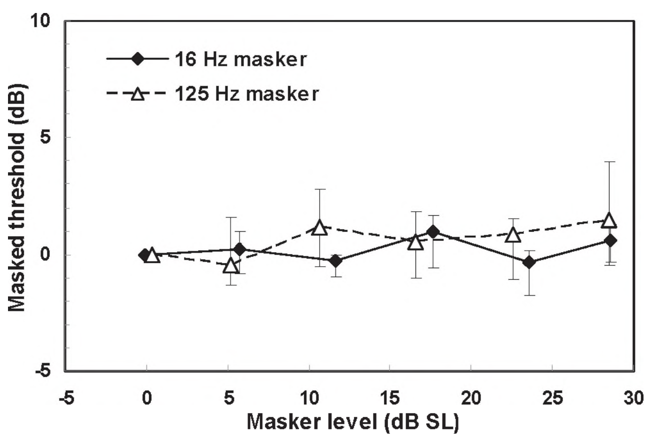

Figure 3. Median thresholds for 125-Hz vibration of the right hand while exposed to 16-Hz or 125-Hz masking vibration of the left hand. Vertical bars indicate inter-quartile range.

4. DISCUSSION AND CONCLUSIONS

In-channel masking has been demonstrated with hand-transmitted vibration when the masker is applied to the same hand (i.e. ipsilateral hand) as the test stimulus (Morioka and Griffin, 2005). However, in the present study, the detection of 125-Hz vibration presented to the right hand was not influenced by a 125-Hz masker applied to the left (contralateral) hand, suggesting that in-channel masking occurs unilaterally but not bilaterally. The absence of bilateral masking is consistent with other studies. More spatial pattern splits were identified when vibrotactile patterns were presented to fingers of both hands than when presented to fingers on the same hand (Craig, 1985a, 1985b). It has also been concluded that the effect of complexity on the recognition of vibrotactile patterns is reduced when the patterns are introduced bilaterally (Horner, 1992). These findings suggest the relevant properties of the tactile channels are exhibited in the peripheral system, because vibration stimuli that excite the same tactile channel can be differentiated when presented bilaterally but not when presented unilaterally.

If bilateral in-channel masking does not occur, the slight increase in the 125-Hz threshold when the 16-Hz masker increased from 24 to 30 dBSL cannot be explained by the masker being of sufficient magnitude to excite the Pacinian channel mediating 125-Hz vibration at threshold levels. It is more likely that high intensities of the 16-Hz masker increased the transmission of vibration from the hand to the arm (whereas the perception of 125-Hz hand-transmitted vibration is localized at the vibrating surface; Morioka, 2002), distracting attention from the 125-Hz vibration presented to the contralateral hand.

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Thermotactile Thresholds Before, During and After Exposure to Hand-Transmitted Vibration

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1. INTRODUCTION

Thermal perception thresholds are used to assess peripheral neuropathy among workers exposed to hand-transmitted vibration. Studies have found associations between exposure to hand-transmitted vibration and impaired thermotactile thresholds (Nilsson *et al.*, 2008). A recent longitudinal study found thermal sensitivity correlated with daily exposure to hand-transmitted vibration, *A*(8), and finger numbness (Bovenzi *et al.*, 2010).

Thermotactile thresholds in the fingers have been reported to exhibit threshold shifts after acute exposures to hand-transmitted vibration. Hirosawa *et al.* (1992) reported effects on warm thresholds but not cool thresholds after exposing the hand to accelerations between 19.6 and 156.8 ms^{-2} at frequencies between 32 and 500 Hz. Burström *et al.* (2008) found minimal effects of vibration on cool thresholds and no effect on warm thresholds with accelerations between 4.8 and 111 ms^{-2} r.m.s. at frequencies between 31.5 and 125 Hz. Recovery of normal thresholds was reported within minutes in both studies.

It has not previously been reported whether thermotactile thresholds change during exposure to vibration. The study reported here was designed to investigate warm and cool thresholds before, during, and after exposure to vibration.

2. METHODS

2.1. Subjects

Twelve healthy male volunteers with a mean age of 26.3 years (SD 2.8) participated in the study. Subjects were screened to exclude those with prior regular exposure to hand-transmitted vibration, diabetes, vascular or neurological disorders and injuries to the right hand. The study was approved by the Human Experimentation Safety and Ethics Committee of the Institute of Sound and Vibration Research at the University of Southampton.

2.2. Apparatus

A circular aluminium plate (55-mm diameter) varied in temperature (between 10 and 55°C) and was controlled by an *HVLab* Thermal Aesthesiometer control system (version 3.0) connected to a computer running *HVLab* diagnostic software (version 8.4) (see Figure 1). A thermocouple at the centre of the top surface of the circular plate provided temperature feedback to the software. Thermocouples measured skin temperature on the dorsal side of the distal phalanx of the middle finger (digit 3) and the centre of the palm.

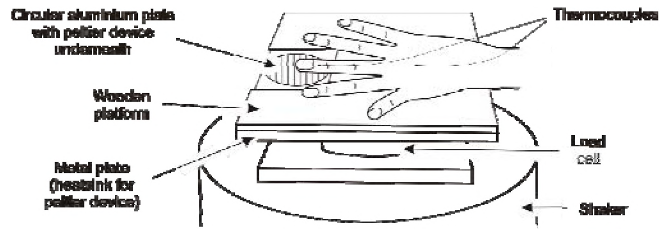

Figure 1. Experimental arrangement.

The temperature-controlled plate was secured to a metal plate mounted on a Tedea-Huntleigh Model 1022 single point load cell and connected to a Derritron VP4 vibrator that supplied sinusoidal vertical vibration to the right hand.

2.3. Experimental Procedure

The experiment was performed in a room with ambient temperature of 23°C (±1°C). Subjects were acclimatised for 10 minutes before the skin temperatures were measured. If either the finger or palm skin temperature was less than 27°C, the hands were warmed. Subjects practiced thresholds using the ring finger of the right hand. Throughout the experiment, subjects applied a force of 5 N, which they monitored on an analogue meter.

Thermotactile thresholds were obtained on the distal phalanx of the middle finger of the right hand using the method of limits. Depending on the threshold (i.e. either a warm threshold or a cool threshold), the temperature of the applicator increased or decreased at 1°C per second from a reference temperature of 32.5°C. Subjects pressed a button when they perceived a change in temperature. Warm and cool thresholds were measured alternately at 30-s intervals.

Subjects attended three sessions at the same time on three days, with the order of sessions randomised. Each session comprised: (i) 5-minutes pre-exposure: 5-N force with no vibration; (i) 30-minutes exposure: 5-N force with vertical vibration at either 16 Hz or 125 Hz or no vibration (control); and (iii) 10-minutes recovery: 5-N force with no vibration. At both frequencies, the vibration magnitude was 5.0 ms^{-2} r.m.s. when weighted according to ISO 5349-1:2001 (5.0 ms^{-2} r.m.s. unweighted at 16 Hz; 39.4 ms^{-2} r.m.s. unweighted at 125 Hz), giving an 8-hour energy equivalent *A*(8) acceleration of 1.25 ms^{-2} r.m.s. This paper compares findings in the control condition and with 125-Hz vibration.

3. RESULTS

Median thresholds were determined over five periods: before exposure (minutes 1 to 5), during exposure (minutes

6 to 15, minutes 16 to 25, minutes 26 to 35), and after exposure (minutes 36 to 45).

Control Condition

In the control condition (no vibration), cool thresholds were unchanged over the five periods (p = 0.399, Friedman; Figure 2), starting with a median of 29.3°C and ending with 29.4°C. However, warm thresholds increased over time, from a median of 39.5°C to 41.6°C (p = 0.006). Warm thresholds differed between the first and last periods (i.e. before and after the exposure period; p=0.007, Wilcoxon) but not between the first and any other period ($p \geq 0.062$).

During the 'pre-exposure period', there was no significant difference in thresholds between the control condition and the 125-Hz session (warm thresholds: p=0.388; cool thresholds: p=0.721; Wilcoxon). Both thresholds were highly correlated between the two sessions (warm thresholds: p=0.003; cool thresholds: $p<0.001$; Spearman).

Cool Thresholds

With 125-Hz vibration, there was no change in cool thresholds over the five periods (p=0.181, Friedman) or over the three periods with vibration (p=0.076).

Within each of the three periods of the 'exposure period', there were no significant differences between cool thresholds obtained with 125-Hz vibration and thresholds during the control condition (period 1: p=0.109; period 2: p=0.223; period 3: p=0.285; Wilcoxon). During the recovery period, the median cool threshold was 28.4°C following vibration, 1.0°C cooler than in the corresponding period of control condition (p=0.050).

Warm thresholds

With 125-Hz vibration, warm thresholds increased over the five periods (p=0.001; Friedman) and also over the three periods during application of vibration (p=0.006).

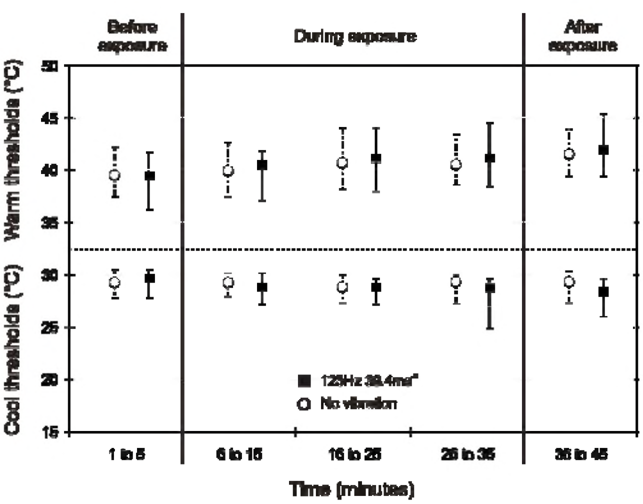

Figure 2. Median and inter-quartile range of warm and cool thresholds.

Compared to the pre-exposure period, warm thresholds during period 1 of the 125-Hz exposure did not differ (p=0.195; Wilcoxon), but thresholds were higher in periods 2 and 3 ($p \leq 0.041$). Within each of the three periods of the 'exposure period', there were no significant differences between warm thresholds during 125-Hz vibration and during the corresponding period of the control condition (period 1: p=0.824; period 2: p=0.722; period 3: p=0.754).

During the recovery period after 125-Hz vibration, warm thresholds were higher than during the pre-exposure period (p=0.017; Wilcoxon). Warm thresholds during recovery after 125-Hz vibration did not differ from those in the corresponding period of the control condition (p=0.754).

4. DISCUSSION AND CONCLUSIONS

Previous studies have found inconsistent changes in thermotactile thresholds after exposure to hand-transmitted vibration of similar magnitudes, but have not investigated thresholds during vibration.

In the present study, cold thresholds were unaffected by 45-minutes of force and unaffected by 125-Hz vibration. Warm thresholds increased during the 45-minute control condition, but there is no statistical evidence of an additional effect of the 125-Hz vibration on the warm thresholds.

It may be concluded that for the vibration magnitudes investigated, any acute effects of hand-transmitted vibration on thermotactile thresholds are small. The effects are less than intersubject variability in thermotactile thresholds and may be less than the changes associated with maintaining constant force. It is concluded that the perception of temperature is not greatly reduced during exposure to this type of hand-transmitted vibration.

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Evaluation of Gender Differences in Foot-Transmitted Vibration

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1. INTRODUCTION

Vibration can enter the body of mobile equipment operators, the hands of workers using power-tools or the feet of workers standing on vibrating platforms (Eger et al., 2006). There has been extensive research on adverse health effects resulting from exposure to vibration when seated or when gripping power-tools. However, research associated with vibration exposure via the feet is limited.

Prolonged vibration exposure at the feet can lead to neurological, vascular and musculoskeletal symptoms occurring either due to direct segmental exposure of the feet to vibration (Thompson et al. 2010;), or as a secondary complication to hand-arm vibration syndrome through sympathetic activation (Sakakibara and Yamada 1995).

Despite evidence of vibration induced white-feet, there is limited research on the biodynamic response of the foot to vibration exposure. Investigating the biodynamic response of the human body to vibration is necessary to understand how vibration influences human comfort, performance and health. Understanding the biodynamic response of the foot is also required to select protective equipment that could help to attenuate foot-transmitted vibration. Therefore, the purpose of this study is to measure vibration transmissibility via the feet in individuals exposed to vibration while standing, and to determine if transmissibility and subjective reports of discomfort differed between males and females.

2. METHODS

Vibration transmissibility through the foot was measured while participants stood on a vibration platform. The Laurentian University research ethics board approved all experimental procedures.

2.1. Participants

Ten healthy participants of university age (five males; five females) were recruited from a sample of convenience, and were ruled out for a history of lower body musculoskeletal injury in the last 6 months, vasculopathy, neuropathy, motion sickness, diabetes or history of head injury. All participants were informed of the nature of the experiment and written informed consent was obtained prior to data collection.

2.2. Vibration Exposure

Participants were exposed to a 31.5 Hz dominant frequency vibration with an average frequency-weighted RMS acceleration between 7-13 m/s^2 via a vibration exercise platform (Power Plate North American, Inc., Irvine, CA). This vibration frequency was selected to simulate the vibration experienced when standing on drilling platforms and raises used in underground mining (Leduc, 2011). Participants were asked to stand on the platform, with socked feet, for two 30-second exposure trials with 20 seconds of rest between trials. Participants were also asked to give a verbal discomfort report, after each trial, using a 9-point discomfort scale and a body chart to indicate regions of discomfort.

2.3. Vibration Measurement

Vibration data were collected in accordance with the ISO 2631-1 standard for whole body vibration. Two S2-10G-MF tri-axial accelerometers (NexGen Ergonomics, Montreal, QC) were used to measure vibration on the floor of the vibration platform and the lateral malleolus of the foot. A DataLOG II P3X8 (Biometrics, Gwent, UK) data logger was used to record the vibration data. Participants stood on a standard rubber pad with a tri-axial accelerometer in order to measure platform vibration, and a second accelerometer was secured to the medial malleolus with medical adhesive tape and athletic wrap.

2.4. Data Analysis

Vibration Analysis Toolset (NexGen Ergonomics, Montreal, QC) was used to calculate the frequency-weighted vibration at the floor and the ankle in accordance with ISO 2631-1.

Frequency-weighted acceleration in the z-axis entering the foot (Fa_{wz}) was compared to frequency-weighted acceleration in the z-axis at the ankle (Aa_{wz}). The percent different between $Aa_{wz,}$ and Fa_{wz} is presented as a crude measure of vibration transmissibility from the floor through the foot to the ankle. Values greater than 100% are indicative of vibration amplification between the floor and the ankle while values less than 100% are indicative of vibration attenuation.

3. RESULTS AND DISCUSSION

Vibration measured at the floor and the ankle and percent difference in z-axis vibration between ankle and floor expressed as a percentage is summarized in Table 1. Measured z-axis vibration was lower at the ankle in all trials with the exception of one male. Thus, it can be hypothesized that anatomical structures of the foot, for example the heel fat pad, could play a role in attenuation of foot-transmitted vibration from the floor through the foot to the ankle.

Vibration transmissibility to the ankle was significantly lower for females than males. This finding is in line with Lundstrom et al., 1998 who reported females tend to absorb more vibration power per kilogram due to higher body fat to muscle mass ratio. Therefore, it could be hypothesized that differences in transmissibility between genders could be the result of difference in the foot architecture in terms of arch type and bony structure. Participants reported whole body, face; neck, upper back, abdomen, thigh, knee, lower leg, ankle, and feet discomfort (Table 1). Several participants also reported tingling of ear and itchiness in the nose and legs.

Table 1. Vibration recorded at the floor and ankle, with % difference and subjective reports of discomfort.

Gender	Mass (lbs)	Floor Faw_z (ms^{-2})	Ankle Aaw_z (ms^{-2})	Percent Difference Aa_{wz}/Fa_{wz} (%)	Discomfort by Body Region* Score 0-9 (9 = max. discomfort)
Male	165	9.4	3.1	32.8	WB=3
Male	184	7.5	9.5	126.7	F=1; T=3; K=3
		8.6	8.1	94.3	T=3; F=3
Male	135	11.8	8.2	69.0	H=7; N=7; K=7; F=7; A=7
		12.2	8.1	66.5	H=8; N=8; K=8; Ft=8; A=8
Male	150	9.3	3.1	33.5	K=9; F=9
		10.1	3.0	29.5	T=9; F=9
Male	160	10.6	7.1	66.7	K=3
		9.8	8.1	82.4	WB= 2
Female	120	11.5	7.1	61.7	WB= 3
		11.4	7.2	63.0	WB= 4
Female	180	9.4	3.5	37.6	F=1
		8.9	3.2	36.0	no discomfort
Female	125	11.6	6.7	98.0	F=7; H=7; LL=2
		12.6	7.8	61.9	LL=4; UB=4
Female	130	11.1	2.5	22.6	H=1; LL=1
		12.8	2.1	16.3	H=1; LL=1
Female	140	10.9	5.5	50.5	F=6; LL=6; Ft=5
		10.8	3.0	27.4	H=8; Ab=3; Ft=6

* WB=whole body; F=face; N=neck; UB=upper back; Ab=abdomen; T=thigh; K=knee; LL=lower leg; A=ankle; Ft=feet

4. CONCLUSIONS

The percent difference in z-axis vibration measured between the ankle and the foot was significantly lower for female participants than male participants suggesting females attenuate foot-transmitted vibration more effectively than males. Future research should evaluate the biodynamic response of the foot to foot-transmitted vibration under a larger range of exposure frequencies. Vibration transmissibility should also be measured at more locations across the foot, and the role of arch type, surface area in contact with the vibration surface, and center of pressure while standing should all be considered in future studies.

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FUNDAMENTAL STUDY OF VIBROTACTILE PERCEPTION THRESHOLD ON JAPANESE-VIBROTACTILE PERCEPTION THRESHOLDS USING NEW MEASUREMENT EQUIPMENT

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1. INTRODUCTION

The ISO 13091-1 standard which was published in 2001 provides direction for the measurement of the vibrotactile perception threshold (VPT), using an internationally standardized method. A compilation of VPT data of healthy persons available at the time of publication are presented in ISO 13091-2:2003, Annex A, which were obtained with subjects in Europe and the US, and not with Japanese.

The purpose of this study is to investigate the VPT of healthy Japanese with new equipment developed according to ISO 13091-1, and compare the results with the ISO 13091-2:2003 reference data.

2. APPARATUS AND METHOD

2.1. Measurement Equipment Specification

New equipment developed according to ISO 13091-1:2001 was used. The equipment employs the "Method B: With surround". The static contact force of the surround is kept constant (2 ± 0.3 N) by a spring. The contact force of the stimulator probe (6 mm diameter) is sensed and indicated so that the subject can easily keep the force constant (1 ± 0.3 N). The summarized specifications of the equipment are as follows: -

Probe tip diameter: 6 mm
Probe contact force: 1±0.3 N (indicator resolution: 0.1 N)
Surround diameter: 10 mm
Surround contact force: 2±0.3 N
Stimulus frequency:
3.15, 4, 5, 20, 25, 31.5, 100, 125 and 160 Hz
Psychophysical algorithm: von Békésy and up-down
(von Békésy algorithm was used for the current study)
Measurement of finger temperature: 0.1 °C resolution

2.2. Subjects

The subjects were 30 males (age: 23 to 40 years) and 17 females (age: 22 to 40 years) healthy Japanese office workers, who do not have a history of undue exposure to vibration. The mean age of the male and the female subjects were 31.3 and 29.8 years respectively. The mean weights were 65.9 Kg (SD: 9.2 Kg) and 50.5 Kg (SD: 5.9 Kg). The mean heights were 172.5 cm (SD: 5.0 cm) and 158.6 cm (SD: 6.0 cm).

2.3. Experimental Conditions

The VPTs of index fingers and middle fingers of right-hands were measured for 9 stimulus frequencies (3.15, 4, 5, 20, 25, 31.5, 100, 125, and 160 Hz).

Table 1. VPT distributions for male and female subjects including index fingers and middle fingers.

	Frequency (Hz)								
	3.15	4	5	20	25	31.5	100	125	160
Males (60 fingers)	VPT (dB re 10^{-6}m/s^2)								
2.5 percentile	70.4	72.6	73.7	86.2	88.9	93.1	97.8	95.1	96.1
15 percentile	73.4	75.0	76.9	88.6	94.9	96.0	100.0	100.0	100.9
50 percentile	78.3	80.9	82.3	93.6	97.7	100.2	104.2	105.2	104.7
85 percentile	83.4	86.3	89.6	98.9	101.2	103.8	112.6	110.7	111.6
97.5 percentile	90.0	89.6	93.5	105.9	106.9	107.9	121.0	115.2	117.0
ISO 13091-2, Annex A 50 percentile	75.0	77.5	81.5	92.3	95.0	100.3	108.5	107.8	108.0
Females (34 fingers)	VPT (dB re 10^{-6}m/s^2)								
2.5 percentile	68.9	70.6	72.1	82.8	85.6	91.3	92.9	93.0	97.4
15 percentile	72.9	72.4	75.1	88.7	91.0	94.2	99.5	96.4	99.2
50 percentile	76.3	76.8	78.9	93.3	95.2	98.1	104.1	106.7	104.8
85 percentile	82.0	82.2	83.6	97.2	99.8	101.7	112.7	112.1	113.0
97.5 percentile	87.3	86.3	90.2	99.9	105.8	108.4	115.8	116.2	115.2
ISO 13091-2, Annex A 50 percentile				94.8		101.8		110.0	

The test room had concrete floor with plastic tiles, which prevented floor vibration influencing the VPT measurement. There was no vibration source nor noise source in the surroundings. The background noise levels were 42 dB (L_{Aeq}) measured with a sound level meter complying with IEC 16172 series. The averaged desk vibration was 66.5dB re $10^{-6}m/s^2$ for Wm Band-limiting according to ISO 2631-2:2003 (0.5 to 125 Hz). The floor vibration was lower than 50 dB.

The room temperatures were in the range from 20.5°C to 24.5°C throughout the experiment and the mean temperature was 22.8°C. The finger temperatures of the subjects were controlled to be within 27.0°C and 33.7°C and the mean temperature was 29.4°C.

3. RESULTS AND DISCUSSION

3.1. VPTs of Japanese Subjects

Table 1 shows 2.5, 15, 50, 85 and 97.5 percentiles of the VPT levels (expressed in decibels) of the male and the female subjects. The numbers of fingers are 60 and 34 because the VPT for the index fingers and the middle fingers are included. No large difference of the VPT levels is observed between the male and the female subjects, except that the VPT levels of the female subjects are a little lower than those of the males for some of the lower frequencies (3.15, 4 and 5 Hz). The largest difference of 50 percentile is 4.1 dB for 4 Hz. The largest difference in the table is that 85 percentile of the females is 6.0 dB lower than the males for 5 Hz.

Mean and standard deviation (SD) of the VPT levels for index fingers and middle fingers of the male and the female subjects are shown in Table 2. Significant differences at the 5 % significance level between the males and the females are measured only for some lower frequencies (t-test). Therefore, we consider that there is only a minor difference between the VPTs of Japanese males and females.

3.2. Comparison of Current Study and ISO 13091-2 Reference Data

Table 1 refers to the 50th percentile of ISO 13091-2:2003, Annex A for comparison. The differences between the current study with Japanese subjects and the ISO data for the males and the females are up to 4.3 and 3.7 dB respectively. The VPT levels of the current study are generally higher for low frequencies and lower in high frequencies, which may be caused by minor differences of the test conditions.

4. CONCLUSION

VPTs were investigated with 30 male and 17 female Japanese subjects. Only small differences in VPTs are observed between the males and the females. We suggest that the possibility of using the same reference VPT levels for males and females for standard testing be considered.

The VPT data obtained by the current study with Japanese subjects show only minor differences from the reference data of ISO 13091-2:2003. Data for larger populations and various age groups need to be considered.

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Table 2. Statistical comparison of VPTs for index fingers and middle fingers of male and female subjects (t-test).

		Frequency (Hz)								
		3.15	4	5	20	25	31.5	100	125	160
Males		VPT (dB re $10^{-6}m/s^2$)								
Index fingers (n = 30)	Mean	78.0	78.8	81.5	94.0	97.6	100.2	104.4	104.3	105.4
	SD	4.5	4.8	5.0	4.9	4.0	4.3	6.1	5.3	5.7
Middle fingers (n = 30)	Mean	78.7	82.0	83.6	94.6	98.3	100.4	106.5	105.7	106.1
	SD	5.7	4.8	5.5	5.7	4.7	4.6	5.8	5.8	5.1
Females		VPT (dB re $10^{-6}m/s^2$)								
Index fingers (n = 17)	Mean	75.3	76.5	78.0	92.4	95.9	97.8	104.7	104.9	105.0
	SD	3.9	3.8	3.3	4.6	5.5	4.2	6.5	6.3	5.8
Middle fingers (n = 17)	Mean	79.3	78.4	80.8	92.8	95.5	99.2	105.5	106.1	106.7
	SD	5.4	5.5	5.9	5.1	4.6	4.7	7.0	7.5	5.9
		Significant differences between males and females								
Index fingers		P<0.05	—	P<0.05	—	—	—	—	—	—
Middle fingers		—	P<0.05	—	—	—	—	—	—	—

EFFECT OF WORK REST SCHEDULE ON PERCEIVED DISCOMFORT SCORE AND THERMAL THRESHOLD SHIFT OF OPERATORS USING HAND-HELD VIBRATING MACHINES

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1. INTRODUCTION

Time-integrated fatigue may lead to different types of injuries during the operation of a machine (Muller, 1953; Folkard and Monk, 1985; Rosa, 1995; Christensen et al., 2000). Such fatigue stretched over a period of months and years may cause physical, physiological and musculoskeletal disorders (Waersted and Westgaard, 1991). In many real working tasks in industrial settings, the periods of intense physical activity alternate with rest periods or periods of lighter work. This maximizes the total quantity of physical work an individual can perform during the working day, compared to working at a steady but lower level (Muller, 1953; Astrand, 1960). In such cases, the work is designed so that the overall energy expenditure, averaged over the working day and taking into account both work and rest, remains within acceptable limits.

According to different classifications, the health effects of hand-arm vibration (HAV) have vascular, neurological and musculoskeletal system components (Griffin, 1990; Mason and Poole, 2004). Vascular disorders are characterized by attacks of cold-induced finger blanching, and are the most extensively studied symptom of hand-arm vibration syndrome (HAVS).

A dose–response relationship has been established between exposure to HAV and the risk of vibration induced white fingers (VWFs) on the basis of several epidemiological studies (Gemne and Lundström, 1996; Bovenzi, 1998). The occurrence of HAVS may be predicted on the basis of cumulative exposure to HAV according to the international standard ISO 5349.

Because of the viscoelastic, time-dependent behaviour of biological tissues, even low intensity loads (such as during drilling operations) applied for longer durations may increase the chances of tissue damage (Goldstein et al., 1987; van Dieën and Toussaint, 1995; van Dieën and Oude Vrielink, 1998). Work-rest schedules allow for more variation and periodic recovery from the stress of the work (van Dieën and Oude Vrielink, 1998).

Thus, under such situation, the administration of suitable work-rest schedules seems to be a feasible approach to reduce the time-integrated (cumulative) workload on the operator, and potential for tissue injury.

The major aim of the study was to identify a work-rest schedule for optimum work output in a hypothetical drilling operation, by assessing operator discomfort and thermal threshold shifts in the fingertips under conditions of variable work-rest conditions.

2. METHOD

The subjects were asked to stand at a fixed position on the floor with respect to the drill rig, which was prepared in the workshop of a mechanical engineering department. The subject was asked to keep the elbow flexed at 90^0, the forearm horizontal and upper arm in vertical position, in the coronal plane. Prior to the start of the actual drilling task, the subjects rehearsed the drilling operation to become familiarized. Five different conditions were defined: A1 (work- 01 minute; rest- 03 minutes), A2 (work- 01.5 minutes; rest- 02.5 minutes), A3 (work- 2 minutes; rest- 02 minutes), A4 (work- 2.5 minutes; rest- 1.5 minutes) and A5 (work- 3 minutes; rest- 1 minute).

Participants worked for 20 minutes on the drilling task, keeping the feed force constant at 60N (±3N). A rest period of 20 minutes was provided to each participant after each series of five conditions, in order to recover from fatigue. The subject performed the different conditions in a random order. At the end of each condition, a perceived discomfort score was recorded on visual analog scale. The Visual Analogue Scale was labeled as: 0 for 'no discomfort'; 5 for 'moderate discomfort' and 10 for 'extreme discomfort'.

The Thermal Threshold Shift (TTS) was measured using a device consisting of a heating plate and a thermocouple for recording the temperature instantly. The subject was asked to keep the fleshy part of the right index finger tip over the centre of a metal plate which was slowly heated. The subject was also asked to report immediately when a change in temperature was sensed, by pressing an alarm button. The TTS (in ^{0}C) was the difference in temperatures of the plate, before and after the tasks when the subject sensed a change in temperature.

3. RESULTS AND DISCUSSION

The results of the study showed similar patterns for perceived discomfort score and TTS (Figures 1 and 2). The condition - A1 showed the least discomfort and lowest

TTS while condition - A4 resulted in highest discomfort and highest TTS.

To understand the effect of order, mean values of discomfort level for all combinations performed at various order were calculated, and a graph of order of the experiment and Mean Discomfort score for different job schedules was plotted (Figure 3). From the graph, it is evident that the discomfort score of participants increased with order of the experiment. It appeared from the graph that the rest duration of 20 minutes was not sufficient to recover fully and perform the next work as if there was no effect of previous work.

Figure 1. Variation of mean discomfort score with work condition (varying work time: rest time).

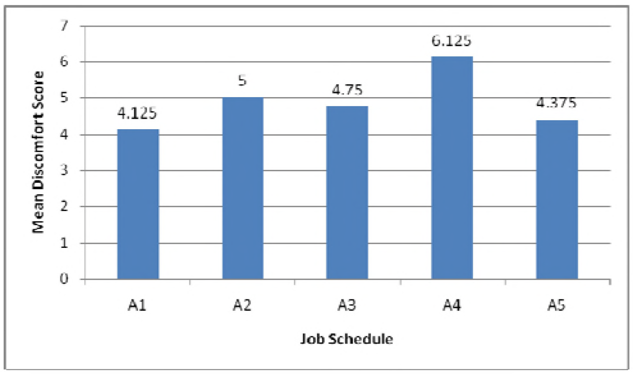


Figure 2. Variation of Thermal TTS with condition (varying work time: rest time).

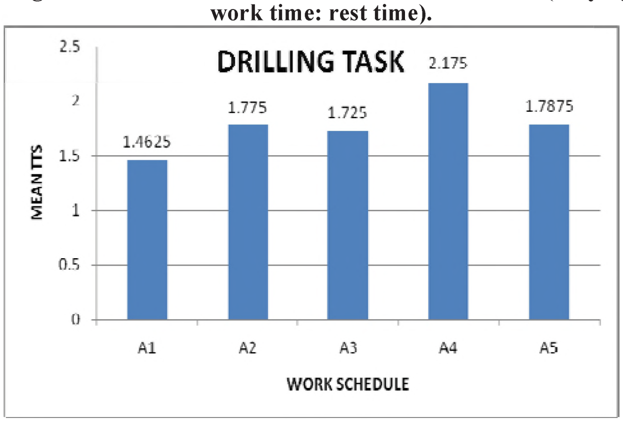
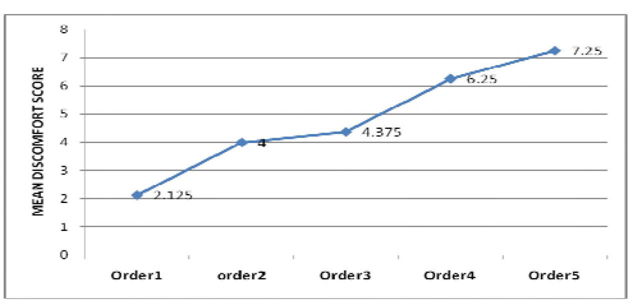


Figure 3. Effect of order of experiment on mean discomfort score for different job schedules.



4. CONCLUSIONS

- Thermal TTS and perceived discomfort score were observed to be similar in nature.
- A low level of discomfort and thermal TTS were observed when the drilling task was performed for one minute duration with a rest period of three minutes.

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Effect of Hand-Arm Vibration and Proximal Neuropathy on Current Perception Threshold Measurement in the Fingers

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1. INTRODUCTION

Hand-arm vibration exposure is associated with sensorineural abnormalities in the exposed fingers and these abnormalities may be measured by quantitative sensory tests such as current perception threshold (CPT) (Kurozawa et al, 2010). This quantitative sensory test allows all of the main sensory nerve fibres to be measured in a simple, non-invasive manner. However CPT measurements may also be affected by proximal neuropathies such as carpal tunnel syndrome (Nishimura et al, 2004) which are common in workers with HAVS, and may confound the demonstration of an effect of vibration exposure on sensorineural dysfunction in the fingers (Pelmear and Taylor, 1994). Therefore, this study was carried out to determine if hand-arm vibration exposure is associated with current perception threshold (CPT) measurement in the fingers after controlling for neuropathy proximal to the hand measured by nerve conduction testing.

2. METHODS

The study was carried out at the Occupational Health Clinic, St. Michael's Hospital and all of the 165 participants were men. They included 117 participants who had been exposed occupationally to hand-arm vibration and were being assessed for possible Hand-Arm Vibration Syndrome (HAVS), and 48 controls with no significant exposure to hand-arm vibration. All of the participants had a detailed occupational and medical history and physical examination to ensure that no other conditions were present that might affect sensation in the hands. In the workers exposed to vibration, the occupational histories were reviewed by a team of industrial hygienists to determine the intensity of daily vibration exposure and the following ordered categories of exposure were determined: miners > non-miners > controls.

All of the participants had nerve conduction tests and measurement of CPT in each hand. The nerve conduction tests were carried out in the hospital's electromyography department using standard methods and conventional electrode placement. The hand temperature was measured continuously and was at least 32°C during testing. This test identified the presence of median and/or ulnar sensory neuropathy proximal to the hand with the results being defined categorically (yes/no) for the purposes of this study. The CPT measurements were carried out using a Neurometer CTP/R (Neurotron Incorporated) with measurement at frequencies of 2000, 250 and 5 Hz corresponding to large myelinated (Abeta), small myelinated (Adelta) and unmyelinated (C) sensory fibres respectively. The measurements were done on the volar surface of the tips of the index finger for the median nerve and the little finger for the ulnar nerve. Therefore, there were 12 CPT measurements (2 hands × 2 nerves × 3 frequencies) on each participant. The nerve conduction and CPT measurements were carried out in a blinded fashion.

The analysis was carried out using SAS 9.2 (SAS Institute, Cary, NC). The principal analysis involved a set of 12 multiple linear regressions, one for each CPT dependent variable to determine key predictors. The independent variables examined in each regression included duration of vibration exposure (years), age (years), daily vibration exposure intensity (categorical variable: miners, non-miners, controls), median neuropathy (yes/no) and ulnar neuropathy (yes/no). In the regressions, the median and ulnar neuropathies were used from the same side on which the CPT testing had been done. In each case a saturated model was initially created which included all of the independent variables, and backwards elimination was then carried out to include only those variables that were statistically significant ($P<0.05$) in the final model.

3. RESULTS

The 165 participants had a mean (SD) age of 45.3 (11.2) and included 34 vibration exposed miners, 83 vibration exposed non-miners and 48 non-exposed controls. In the vibration exposed participants, the mean (SD) duration of exposure was 23.8 (11.3) years overall, 23.3 (9.5) years for the miners and 24.1 (12.0) for the non-miners. Forty-eight participants had median neuropathy on the right upper extremity and 30 on the left; 10 had ulnar neuropathy on the right side and 8 on the left. The prevalence of each of these proximal neuropathies was higher in the vibration exposed participants than in the controls on each side, and the differences were statistically significant ($p<0.05$) in all instances except for ulnar neuropathy on the left side.

In the multiple linear regression analysis, the only statistically significant variable included in the six regression models in the right upper extremity, after backwards stepwise elimination, was the variable for daily vibration exposure intensity. In all instances, the effect estimate for miners (with higher daily vibration exposure intensity) was greater than for non-miners. In the left upper extremity, the daily vibration exposure intensity variable was also included in all six regression models and was the key predictor variable. However, on this side, several proximal neuropathy variables were also found to be statistically significant – median neuropathy for the 5 Hz median CPT outcome and ulnar neuropathy for the 2000 Hz and 250 Hz ulnar CPT outcomes. Table 1 summarizes the R^2 values for the 12 CPT regression models which indicated that the vibration effect on CPT was greatest at 2000 Hz.

Table 1. R^2 Values for Regression Models for CPT Dependent Variables

Side	CPT	R^2
Right	Median 2000 Hz	0.408
	Median 250 Hz	0.207
	Median 5 Hz	0.236
	Ulnar 2000 Hz	0.356
	Ulnar 250 Hz	0.231
	Ulnar 5 Hz	0.188
Left	Median 2000 Hz	0.351
	Median 250 Hz	0.197
	Median 5 Hz *	0.208
	Ulnar 2000 Hz **	0.420
	Ulnar 250 Hz **	0.212
	Ulnar 5 Hz	0.170

All backwards stepwise models included daily vibration exposure intensity variable (categorical: mining>non-mining>control).
* Also included left median neuropathy variable.
** Also included left ulnar neuropathy variable.

4. DISCUSSION AND CONCLUSIONS

In this study, the main factor affecting CPT in the fingers was vibration exposure. In all of the 12 CPT regression models, the backwards stepwise elimination procedure resulted in the inclusion of the daily vibration intensity variable as the key predictive factor. If this daily vibration intensity variable was excluded and the regression modeling was repeated, the key predictor became the duration of vibration exposure.

In some of the models, in the left hand where vibration exposure is often less than in the right, proximal neuropathy variables were also found to be statistically significant. In these instances, median or ulnar CPT abnormalities were predicted by the corresponding median or ulnar proximal neuropathies. Proximal neuropathies, in particular median neuropathy at the wrist associated with carpal tunnel syndrome (CTS), commonly occur in workers exposed to hand-arm vibration (Pelmear and Taylor, 1994). As well, proximal neuropathy may be associated with CPT abnormalities in the fingers (Nishimura et al, 2004). However our findings indicated that the sensory abnormalities measured by CPT in workers exposed to vibration were not due to confounding by proximal neuropathy.

All of the fibre types measured by CPT were found to be affected by vibration exposure. The R^2 values were highest for the CPT 2000 Hz dependent variable regression models, indicating that vibration had the greatest effect on large myelinated fibres, although all fibre types were affected. This is consistent with previous CPT studies that have shown that CPT thresholds at 2000 Hz are most predictive of the Stockholm sensorineural scale in workers exposed to hand-arm vibration (Kurozawa et al, 2001; House et al, 2009). The results are also consistent with animal studies which have shown that acute high exposure of the rat tail to vibration is associated with an increase in CPT thresholds at 2000 Hz. (Krajnak et al, 2007). As well, chronic exposure of the rat tail to vibration has been found to be associated with ultrastructural changes in the myelin sheaths of large myelinated fibres (Chang et al, 1994), and biopsies of workers with HAVS have shown similar lesions (Takeuchi et al, 1988).

In conclusion, despite the high prevalence of proximal neuropathy in workers exposed to hand-arm vibration, there is an effect on nerve fibre damage in the fingers due to hand-arm vibration that cannot be explained by common median or ulnar neuropathies proximal to the hand.

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FUNDAMENTAL STUDY OF VIBROTACTILE PERCEPTION THRESHOLD ON JAPANESE - EFFECTIVENESS OF NEW EQUIPMENT TO DIAGNOSE WORKERS EXPOSED TO HAND-TRANSMITTED VIBRATION

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1. INTRODUCTION

The Japanese government recently adopted international standard ISO 13091-1:2001, and a new vibrotactile perception threshold (VPT) measurement equipment based the ISO standard has been produced. However, Japanese data measured by the new machine has never been reported. In the present study, we aimed to evaluate the effectiveness of the new equipment by: 1) collecting data from Japanese workers having exposure to hand-arm vibration; 2) comparing VPTs of HAVS free workers with those of contained in ISO 13091-2:2003, and; 3) comparing VPTs between persons with and without HAVS for Japanese workers.

2. APPARATUS AND METHODS

2.1. Apparatus

A new Vibrotactile Perception Thresholds (VPTs) measurement equipment based on ISO 13091-1 standard was produced by Rion Co., Ltd. (Kokubunji, Tokyo) and used in the series of experiments by Bekesy algorithm. Details of the equipment have been described by Nakajima. R. et al. at this conference ("Fundamental study of vibrotactile perception thresholds on Japanese New measurement equipment of vibrotactile perception thresholds").

2.2. Study Subjects

The study subjects comprised twenty-seven Japanese male workers who were exposed to hand-transmitted vibration. Seventeen workers were engaged in road maintenance as public servants (Group 1), and the rest (ten workers) were engaged in forestry work (Group 2).

The mean age of Group 1 was 53.5 years (ranged 43-66 yrs) and the mean period of exposure to hand-transmitted vibration was 20.7 years (range 3-34 yrs). The mean age of Group 2 was 67.7 years (ranged 62-71 yrs) and the mean period of exposure to hand-transmitted vibration was 36.7 years (range 11-50 yrs).

2.3. Methods

Assessments were performed in January and February 2009. The test room temperature was 20-24°C during measurements on Group 1, and 22.7-27.1°C on Group 2. The blood pressure of all subjects was measured and the hand-arm vibration syndrome (HAVS) was assessment on the basis of Stockholm classification by physical examination and by self-reported questionnaire. The upper limbs were also checked for pain and dysesthesia in the HAVS assessment. From the interview and physical examination (and not using EMG), none of the subjects were regarded as suffering from carpal tunnel syndrome.

Vibration perception thresholds of six fingertips (bilateral index, middle and ring fingers) were measured at three frequencies (4 Hz, 31.5 Hz, 125 Hz) using the new equipment.

2.4. Statistical Analysis

First, Group 1 data were compared with the reference values in ISO 13092-2 by using z-test. Second, VPTs were compared between Group 1 and Group 2 by using non-paired t test. By dividing at the mean age or period of exposure to HAV, VPTs comparisons were made for each condition, respectively. All tests were two-tailed and the statistical significance was set at $P < 0.05$. All statistical analyses were performed by SAS software Version 9.

3. RESULTS

Four (24%) workers in Group 1 and nine (90%) in Group 2 reported they had some dysesthesia in fingers. These dysthesia were regarded as being related to vibration exposure, because diseases which might cause dysthesia had been excluded by examination and interview. Also, one (6%) worker in Group 1 and eight (80%) in Group 2 reported that they had Raynaud's phenomenon in the questionnaire. For the purposes of the present work we roughly defined Group 1 as 'Without HAVS' and Group 2 as 'With HAVS', i.e., because workers in Group 1 had little dysesthesia. Moreover, Raynaud's phenomenon could not be observed among subjects in the physical examination.

Table 1. Comparison of VPTs between the subjects and ISO 13091-2 50 percentile reference at three frequencies.

Frequencies (Hz)	50 percentile ISO Reference (dB)	Right (dB)			Left (dB)		
		Index	Middle	Ring	Index	Middle	Ring
4	77.5	86.2*	86.1*	86.9*	85.4*	86.4*	86.7*
31.5	100.3	104.4*	103.0	103.8	101.7	103.6	103.7
125	107.8	110.6	110.0	11.7	109.8	111.5	110.4

Non-paired t-test. * *P* <0.05

3. RESULTS

3.1. Comparison of VPTs with ISO Reference

Table 1 shows a comparison of VPTs between the Group 1 subjects and the 50th percentile of the ISO 13091-2 reference thresholds at six fingertips (bilateral index, middle, ring) and three frequencies. The mean VPT values for the subjects were statistically significantly higher than ISO references on all fingers at 4Hz. In contrast, no significant difference was observed at 31.5Hz and 125Hz with one exception (right index finger). Moreover, VPTs of Group 1 subjects ranged within 2.5 and 97.5 percentile of the ISO references at all three frequencies (data not shown). Moreover, older people or those who had longer exposure periods to HAV had not significantly higher VPTs (data not shown).

3.2. Comparison of VPTs between Groups 1 and 2

Figure 1 indicates the comparison of VPTs between Group 1 and Group 2 subjects for the right middle fingers. Group 2 consistently had statistical significantly higher VPTs than those of Group 1 for bilateral six finger data at three frequencies. In subgroup analysis, those who have Raynaud's symptom (n=9), dysesthesia (n=13) had significantly higher VPTs than those have no symptoms in some fingers and at some frequencies. In contrast, older people or those who have longer exposure periods to HAV had not significantly higher VPTs (data not shown).

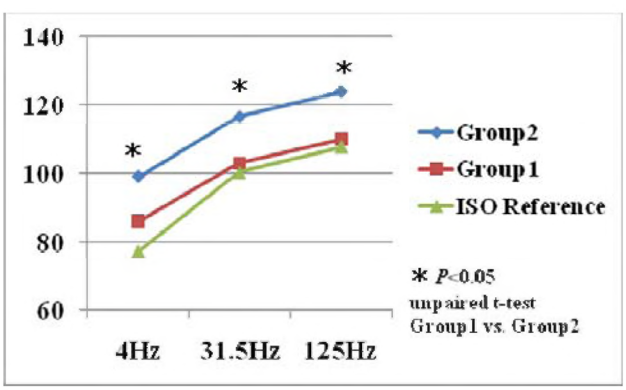

Figure 1. A comparison of VPTs between Groups 1 and 2 at three frequencies for the right middle finger

4. DISCUSSION

In the first analysis, significantly higher VPTs of Group 1 subjects were observed compared with ISO 13091-2 reference thresholds at 4Hz. However, this significance disappeared at 31.5 and 125Hz. Generally, as getting older, VPTs increased at higher frequencies. The mean age of Group 1 subjects was relatively higher than the ISO 13091-2 standard group (53.4 years versus 30 years). The reason for the inconsistent result at 4 Hz remains unclear. On the other hand, VPTs of Group 1 subjects ranged within the 2.5 and 97.5 percentiles of the ISO 13091-2 references. These results suggest this equipment can generally evaluate workers without HAV properly in accordance with the ISO 13091-2 standard. In the second analysis, Group 2 consistently had higher VPTs than Group 1, with statistical significance for all conditions. Moreover, these significances remained in the additional analyses relating to HAVS, Raynaud's symptom, and dysesthesia. These results suggest this equipment can discriminate VPTs of workers with HAVS from those without HAVS. Because of the small number of study subjects, the test sensitivity and specificity could not be calculated.

5. CONCLUSIONS

VPTs of HAVS-free workers were measured by a new ISO 13091-based equipment, and the results fitted the reference values of the ISO 13091-2 standard. The VPTs derived from subjects with HAVS were consistently significantly higher than those without HAVS. These results provide suggestive evidence that the new equipment can evaluate appropriately workers having exposure to hand-arm vibration with or without HAVS.

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MEASURING CONDITIONS OF COLD PROVOCATION TESTS: A REVIEW OF THE LITERATURE

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1. INTRODUCTION

Prolonged exposure to hand-arm vibration is a cause of hand-arm vibration syndrome (HAVS). This disorder is characterized by neurological, vascular and musculoskeletal disturbances in upper extremities. In health screening of HAVS, cold provocation tests (CPTs) have been widely conducted to evaluate the severity of the damage in the peripheral vascular function. However, there is a wide difference in test conditions among countries and researchers.

The International Organization for Standardization (ISO) released ISO 14835-1 in 2005, which proposed a water temperature of 12 °C and an immersion duration of 5 minutes in cold provocation tests (CPTs) for assessing peripheral vascular function. Many results have been reported since the ISO recommendation, but findings are not always consistent. It is necessary to re-evaluate them. The purpose of this study is to review measuring conditions of CPTs recently reported and to establish a new database.

2. METHODS

Relevant articles were identified using the PubMed database from 2002 (the year the latest article ISO 14835-1 referred to was published) to October 2010. The electronic search included both free-text and MeSH terms. Used terms were: "vibration white finger," "hand-arm vibration syndrome," "vibration-induced white finger," "cold temperature [MeSH Terms]," "cold climate [MeSH Terms]," "cold water," and "cold provocation test." Articles included in this review were written in English, published as an original article, with human subjects and had no obvious overlap of subjects with other studies. Case reports, letter articles and reviews were excluded.

Literature searches identified a total of 52 articles. Of these, four review articles, one case report, two articles with nonhuman subjects, four articles which conducted no CPT, three letter articles, and three articles written in non-English languages were excluded, leaving 35 articles.

These 35 articles were reviewed to identify the purpose of tests (diagnosis, compensation, etc.), measuring conditions of CPTs, including acclimatization period, water temperature, hand immersion duration, measuring methods of outcomes (e.g. finger skin temperature, finger systolic blood pressure), and diagnostic criteria. If available, the sensitivity and specificity of CPTs were also noted.

3. RESULTS

A total of 35 studies were selected for this review. Published articles were chiefly from temperate and subarctic zones. They were conducted chiefly for diagnosis while some of them also mentioned compensation. In longitudinal studies, the follow-up period ranged from 1 to 15 years.

Water temperature ranged from 5 to 15 °C, (5 °C in 1 study, 8 °C in 1 study, 10 °C in 23 studies, 12 °C in 4 studies, and 15 °C in 11 studies). In some studies, more than one temperature level was set in a single CPT (e.g., 15 °C for 5 minutes followed by 10 °C for 5 minutes.). Hand immersion period for a single temperature varied from 2 to 10 minutes, mainly 5 or 10 minutes.

Outcomes chiefly measured were the change of finger skin temperature (22 studies) and finger systolic blood pressure (13 studies). In some studies, peripheral vascular function was evaluated with laser-Doppler imaging (2 studies) or infrared thermography (2 studies).

Six studies mentioned the sensitivity and specificity of tests (Table 1). In the 10 °C, 10-min method, both sensitivity and specificity were high while the 15 °C, 5-min method, the sensitivity was lower and the specificity was fairly high. The 10 °C, 5-min method showed lower sensitivity and comparably high specificity. These findings do not support the accuracy of the diagnostic value of the 15 °C, 5-min method.

4. DISCUSSION AND CONCLUSIONS

After the release of ISO 14835-1, there was limited data on the usefulness of the 12°C, 5-min method. More evidence will be required to establish the diagnostic ability of the 12 °C, 5-min method.

The sensitivity of the 15 °C, 5-min method is relatively low, and insufficient to provoke peripheral vascular dysfunction. This finding is consistent with a previous review (Harada, 2002). However, it seems premature to conclude which method is the best to evaluate peripheral vascular function. To evaluate HAVS, findings from CPTs should be interpreted carefully, and combined with findings from other tests.

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Table 1. Sensitivity and specificity of cold provocation tests.

References	Subjects	Patients vs. controls	Adaptation	Room temp. (°C)	Exposure to cold	Outcome measures (cut-off point)	Se(%)	Sp(%)
Nasu (Japan, 2008)	154 NVEC, 21 VEC, 21 inactive VWF (SV=0), 83 active VWF (SV>0)	(Inactive VWF + active VWF) vs. NVEC	30+ min.	(a) 21±1 (b) 23±1	10 °C, 5 min.	FSBP% (75%)	(a) 73.9 (b) 65.2	(a) 82.5 (b) 87.5
Negro (Italy, 2008)	113 forestry workers, 33 stone workers (Number of VWF cases confirmed with a color chart: (a: baseline)17; (b: 1-year follow-up)18)	VWF vs. non-VWF	20-30 min.	20-22	30 °C, then 10 °C	Medical history (self-reported history of finger whiteness)	(a) 88.2 (b) 94.4	(a) 93.8 (b) 97.7
Terada (Japan, 2007)	31 NVEC, 20 HAVS (SV>0)	HAVS vs. NVEC	Sufficiently long time	24.2±0.4	10 °C, 10 min.	LDPI (Any abnormal LDPI finding)	80.0	84.6
Poole (UK, 2006)	21 NVEC, 33 HAVS (SV=2 or 3)	HAVS vs. NVEC	15 min.	23.1 (SD, 1.4)	15 °C, 5 min.	(a) T4°C (N/A) (b) Tip-middle minute 6 (N/A)	(a) 69.7 (b) 57.6	(a) 66.7 (b) 85.7
Poole (UK, 2004)	22 NVEC, 24 HAVS (SV=2 or 3)	HAVS vs. NVEC	N/A	22±2	15 °C, 5 min.	FSBP% * (56.7-79.5%)	43.5-60.9	90.5-95.2
						T4°C (276 sec.)	70.8	77.3
Mason (UK, 2003)	727 miners (SV=0, 10%; SV>0, 90%)	SV>0 vs. SV=0	N/A	N/A	15 °C, 5 min.	T4°C (173 sec.)	65.8	58.5

UK: United Kingdom. NVEC: non vibration-exposed controls. VEC: vibration-exposed controls. VWF: vibration-induced white finger patients. SV: Stockholm vascular staging. HAVS: hand-arm vibration syndrome patients. Temp: temperature. SD: standard deviation. FSBP: finger systolic blood pressure. LDPI: laser Doppler perfusion imaging. T4°C: time taken to increase the finger skin temperature by 4 °C after exposure to cold. Tip-middle minute 6: difference between finger tip and middle temperature for the sixth minute of recovery. Se: sensitivity. Sp: specificity. N/A: not available.

* FSBP% was calculated with eight formulae, and the ranges of the FSBP% cut-off point, the sensitivity and the specificity are shown.

COMPARISON OF COLD IMMERSION TESTS WITH WATER AT 12°C AND 10°C FOR 5 MINUTES IN DIAGNOSING VIBRATION-INDUCED WHITE FINGER

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1. INTRODUCTION

To diagnose vibration-induced white finger (VWF) objectively, application of a cold provocation with immersion of the hand/s in water is a commonly employed test modality. But questions have been raised regarding the diagnostic ability of such a test (Harada and Mahbub 2008). For the cold water immersion test, ISO 14835-1 (2005) recommends a 12°C water temperature, with immersion of the hand/s for a duration of 5 min. In Japan, immersion of the hand/s in water at 10°C temperature for 10 min is commonly applied for this purpose (Harada et al. 1999). A cold water immersion test is desirable that is less painful to the subject, but sufficient to demonstrate the augmented vasoconstriction among VWF patients (Lindsell and Griffin 2000). There is a lack of studies investigating and comparing the diagnostic performance of cold water immersion tests including the ISO recommended test for the above-mentioned purpose. The objective of this study was to compare the diagnostic performances of two different cold provocation tests with water immersion at 12°C and 10°C for 5 min in distinguishing VWF.

2. METHODS

The cold water immersion tests were conducted on 26 male patients diagnosed with VWF, and 27 healthy male controls who did not regularly use hand-held vibrating power tools, using the protocol of ISO 14835-1:2005. The subjects were acclimatized to the room temperature (21±1°C) for a period of approximately 30 min in a temperature-controlled room, seated comfortably on a chair. Thermistors (SZL-64, Technol Seven, Japan) were fixed with adhesive tape but without tape tension to the middle of the palmar side of the distal phalanges of all fingers. The baseline values of finger skin temperature (FST) were recorded after ensuring stable FST in both hands positioned approximately at heart level, palm up on a wooden table. Then the subjects immersed both hands up to the wrist into stirred water at 12°C or 10°C (on different days) for 5 min, with waterproof coverings on both hands (AS ONE Corp., Japan). The gloves were removed immediately after the immersion period. The FST values were continued to be recorded at each minute during immersion and during a 15 min recovery period.

Twenty individually matched (by age) case-control pairs were selected. For the analysis, the minimum value of FST among 4 fingers (excluding thumb) was used. Data were analyzed at five time points: just before immersion (Baseline), last minute during immersion (Immersion5), at 5 (Recovery5), 10 (Recovery10) and 15 min (Recovery15) during the re-warming period. The Wilcoxon signed-ranks test was used to examine the differences between the patient and control groups (significant difference if Wilcoxon signed-ranks test $P < 0.05$, shown as * in Table 1). To evaluate the diagnostic performances of two different immersion tests, receiver operating characteristic (ROC) curve analysis was performed and sensitivities were calculated at 70% and 95% specificities. Using a nonparametric approach, the areas under the ROC curves (AUCs) with the related 95% confidence interval was determined; the differences between the paired areas for the AUCs under 12°C and 10°C immersion conditions were compared. Statistical analysis was done using Medcalc v. 10.0.2 and SPSS v. 16.0.

3. RESULTS

Average ages and average values of body mass index did not differ between patient and control groups. Among the 20 patients with current symptoms of VWF, 2, 12 and 6 subjects had vascular stages 1, 2 and 3 of the Stockholm Workshop Scale, respectively. The baseline and during immersion values of FST did not differ significantly between the patient and control groups under any immersion

Table 1. Median (inter-quartile range) values of FST (°C) from right and left hands at different time points

	12 °C		10 °C	
Time point	Patient	Control	Patient	Control
Right hand				
Baseline	29.7 (7.8)	31.7 (4.5)	29.8 (7.8)	31.5 (6.5)
Immersion5	13.2 (0.7)	13.5 (1.0)	11.2 (1.0)	11.8 (1.3)
Recovery5	16.0 (2.5)*	17.3 (2.6)	15.0 (3.7)	17.6 (2.9)
Recovery10	17.3 (2.7)	19.1 (4.1)	16.6 (5.8)*	19.2 (7.7)
Recovery15	18.3 (3.7)*	20.1 (12.9)	17.7 (7.9)*	20.0 (13.7)
Left hand				
Baseline	29.4 (9.8)	30.0 (5.7)	26.2 (8.5)	29.1 (8.6)
Immersion5	13.0 (1.2)	13.1 (1.0)	10.9 (1.6)	11.5 (1.7)
Recovery5	15.9 (2.5)*	17.0 (1.9)	14.9 (3.2)	17.6 (4.0)
Recovery10	17.1 (3.6)	18.6 (5.0)	16.4 (4.1)*	20.1 (8.4)
Recovery15	17.9 (8.8)*	19.7 (11.6)	17.5 (4.6)*	22.1 (12.5)

n = 20 at each time point;
Significant difference if Wilcoxon signed-ranks test $^*P < 0.05$;.

Table 2. Sensitivity (Sn%) and specificity (Sp%) with cut-off value for 12°C and 10°C immersion conditions.

	12°C				10°C			
	Sp 95%		Sp 70%		Sp 95%		Sp 70%	
Time point	Sn%	Cut-off value (°C)	Sn%	Cut-off value (°C)	Sn%	Cut-off value (°C)	Sn%	Cut-off value (°C)
Right hand								
Baseline	25	23.8	45	28.2	10	22.2	45	27.6
Immersion5	5	12.4	50	13.1	0	10.3	55	11.2
Recovery5	20	15.4	60	16.3	20	14.4	65	15.7
Recovery10	20	16.5	60	17.8	15	15.8	65	17.7
Recovery15	35	17.7	60	18.9	25	16.9	65	18.6
Left hand								
Baseline	30	23.6	45	27.7	15	22.0	30	24.2
Immersion5	10	12.4	35	12.8	0	10.3	50	10.8
Recovery5	15	14.8	65	16.3	30	14.3	65	15.3
Recovery10	35	16.8	65	18.0	35	15.9	60	16.8
Recovery15	45	17.8	65	19.0	35	16.9	60	17.7

condition. In contrast, during recovery, the FST values of the patients were significantly ($P < 0.05$) lower at 5th and 15th min under 12 °C immersion condition, and at 10th and 15th min under 10°C immersion condition, for both hands (Table 1).

Table 2 shows the sensitivity and specificity at different time points with the corresponding cut-off values for both immersion conditions. During recovery at 95% specificity, the sensitivity ranged from 15% to 45% and 15% to 35% for the 12°C and 10°C immersion conditions, respectively. On the other hand, the values of sensitivity at 70% specificity ranged from 60% to 65% under both immersion conditions. Overall, the larger value of AUC was found at the 15th min of recovery (results not shown). However, the paired AUCs for the two different immersion conditions did not differ significantly at any time before, during, or after immersion.

4. DISCUSSION

In diagnosis of a prescribed disease like VWF, a diagnostic test needs to be highly specific so that as few subjects as possible without it are diagnosed as having it (Cm 6098). During recovery at 95% specificity, the sensitivity was low under both immersion conditions. On the other hand, at 70% specificity during recovery, the sensitivity was found to be around 60-65% for both tests. Furthermore AUCs, which are commonly used measures to compare the overall diagnostic performances of different tests, showed similar values for 12°C and 10°C immersion conditions in this study, indicating that the two tests yield the same overall diagnostic performance.

A good diagnostic performance of cold water immersion tests was not demonstrated convincingly in previous studies (Harada and Mahbub 2008). Also, in this study at 95% and 70% specificities, the corresponding sensitivities were not satisfactorily high for both conditions: however, the positive group differences observed only during the recovery period emphasize the importance of conducting such a test for the discrimination of patients with VWF.

5. CONCLUSIONS

Cold provocation tests with hands immersed in water at 12°C or 10°C for 5 min could reveal group differences between VWF patients and matched healthy controls, and the diagnostic performance of these tests in distinguishing patients with VWF were similar.

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GUIDELINES OF THE JAPANESE RESEARCH SOCIETY FOR VIBRATION SYNDROME TO DIAGNOSE HAND-ARM VIBRATION SYNDROME

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1. INTRODUCTION

The methods recommended by the Japanese Ministry of Labour are usually employed to diagnose hand-arm vibration syndrome (HAVS) in Japan, especially for recognition of it as a work-induced disease, and for medical treatment and compensation (Yamada 2002). The diagnostic methods for HAVS have not been revised in Japan for the past 35 years. In the meantime, there have been improvements in scientific and technological knowledge. Several new diagnostic modalities have been developed to diagnose HAVS. Nonetheless, the objective diagnosis is still difficult and sometimes controversial, as there is no 'gold standard' test for HAVS. In these contexts, a new set of guidelines for diagnosing HAVS appears to be desirable in Japan. The purpose of this paper is to present a draft of the diagnostic guidelines for HAVS proposed by a working group of the Japanese Research Society for Vibration Syndrome, which is currently under discussion by the Society.

2. METHODS

The working group has performed i) reviews of the current diagnostic methods for HAVS recommended by the Japanese Ministry of Labour, and those used in other countries, ii) evaluation of clinical usefulness of different diagnostic modalities available for HAVS, iii) comprehensive reviews of the relevant literature, including the most recent research works and critical evaluation of consistency of data concerning the recognized diagnostic methods, and iv) analyses of data from multicenter studies conducted in Japan among HAVS patients and control subjects, including different tests. Furthermore, the areas of consensus and dissensus were addressed. After several rounds of discussion, the working group is going to propose draft guidelines for diagnosing HAVS in Japan.

3. RESULTS

This new diagnostic guidelines will serve two purposes: first, workplace health examination for HAVS, and second, clinical diagnosis of HAVS. The whole diagnostic process will essentially be accomplished through taking the history (family, social, medical and occupational) and reporting of subjective symptoms, physical and laboratory examinations of circulatory, nervous, musculoskeletal and other systems, and differential diagnosis.

3.1. Workplace Health Examination

The purposes of workplace health examination are to detect early any signs/symptoms of HAVS, and to prevent any progression of HAVS. It will be carried out periodically at two stages: 1) general (primary) medical examination for screening purposes, and 2) special (secondary) medical examination for evaluating the disease severity (stage) of HAVS.

General (Primary) Medical Examination

A general medical examination should be provided for workers regularly or occasionally exposed to potentially harmful levels of HAV. The examination will include: i) a brief history; ii) subjective symptoms to assess vascular (white finger, finger coldness), neurological (tingling, numbness in fingers, reduced sensitivity), and musculoskeletal (joint pain, reduced strength) systems, as well as other symptoms (insomnia, headache, hearing loss, stiff neck, backache, etc); iii) physical examination to assess neurological (including, at the discretion of the physician - sensory perception and reflexes), and musculo-skeletal disorders (range of motion, exercise pain); and iv) laboratory examinations. As clinically indicated, limited laboratory examinations will be performed to evaluate vascular (measurement of finger skin temperature and nail compression test at room temperature), neurological (vibrometry with simple equipment for index and little fingers), and musculoskeletal (grip strength test) disorders.

Special (Secondary) Medical Examination

Individuals with abnormal findings or reporting any HAVS-related impairments or symptoms will undergo a special medical examination for further investigation. The procedure is basically the same as that for the basic diagnosis (discussed later), except for the detailed worksite evaluation for preventing the progression of HAVS.

3.2. Clinical Diagnosis

The clinical diagnosis of HAVS will be established also at two stages: 1) basic diagnosis, and 2) specialized examination (laboratory-based objective diagnosis).

Basic Diagnosis

The basic diagnosis is expected to be done at the clinic level with basic equipment. The process will involve the following: i) a comprehensive history; ii) subjective symptoms for the evaluation of vascular (white finger, finger coldness), neurological (tingling, numbness in fingers, reduced sensitivity, pain), musculoskeletal (joint pain, reduced strength) systems, and other related symptoms; iii) physical examination to assess neurological (detailed examinations including sensory perception and reflexes), musculoskeletal (range of motion, exercise pain, Tinel sign, Phalen test, Froment sign) disorders; iv) laboratory examinations for the evaluation of a) vascular (cold water immersion test - 10°C 10 min of one hand with temperature measurement of five fingers, nail compression test at one finger), b) neurological (vibrometry with a simple equipment like AU02 at 125Hz for all fingers, and, at the discretion of the physician, thermal perception test using simple equipment, and nerve conduction test), and c) musculoskeletal (grip strength, and at the discretion of the physician, X-rays) systems; and v) differential diagnosis (neurological examination, and at the discretion of the physician, peripheral blood examination and X-ray).

Based on the various findings, the diagnosis of HAVS will be determined, and it will be classified according to a revised/new classification system. If HAVS is diagnosed, the individual will be advised on fitness for work with exposure to vibration, and on medical treatment.

Although the diagnosis of HAVS can be determined in most cases at this stage, where a diagnosis can not be established, these cases will be considered for the specialized examination.

Specialized Examination

Specialized examination includes laboratory-based objective diagnosis tests which will facilitate a more accurate diagnosis. Specialized examination will be performed in specialized centres under controlled conditions. This will involve FSBP (ISO 14835-2 method, four fingers) and others (angiography, thermography, etc) to evaluate vascular disorders; sense of vibration (ISO 13091-1 method, all fingers); segmental nerve conduction test; and others (hot and cold threshold tests, X-ray, Purdue pegboard test or bean transfer test).

4. DISCUSSION

In Japan, there is need for comprehensive and universally accepted diagnostic guidelines for HAVS. For this purpose, a working group was convened by the Research Society for Vibration Syndrome, Japan Society for Occupational Health that began work in 2009 to propose new guidelines for diagnosing HAVS in Japan. Each working group member has the responsibility for a selected part of the diagnostic guidelines currently under discussion by the Research Society for Vibration Syndrome.

The proposed diagnostic guidelines incorporate several functional tests considered suitable for workplace health examination and clinical examination for HAVS. The new diagnostic guidelines consider equipment availability and diagnostic value for workplace health examination or basic diagnosis. They recommend simple equipment in common use in Japan, such as the Vibrometer AU-02 (RION Co. Ltd., Tokyo, Japan), and for specialized examination, the Tactile Vibrometer (HVLab, UK) which meets the ISO standard.

Severity grading of vascular or neurological disorders of HAVS may provide important diagnostic advantages, as it may also help to assess fitness for work. The working group is now discussing the issue of grading disease severity in HAVS, and considering the use of a revised classification system or establishing a new classification method for this purpose. The working group is also discussing the optimum cut-off values for different diagnostic tests, because variations in cut-off values lead to variations in the performance of diagnostic tests (Harada and Mahbub 2008).

5. CONCLUSION

The guidelines are expected to facilitate improved and more accurate diagnosis of HAVS in Japan.

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Clinical Assessment of HAVS: Controversies in Diagnosis and Measurement

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1. INTRODUCTION

The clinical assessment of workers to diagnose Hand-Arm Vibration Syndrome (HAVS) presents numerous challenges, especially in the context of compensation or litigation. There is controversy about the specific health effects due to hand-arm vibration and how these effects should be evaluated and measured for diagnostic purposes. In this paper, we discuss the health effects due to hand-arm vibration and their measurement.

2. METHOD

The information presented is based on our clinical experience in assessing HAVS patients at the Occupational Health Clinic, St. Michael's Hospital, Toronto. This clinic has the largest volume of HAVS patients in Canada (approximately 350 per year) and provides comprehensive HAVS assessments, often for compensation purposes. Our clinical experience has been supplemented by a literature review using Medline and Google Scholar, and the prior development of a discussion paper on this topic for the Workplace Safety and Insurance Appeals Tribunal (WSIAT) in Ontario (House, 2010).

3. RESULTS

The principal health effects associated with vibrating tools are summarized in Table 1. The use of vibrating tools results in exposure to various ergonomic stresses as well as hand-arm vibration. Therefore, this table includes a broad list of health effects, only some of which are clearly related to vibration.

3.1. Health Effects Definitely Related to Vibration

Raynaud's phenomenon in the exposed fingers is the effect most clearly related to hand-arm vibration exposure, and the evidence of a causal association for this effect is strong. As well, there is good evidence that digital sensory neuropathy occurs due to hand-arm vibration exposure. However, after consideration of these two key outcomes, the evidence for other outcomes being due to hand-arm vibration is less definitive.

3.2. Other Health Effects Possibly Related to Vibration

There is evidence that suggests that Raynaud's phenomenon may also develop in the feet in workers with HAVS (Schweigert, 2002). The key predictor of vasospasm in the feet appears to be vasospasm in the hands, with the hand effects presumably developing first. Generalized stimulation of the sympathetic nervous system is thought to be a likely mechanism, although other factors may play a role, such as systemic release of the vasoconstrictor endothelin 1 from damaged endothelial cells. Thrombi may occur in the hands of workers using vibrating tools (Thompson and House, 2006). This mainly affects the ulnar artery but may also affect the radial and digital arteries. Forceful striking with the hand (i.e. hypothenar hammer syndrome) is also a risk factor and it is not clear if the thrombi reported in workers using vibrating tools are due to work practices involving forceful hand striking or some aspect of vibration exposure, such as the impulsivity or dominant frequency.

The Stockholm sensorineural HAVS classification is based on digital sensory neuropathy and does not include carpal tunnel syndrome (CTS) due to median nerve compression at the wrist. However, neuropathy proximal to the hands including CTS and ulnar neuropathy are common in workers being assessed for HAVS. Although ergonomic stressors, in particular, forceful, repetitive flexion and extension of the wrist appear to be stronger risk factors for CTS, there is increasing evidence that hand-arm vibration may also be a risk factor for CTS (Palmer et al, 2007).

There is epidemiologic evidence suggesting that various musculoskeletal outcomes may be associated with hand-arm vibration exposure. A comprehensive review by Hagberg (2002) found that the evidence that hand-arm vibration was a risk factor for specific musculoskeletal outcomes was weak, although there was stronger evidence for work with vibrating tools and the associated ergonomic factors and/or work practices.

3.3. Measurement and Evaluation of Health Effects

A medical and occupational history and focused examination are essential. Blood tests are needed to rule out other common causes of vascular symptoms, such as collagen vascular disease, and neurological symptoms, such as diabetes mellitus. There is no single diagnostic test and a test battery is preferred with the overall results being interpreted by a physician experienced in HAVS diagnosis.

The history of the frequency and severity of finger blanching is often imprecise and should be supplemented by objective tests of cold-induced vasospasm. The most commonly used tests are plethysmography and thermometry/thermography. However, there is variation in test technique reported in the literature, including the temperature and duration of cold water immersion and the timing of measurements after cold exposure. Measurement of hand thrombi requires an arteriogram which should only be done if clinically indicated.

Table 1. Health Effects Associated with Vibrating Tools

Category	Specific Effects
Vascular	Raynaud's phenomenon
	-Hands **
	- Feet
	Thrombi in hands
Neurological	Digital sensory neuropathy **
	Proximal neuropathies
	- Carpal Tunnel Syndrome
	- Ulnar neuropathy
Musculoskeletal	Decreased Grip Strength
	Duputyren's contracture
	Bone cysts
	Osteoporosis - hand, wrist
	Osteoarthritis – wrist, elbow, shoulder
	Upper extremity pain

** Definitely recognized to be due to hand-arm vibration.

The measurement of digital sensory neuropathy is difficult, because conventional electrode placement does not allow measurement in the distal parts of the fingers that are initially affected by hand-arm vibration exposure. Segmental or fractionated nerve conduction with electrode placement in the distal parts of the fingers is possible, but presents technical challenges including the control of finger temperature that may also affect the measured nerve conduction. Quantitative sensory tests, in particular vibration perception threshold (VPT) and current perception threshold (CPT) are better predictors than conventional nerve conduction tests of the Stockholm sensorineural scale, and present an alternative to fractionated nerve conduction. However, the neurological assessment should also include conventional nerve conduction testing to detect common co-morbid neuropathies proximal to the hand, in particular CTS, which may affect the attribution of neurological symptoms to hand-arm vibration.

Assessment of musculoskeletal abnormalities associated with the use of vibrating tools requires a thorough examination of the upper extremities and other tests, such as x-rays, CT scan, MRI, bone density measurement, as indicated by the history and examination. These tests should not be part of a standard battery. However, grip and pinch strength are helpful to measure impairment in hand strength, and the Purdue pegboard is a useful test of fine motor hand function; these tests could be included in a standardized battery.

4. DISCUSSION

Ordinarily, symptoms of numbness and tingling in the fingers and cold-induced finger blanching, which are common, might not prompt a physician to do detailed objective tests, aside from possibly nerve conduction. However, compensation by a workers' compensation board or litigation in the courts requires more objective proof of disease and it is this context which often drives the detailed testing in the assessment of HAVS patients. In the absence of an agreed upon protocol or clinical guideline, this is a recipe for controversy and disagreement.

This controversy can be reduced, if not resolved, by an evidenced-based determination of the key outcomes associated with hand-arm vibration and the best methods to measure and evaluate them. The outcomes clearly associated with hand-arm vibration include Raynaud's phenomenon and digital sensory neuropathy. These should form the basis of a case definition of HAVS for clinical assessment purposes. In the selection of diagnostic tests, it should be borne in mind that no test is definitive and a battery of tests is required. The interpretation should be informed by the sensitivity and specificity of the tests for their intended diagnostic purposes. Key competing diagnoses, in particular CTS, need to be carefully evaluated. Given the plethora of data obtained, the judgment of an experienced physician is required and the process is not easily reducible to a simple algorithm (Pelmear, 2003).

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REDESIGN OF HAND-HELD IMPACT MACHINES TO REDUCE HAND-ARM VIBRATION

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1. INTRODUCTION

Vibration exposure to workers from hand-held impact tools causes considerable injuries in the stone industry. In order to improve the work environment, a project was started with the objectives to redesign the tools to achieve low vibration, as well as improved ergonomics, dust removal and reduced noise while maintaining productivity. Redesign of current hand-held pneumatic impact machines can reduce the vibration level and thereby reduce injuries to workers. Hand-arm vibration injury, often called Hand-Arm Vibration Syndrome (HAVS) is one of the most common reasons for work-related injuries among this group of workers in the stone industry.

Although pneumatic impact machines have been used since the early 20th century, little has changed in their fundamental design. Despite their being robust and efficient, vibration, noise, dust and poor ergonomics cause a large number of injuries to the operators. Previous work has been done to improve these machines, and some results have been patented, e.g. [1], [2]. Yet these improvements seldom reach the market. The main reasons seem to be that the results remained questionable, costly, and reduced the efficiency and robustness of the machines. Another contributing cause could be lack of customer interest.

However, a new generation of impact machines can be developed by approaching the redesign from a user perspective, and by adhering to strict conditions of low vibration, noise and dust as well as good ergonomics. The objective of this study was therefore to develop a user-friendly, low vibration impact machine using a tuned vibration absorber, together with integrated vibration isolation. A tuned vibration absorber combined with vibration isolation has shown to significantly reduce the vibration exposure of the operator. The machine is also designed so that it can be manufactured in small volumes.

2. METHOD

The first part of the project was a survey of vibration exposure to workers in the stone industry. The different working operations were investigated and characterized, and their contribution to the total vibration measured. The results from the survey showed that three work operations contributed to more than 90% of the vibration exposure. These operations are executed using machines that are similar in design, namely pneumatic reciprocating impact machines with a piston that hits the work piece, but with different impact energy for various operations. By improving this type of machine, a large part of the problem with vibration injuries could be solved.

The second part of the project, the redesign of the tools was carried out using three approaches: analytical calculation, multi-body simulation and experimental study. The machine used in this part of the study was an impact machine used for chiseling oval holes of about 20 x 10 mm wide and 30 mm deep. The machine is a KV434 from Atlas-Copco and has an impact energy of about 25 Joules. Its total weight is 11 kg with a piston weight of 530 grams and a hitting frequency of 35 Hz. The hand-arm filtered acceleration is about 20 m/s^2, which allows the worker to use the machine for only a few minutes per day before the exposure action value (2.5 m/s^2, A(8h)) is reached. This time limit is regularly exceeded during a normal 8 hour work day.

The redesigned machine has the same properties as KV434 with respect to total weight, piston weight, impact energy and operating frequency. The vibration reduction was accomplished by using two combined approaches: 1) a tuned vibration absorber that creates a counter force to the reaction forces on the cylinder of the piston, and 2) isolation of the vibration between the impact mechanisms and the housing to which the handles are attached (see Figure 1).

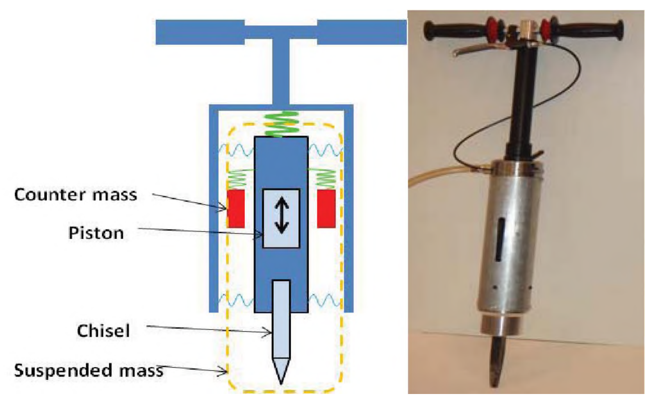

Figure 1. Principle of redesigned machine and prototype

2.1. Tuned Vibration Absorber

Using a tuned vibration absorber is a well known method, frequently described in the literature but not commonly used in products. It has been used in, for example, electric hair clippers, airplanes and cars (see [2] for a description of the theory). An initial problem was the narrow operating frequency range associated with the method; however, successful development of the method at Swerea IVF has resulted in a broader frequency.

The counter mass of the tuned absorber in this study weighs 930 grams and is attached to the suspended mass via a spring. The spring and counter mass are tuned to a resonance frequency of 35 Hz with respect to the suspended mass. Care has been taken to reduce friction in the system as much as possible. The damping coefficient is estimated to be below 2 % of critical damping (see Figure 1). The mass of the suspended system is 4.4 kg and the total weight of the machine is 11 kg.

2.2. Vibration Isolation

In order to achieve effective vibration reduction, the machine has been divided into two functional parts: first a suspended mass that contains the impacting mechanism and the tuned vibration absorber, and second, a housing with the interface to the operator. Vibration isolation between the suspended mass and the housing is applied in the axial, radial and rotational directions in order to handle the vibrations that still remain after the tuned absorber. Care has been taken not to compromise the ability to accurately control the machine.

2.3. Vibration Measurement

The vibrations on the handles of the machines were measured in a test rig, which yielded the same characteristics as described in ISO 8662-5. A three-axis Dytran 3053B2 accelerometer with mechanical filter was used to measure the vibrations. The signals were analyzed in Labview. Vibration measurements on the suspended mass and the counter mass were done with stroboscopic light and a steel scale.

3. RESULTS

In order to test the effect of the vibration reduction measures, three test configurations were set up and compared with the original machine. The test procedure was in accordance with ISO 8662-5, and results are shown in Table 1.

Table 1. Handle vibration

Configuration	Hand-arm filtered vector sum acceleration (m/s^2)
Original machine KV434	20.2
Redesigned machine with counter mass active	2.7
Redesigned machine with blocked counter mass	6.7
Redesigned machine with removed counter mass	8.4

The redesigned machine reduced the vibration by 87%, from 20.2 to 2.7 m/s^2. The vibration isolation on its own reduced the vibration by 58% from 20.2 to 8.4 m/s^2; the tuned vibration absorber produced a further reduction of 68% from 8.4 to 2.7 m/s^2. The stability of the operation of the tuned vibration absorber was tested by varying the air pressure to the machine from 3 to 7 Bar, as well as by varying the feed force from -110 N to 450 N. It was found that the vibration level varied between 2.2 and 3.6 m/s^2.

An analysis of the behavior of the counter mass and how it affects the vibrations of the suspended mass was also carried out. Results are shown in Table 2.

Table 2. Vibration of suspended mass and counter mass

Configuration	Suspended mass, displ. (mm p-p)	Counter mass, displ. (mm p-p)
Counter mass active	1.9	30.4
Blocked counter mass	5.2	5.2
No counter mass	6.4	-

From these results, the generated peak force from the counter mass was calculated to reach 684 N, providing the movement of the mass is sinusoidal.

4. DISCUSSION AND CONCLUSION

This study has shown there is a substantial potential for reducing vibration from hand-held pneumatic impact machines through redesign. This was done by dividing the machine into two functional parts and applying proper vibration isolation between the parts, as well as by adding a tuned vibration isolator. In this case, the vibration level was reduced from 20.2 to 2.7 m/s^2 hand-arm filtered vector sum acceleration.

It was also found that the operation of the tuned vibration absorber was stable over a relative wide range of feed forces and pneumatic pressures to the machine. This means that there is a possibility to substantially reduce the risk for vibration related injuries. In this case, the vibration level was reduced by a factor of more than 7, which would give a reduced risk according to ISO 5349 by a factor of about 50.

During spring 2011 the machine will be field tested in the stone industry.

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REDUCTION OF VIBRATIONS GENERATED BY AN IMPACT WRENCH

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1. INTRODUCTION

The 2002/44/EC directive of the European Parliament and of the Council established the minimum health and safety requirements regarding the exposure of workers to vibration.[1] The international standard coding hand-arm vibration (HAV) measurements establishes that the risk must be assessed using the vibration daily exposure A(8), determined from the weighted vibration measured at the hand vibrating part interface along three mutually perpendicular axes.[2] Given the definition of A(8), the exposure is affected by the vibration source amplitude and spectrum, by the operator biomechanical characteristics, and by the exposure time. The EU directive also defines the A(8) limits, together with the corrective actions that must be undertaken by the employer when these limits are exceeded. Corrective actions are based on vibration reduction or on limiting the time exposed to vibration. Reduction of the vibration can be obtained either by acting on the sources (e.g., changing the working principle of tools) or by auxiliary equipment to reduce the vibration transmitted to the operator.

We describe here the design and the verification of an anti vibration device (AVD) meant to reduce the HAV transmitted by an impact wrench. The tool has been initially characterized using different operators, postures, air pressures, grip and push forces. The optimal AVD mechanical characteristics have been identified starting from the average vibration spectrum and design constraints (AVD mass, deflection, damping along the three axes). Experimentally verified AVD performances demonstrated the validity of the proposed approach.

2. METHOD

2.1. Tool Description and Characterization

The tool studied is an impact wrench - the Ingersoll–Rand 3940 P2 Ti. The tool mass is 9.6 kg, the maximum torque is 3390 Nm, the free rotation speed is 5300 rpm and the tool is capable of 800 impacts per minute. According to the manufacturer, the tool produces both very high sound pressure level (106.6 dB(A)) and high vibration (10.9 m/s^2). The tool is used for fastening and unfastening bolts with both horizontal and vertical axes, in the presence of coke dust and water. A picture of the tool is shown in Figure 1. The users typically grip the tool with two hands: one grips the tool on the main handle, while the other is usually placed on the air supply (not shown in the figure).

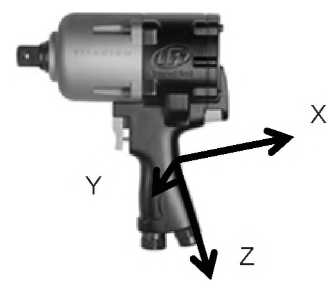

Figure 1. Impact wrench and reference coordinate system.

The tool vibration has been measured both in the field and on a purposely designed workbench: the effect of air pressure was included in the analysis. The non weighted vibration spectra possess components up to 2 kHz. The average weighted vibration spectra are shown in Figure 2.

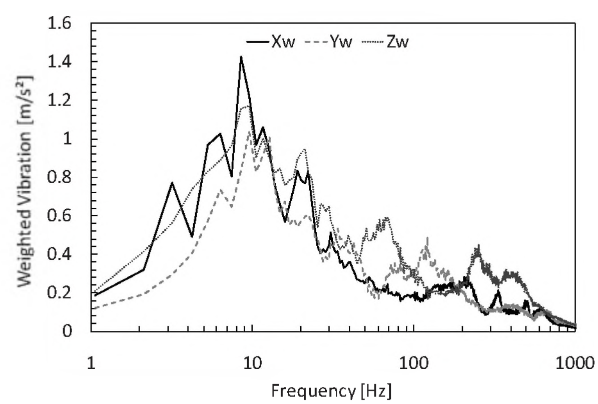

Figure 2. Vibration spectra for different working conditions.

Relevant frequency components are present both in the low frequency region (from 3 to 30 Hz) and at high frequencies, where no attenuation is provided by the metallic impact wrench frame. The weighted vibration levels along the X, Y and Z axes were 5.9, 6.4 and 8.8 m/s^2. The vector sum acceleration a_v was 12.4 m/s^2, i.e., slightly larger than the value declared by the manufacturer. A similar value (11.7m/s^2) was measured on the secondary grip (air supply pipe).

2.2. Method

The interaction between the tool and the operator was modeled with the lumped parameter scheme of Figure 3. The characteristics of the velocity generators (v_{eq}, three generators for each handle) were identified under the hypothesis of purely inertial tool impedance (Z_{eq} equal to $1/j\omega{\cdot}m$ where m is the tool mass) and with operator impedances derived from ISO 10068:1998[3].

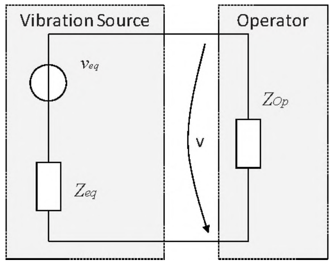

Figure 3. Characterization of the tool as a vibration generator

Once the characteristics of the vibration generators along the three axes have been identified, the characteristics of the suspension systems (stiffness k, viscous coefficient c and suspended mass m_{susp}) were identified with a constrained nonlinear optimization. The constraints considered in the suspension design concerned the total suspension system mass (lower than 1 kg), the maximum static deflection under the tool weight (10 mm) and some constructive details (damping achieved only with the materials' elastic hysteresis, vibration attenuation along three axes and use of both hands during fastening and unfastening operations). A simplified model considering each handle independently from the other was adopted. Also in this case, the three Z_{op} were derived from the ISO 10068:1998.[3]

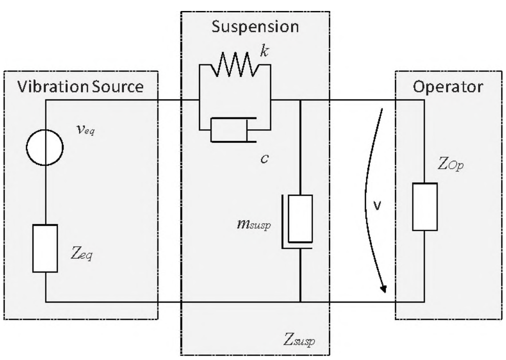

Figure 4. Lumped parameter scheme for interaction between the source, the suspension and the operator for each axis of each handle.

Given the nominal suspension characteristics, finite elements analysis was used to identify a geometry allowing the desired stiffness along the axial and radial directions to be obtained. Isolators were designed so as to have a nonlinear (increasing stiffness) behavior, in order to prevent the suspension from being ineffective in presence of high static handles loads. The mounting scheme is shown in Figure 5. Two different handles prototypes were designed and realized (Figure 6): both granted similar vibration attenuation, but the left one was judged more comfortable by users. In one case the pneumatic switch was moved to the rear handle for a more ergonomic tool control.

3. RESULTS

Given the nonlinear behavior of the elastic elements, vibration transmissibility strongly depended on the static forces that the operator exerts on the handles.

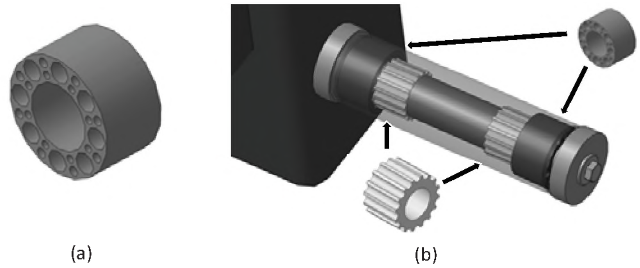

Figure 5. Isolators, a, and mounting on the lateral handle, b.

Figure 6. Pictorial views of the two handle prototypes

Laboratory characterizations were therefore scarcely representative. With the proposed solution a_v was reduced to 5.3 m/s^2 on the rear handle and 8.2 m/s^2 on the lateral handle (average of 30 on-field tests performed by three operators in fastening and unfastening operations) (see Figure 7). This vibration leads to practically no limitations given the typical fraction of time the tool is used during a normal work shift.

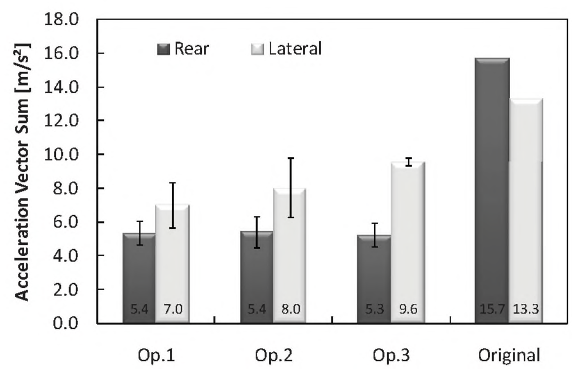

Figure 7. Performances of the proposed AVD

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MITIGATION OF HAND-ARM VIBRATION IN WORKERS ON A PNEUMATIC NAIL GUN ASSEMBLY LINE

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1. INTRODUCTION

A pneumatic nail gun company has an assembly line on which operators have high rates of musculoskeletal complaints. The standard assembly procedure with highest complaint rate requires an operator to hold the handle of an assembled nail gun by one hand and install a screw top at the handle butt by the other hand (Figure1a). Inspectors interviewing operators found that a task involving the use of a pistol-grip air impact wrench to tighten the screw top also caused high hand-arm vibration (HAV) to both hands of the operator (Figure1b). Job rotation was adopted onsite to prevent operators from suffering numbness of the fingers.

In this preliminary study, a wooden fixture was developed to reduce the exposure of assembly line operators to HAV caused by the impact wrench. Experienced operators were recruited to assess the effectiveness of the fixture in reducing their HAV. Experimental findings and operators' subjective responses are reported in this paper.

(a) (b)

Figure 1. Work postures of an assembly operator while - (a) installing a screw top at the handle butt, and (b) tightening the screw top using an impact wrench

2. METHOD

2.1. Apparatus

Vibration is transmitted to operators' hands during the use of a pistol-grip air impact wrench. Vibration was measured using three piezoelectric accelerometers (model 4374L, Brüel & Kjær, Denmark). These accelerometers had a frequency sensitivity range of 1–26,000Hz, and were pre-calibrated using an excitation of 10 m/s^2 (r.m.s.) at 159.2 Hz, with a hand-held calibrator (model 4294, Brüel & Kjær). The three accelerometers were mounted on a lightweight adapter, which was held in contact with the handle-hand interface by the operator, to measure the vibration level in three orthogonal axes (X, Y and Z). Accelerometer outputs were connected to a 3-channel amplifier (Model 2693, Brüel & Kjær) with a signal conditioning gain of 31.6 mV/G. Outputs of the amplified signals were recorded on a portable data logger at a rate of 5000 samples/s per channel. The logger stored collected data on a compact flash memory card. The logged data were downloaded onto a personal computer using a card reader for further data processing (Chen et al., 2006).

A simple wooden fixture, which fastened the impact wrench to a worktable and held the assembly part of nail gun, was designed to reduce the vibration at the operators' hands by supporting the impact wrench and incorporating shock absorbing polyurethane material (Figure 2).

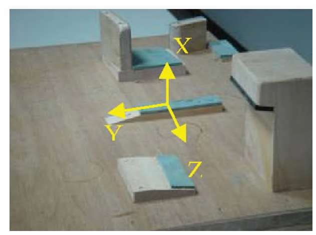


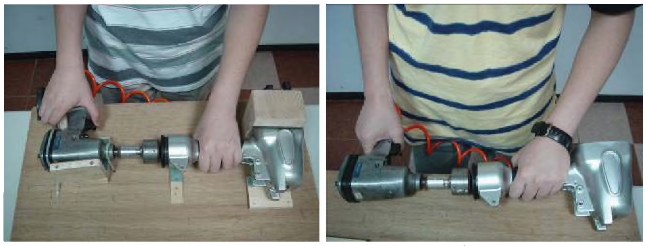
Figure 2. The designed wooden fixture, and directions of the measurement coordinate system for HAV measurement.

2.1. Subjects

Six experienced operators (three males and three females) were recruited as subjects from the assembly line for HAV tests. All subjects were informed about the purpose of the study and signed a consent form before participating in the experiments. All subjects were asked to complete two assembly tasks of fastening the screw top, with and without the wooden fixture (WF/WOF), with a 5-minute rest break between each task. For the task with the wooden fixture plate, each subject capped the screw top, held the assembled nail gun and lodged it in the L-shape hook of the fixer, then triggered a fastened impact wrench to tighten the screw top (Figure 3a).

For the task without the fixture, subjects performed the assembly task by holding the assembled nail gun on the worktable with their left hand while tightening up the screw top using an impact wrench in their right hand (Figure 3b).

Each operator repeated six trials, with HAV measured three times in each hand. Each trial included 10 seconds of data.



(a) (b)

Figure 3. Subjects' typical posture in performing screw top fastening task (a) with, and (b) without the fixture use

2.3. Data Analysis

The HAV levels, frequency-weighted root mean square acceleration, with and without the fixture plate were evaluated according to the ISO 5349-1 (2001) and ISO 8041 (2005) standards using Viewlog software (Chen et al., 2009). The results for the two procedures were compared using the Wilcoxon test. The difference was considered significant at a level of $p<0.05$.

Table 1. HAV levels (mean±SD, unit: m/s^2) With fixture (WF) and without fixture (WOF). ** $p<0.05$ for significant task difference by Wilcoxon test

Direction	Task (n=5)		Difference
Part-holding hand	WF	WOF	
X**	8.880 ±0.528	4.667 ±0.198	47.4%
Y**	4.857 ±0.253	2.208 ±0.459	54.5%
Z**	2.709 ±0.156	1.275 ±0.583	52.9%
Tool-grip hand			
X	2.237 ±0.585	1.563 ±0.387	30.1%
Y	0.981 ±0.445	0.627 ±0.106	36.1%
Z**	4.144 ±0.361	1.102 ±0.348	73.4%

3. RESULTS

Measurements indicate that using the fixture resulted in the dominant HAV levels being significantly reduced in both hands. The results given in Table 1 show the greatest mean HAV level to be 8.88 m/s^2, for the palmar direction (X-axis) in the part-holding hand. The greatest mean HAV level in the tool-gripping hand was 4.14 m/s^2, in the bushing spinning direction (Z-direction). The dominant frequency-weighted root mean square acceleration was reduced by 73.4% (from 4.14 to 1.10 m/s^2) in the tool-gripping hand and by 47.4% (from 8.88 to 4.67 m/s^2) in the part-holding hand. All subjects reported a recognizable reduction of HAV in the task when using the fixture.

4. DISCUSSION

Significant reductions were achieved in frequency-weighted accelerations using the fixture plate. However, only 30% reduction (from 2.237 m/s^2 to 1.563 m/s^2) was obtained in the palmar (X-axis) direction in the tool-gripping hand. This may because the plastic fastener, which fixed and restricted vertical movement of the impact wrench, could not diminish the vertical vibration effectively. Metal fasteners with better anti-vibration materials may improve vibration attenuation at the operator's tool-gripping hand.

With regards to work efficiency, the design of the fixture requires parts for assembly to be mounted and removed easily and quickly. Therefore, a loose-fitting L-shape hook was used to expedite lodging of parts during assembly. However, such design still requires an operator to hold the assembly part while tightening the screw top with the impact wrench. This design reduces the HAV of the part-holding hand by 47.4%, in comparison to assembly without the fixture.

This preliminary study demonstrates an economically feasible means of reducing HAV in an industrial context, by using a fixture and anti-vibration polyurethane material. An improved fixture design in the future, particularly one which helps hold the assembly part, seems promising to reduce further the operators' exposures to HAV in their part-holding hands.

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QUANTIFICATION AND COMPARISON OF SELECTED MATERIAL PROPERTIES FOR ANTI-FATIGUE MATS TO INVESTIGATE VIBRATION TRANSMISSION REDUCTION POTENTIAL

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1. INTRODUCTION

It is common for workers in many industries to experience vibration transmitted to the feet while standing. It has recently been suggested that this exposure can lead to a condition beginning to be known as vibration induced white foot[1]. Vibration induced white finger or hand-arm vibration syndrome (HAVS), which is common in occupations such as mining, forestry and construction, results in many of the same symptoms in the hands that can be observed in the lower extremities in the case of vibration induced white foot. Although vibration at the feet can be considered to be whole-body vibration (WBV), the effects can have more in common with HAVS[2] particularly if the dominant frequency of the foot-transmitted vibration is in the range known to be associated with the development of HAVS.

Anecdotal evidence has suggested that the use of anti-fatigue mats may be beneficial in reducing vibration exposure to the feet; however, little is known about the mat material properties in the context of vibration reduction. Therefore, the purpose of this preliminary study was to quantify selected material properties. These can be used to determine vibration properties using 2 physiologically-based loads and loading rates for 5 commonly used anti-fatigue mats, to begin to determine if they could be successful in reducing vibration transmission.

2. METHODS

The mats tested included:

1. 3M Safety-Walk Cushion Matting 5100 (3M, Canada),
2. Tilecote Sponge Mat (Style 46948, Seton, Canada),
3. KMB-1100 General Purpose Mat with Bevel Edge (GO Resiliant, Canada),
4. 3M Nomad Scraper Matting 8150 Backed (3M, Canada) and
5. 3M Nomad Scraper Matting 8100 Unbacked (3M, Canada).

Twenty-four, approximately equal small samples were cut from each mat and weighed. Samples were then compression tested using an Instron universal testing machine (Model 4204, Instron, Norwood, MA) (Figure1). Each sample was tested at one of two speeds ramping up to one of two maximum forces. The slow speed (0.000833 m/s) was chosen to represent how a mat would be loaded if a subject stepped onto it slowly. The fast speed (0.005 m/s) was chosen because it was the highest speed the Instron could produce without overshooting the maximum force constraints, and was intended to represent the loading on a mat of a subject stepping onto it quickly. The low and high forces were selected to represent 0.5(Body Weight) and 1.5(Body Weight) for a 50 percentile sized male, respectively. The two maximum forces were determined by finding the area of the sole of a shoe that would be in contact with the ground for a 50 percentile sized male. This, together with the Body Weight of a 50 percentile male, was used to determine how much force should be placed on the mat samples based on the cross sectional area of the compression platen being used.

Testing was randomized on the basis of speed, force and mat type in order to avoid order effects. The variables determined for each sample included Young's Modulus (E) (MPa), stiffness (k) (kN/m), natural frequency (fn) (Hz) and displacement (Δd) (mm).

Figure 1. Experiment Setup

3. RESULTS

Means and standard deviations for all variables and experiment conditions are presented in Table 1. Factorial ANOVA (Minitab 16, State College, PA) results revealed significant differences ($p \leq 0.05$) between mats and speeds for all variables. Bonferroni post-hoc procedures revealed that the faster speed resulted in higher values for E, Δd, k and fn whereas the higher force condition resulted in larger Δd. The following differences were observed between mats (numbers refer to mat types defined in the methods):

E	(3,2)>(1,4,5);
Δd	5>(1,4,3,2); 1>(4,3,2); 4>(3,2);
k	3>(2,1,4,5); 2>(1,4,5);
fn	3>(2,1,4,5); 2>(1,4,5).

A number of significant two-way interactions were observed. A (mat type)*(speed) interaction was found for E, k and fn, whereas a (mat type)*(force interaction) was observed for Δd. These interactions revealed that mat types do not all follow the same trend for different loading speeds and forces.

4. DISCUSSION AND CONCLUSIONS

Further work is needed but the results from this study suggest that some mats may be better than others at reducing vibration transmission to the feet. This study showed that when mats were compressed at a higher speed, they exhibited higher stiffness. It stands to reason that when a material is compressed faster, it will provide more resistance. It was also determined that at a higher force, all mats showed a larger displacement. The 3M Safety-Walk showed the highest stiffness followed by the GO Resilient mat. While the higher stiffness results in a higher fn, this may not always be desirable depending on how the mat will be used. As an example, a worker standing on a mat for long periods of time may wish to have a less stiff mat from a comfort perspective. While the predicted resonant frequencies of the mats were all well above the known resonant frequencies of the ankle (4-8 Hz, 12.5 Hz and 25-63 Hz[3]) and the whole body (9-16 Hz[4]), it would be none the less important to know the vibration characteristics of the input vibration to the matting in order to avoid using a mat whose resonant frequency is the same as the input vibration. Given the viscoelastic nature of the mats, future work is needed to quantify damping, stress relaxation and creep properties.

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Table 1. Young's Modulus (E), Stiffness (k), Displacement (Δd) and Natural Frequency (fn) expressed by Mat Type, Force (Low=0.5*50th%ile Male Body Weight; High=1.5*50th%ile Male Body Weight) and Speed (Slow=0.000833 m/s; Fast=0.005 m/s) (n=3) (mean±SD)

Mat Type	Force	Speed	E (MPa)	k (kN/m)	Δd (mm)	fn (Hz)
Seaton Tilecote Sponge Mat	Low	Slow	1.07 ± 0.07	460.89 ± 55.32	5.36 ± 0.53	193.80 ± 11.87
		Fast	4.16 ± 3.17	1773.83 ± 1449.77	5.83 ± 0.37	360.73 ± 148.97
	High	Slow	1.45 ± 0.61	610.96 ± 217.94	7.29 ± 0.18	221.21 ± 38.33
		Fast	4.60 ± 1.46	2032.99 ± 645.11	7.68 ± 0.16	403.78 ± 67.69
GO Resilient KMB-1100	Low	Slow	11.46 ± 2.49	3544.86 ± 851.83	1.03 ± 0.06	504.21 ± 59.29
		Fast	33.21 ± 19.03	12558.50 ± 8034.61	1.83 ± 0.04	910.41 ± 346.62
	High	Slow	7.50 ± 1.55	2631.06 ± 946.99	1.66 ± 0.24	432.00 ± 75.58
		Fast	36.71 ± 17.24	12078.33 ± 6247.00	2.11 ± 0.22	915.67 ± 231.57
3M Safety-Walk Cushion Matting	Low	Slow	14.56 ± 9.43	7041.39 ± 2509.66	0.91 ± 0.23	775.23 ± 135.02
		Fast	56.40 ± 14.75	21908.34 ± 5244.35	2.01 ± 0.52	1374.00 ± 172.30
	High	Slow	17.55 ± 1.05	6657.71 ± 497.57	1.68 ± 0.16	761.03 ± 28.74
		Fast	34.57 ± 13.22	13597.99 ± 5176.55	2.45 ± 0.28	1072.93 ± 222.02
3M Nomad Scraper Matting 8150	Low	Slow	0.33 ± 0.17	152.37 ± 15.17	5.21 ± 0.13	129.71 ± 6.38
		Fast	1.87 ± 0.20	706.41 ± 24.85	4.87 ± 0.15	279.48 ± 4.92
	High	Slow	0.99 ± 0.37	403.83 ± 134.27	6.56 ± 0.45	209.28 ± 35.99
		Fast	3.74 ± 1.07	1404.08 ± 459.29	7.34 ± 0.24	390.09 ± 68.29
3M Nomad Scraper Matting 8100	Low	Slow	0.44 ± 0.13	129.35 ± 29.39	5.50 ± 0.56	123.71 ± 14.58
		Fast	1.05 ± 0.30	393.58 ± 124.76	6.05 ± 0.59	214.75 ± 36.40
	High	Slow	0.76 ± 0.06	238.32 ± 19.95	8.85 ± 0.53	168.60 ± 6.98
		Fast	2.50 ± 0.16	832.57 ± 75.39	8.36 ± 0.25	315.09 ± 14.43

EVALUATION OF TRANSMISSIBILITY PROPERTIES OF ANTI-FATIGUE MATS USED BY WORKERS EXPOSED TO FOOT-TRANSMITTED VIBRATION

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1. INTRODUCTION

Miners can be exposed to foot-transmitted vibration when operating locomotives, bolters, jumbo drills and/or drills attached to platforms workers also stand on. Case reports suggest miners are reporting pain, discomfort and blanching in the toes more often than their co-workers who are not exposed to vibration via the feet (Choy et al., 2008; Thompson et al., 2010). A recent field study reported considerable differences in the dominant frequency associated with locomotive operation (3.15–6.3 Hz) compared to drilling or 'bolting off' from platforms (31.5-40 Hz) (Leduc et al., 2010), suggesting a rationale for greater reports of vibration-induced white feet in workers with a history of exposure to higher frequency vibration at the feet. Although little is known about the resonant frequency of the foot, researchers have suggested the hands and fingers are at a greater risk of injury when exposed to frequencies in the range of 20-25 Hz, and greater than 100Hz, respectively (Dong et al., 2004). Given the anatomical similarity between structures of the feet and the hand, it is reasonable to hypothesize that workers exposed to frequencies in this range could be more susceptible to vibration-induced white feet.

In order to decrease injury risk, engineering controls could be used to decrease vibration exposure at the source, administration controls could be used to decrease a workers daily exposure, and/or personal protective equipment could be used to attenuate vibration before it enters the feet of the workers. Engineering controls would be ideal and several mining companies are working to reduce vibration produced by drills, and manufacturers are working on new platforms designed to isolate the worker from vibration; however, these changes will take time and workers continue to report health problems associated with vibration exposure at the feet. The use of mats to attenuate vibration at the feet has been suggested as a possible intervention. However, controlled studies have yet to evaluate the effectiveness of mats in attenuating vibration. Therefore, the purpose of this study was to evaluate the transmissibility properties of three commercially available “anti-fatigue” mats currently used on equipment operated in underground mines in Ontario, Canada.

2. METHODS

All procedures were approved by the Laurentian University Research Ethics Board and informed consent was provided.

2.1. Participants

Ten participants, with no history of lower body musculoskeletal injury, head injury, diabetes, vasculopathy, or neuropathy participated in this study.

2.2. Experimental Design

A four mat (M1; M2; M3; NM) by two vibration exposure profile (VP1; VP2) experimental design with one repeat was carried out. The order of mats tested was randomized within each vibration exposure block and the order of vibration exposure profile was also randomized. Participants were exposed to foot-transmitted vibration for 20 seconds while standing on each mat with 10 seconds of rest between mat conditions.

2.3. Vibration Exposure

VP1 was generated by a custom-built whole-body vibration simulator while VP2 was generated by a vibration exercise platform (Power Plate North American, Inc., Irvine, CA). VP1 had a dominate frequency between 3-5 Hz with a frequency-weighted RMS acceleration ranging between 1-5.5 m/s^2, while VP2 had a dominant frequency between 30-31.5 Hz with frequency weighted RMS acceleration ranging between 8-12.5 m/s^2. The vibration profile frequencies were selected to simulate the dominant vibration frequency experienced when operating a locomotive and drilling from a raised platform, respectively (Leduc et al., 2010).

2.4. Vibration Measurement

Vibration data were collected in accordance with ISO 2631-1:1997. Two S2-10G-MF tri-axial accelerometers (NexGen Ergonomics, Montreal, QC) were used to measure vibration on the floor of the vibration platform and on the surface of the mat. The accelerometers were aligned and positioned directed underneath the right foot of the standing participant. A DataLOG II P3X8 (Biometrics, Gwent, UK) data logger was used to record the vibration data. Participants stood on a standard rubber pad with an embedded tri-axial accelerometer in order to measure vibration on top of the mat.

2.5. Data Analysis

Vibration Analysis Toolset v. 5.0 (NexGen Ergonomics, Montreal, QC) was used to calculate the frequency-weighted vibration at the floor and above the mat in accordance with ISO 2631-1:1997 and ISO 5349-1:2001. A mat effective amplitude transmissibility (MEAT) value was calculated as a percent ratio between frequency-weighted acceleration in the z-axis on the mat (Ma_{wz}) to frequency-weighted acceleration in the z-axis on the floor (Fa_{wz}). A MEAT value greater than 100% indicated vibration was amplified as it travelled through the mat while a value less than 100% suggested the mat attenuated the vibration.

3. RESULTS AND DISCUSSION

The purpose of this study was to determine if any commercially available mats used in underground mines in Ontario were effective at attenuating foot-transmitted vibration. The ISO-2631-1 z-axis MEAT score for M2 was slightly less than 100 % for both vibration exposure profiles and at/slightly above 100% for M1 and M3 (Table 1). When the MEAT score was calculated using ISO 5349-1 weighted z-axis data, only M2 when exposed to higher frequency vibration was below 100%.

Table 1. Mean M.E.A.T. values for mat and vibration conditions determined with frequency weighted acceleration calculated according to ISO 2631-1 and ISO 5349-1.

Mat	Vib. Profile	Mean MEAT Z –axis IS0 2631-1 % (SD)	Mean MEAT Z –axis IS0 5349-1 % (SD)
M1	VP1	103 (6)	107 (12)
M1	VP2	100 (5)	100 (11)
M2	VP1	96 (5)	102 (9)
M2	VP2	99 (2)	99 (6)
M3	VP1	102 (5)	103 (8)
M3	VP2	100 (4)	100 (7)

Vibration-induced white feet has been reported in miners exposed to foot-transmitted vibration with a dominant frequency in the 30-40 Hz range (Thompson et al., 2010; Leduc et al., 2010). Miners who experienced Raynaud's phenomenon in the toes in Hedlund's study (1989) also operated equipment known to expose workers to higher frequency foot-transmitted vibration. Therefore, if a mat is going to be used as an effective piece of personal protective equipment it needs to be able to attenuate higher frequency vibrations. None of the mats tested in the current study showed any meaningful attenuation of vibration at the low frequency (3-5 Hz) or the high frequency (30-31.5 Hz). However, workers might still benefit from standing on the mats when the "anti-fatigue" features of the mats are considered. Anti-fatigue mats are designed to allow the body to sway naturally while standing (King, 2002), leading to small subtle movements of the calf and leg muscles resulting in improved blood flow and reduced fatigue (King, 2002). Positive anecdotal feedback provided by miners in a field study also supports continued use of mats in underground mines (Leduc, 2011). Future research should evaluate mats with a larger range of frequencies in order to replicate better the spectral content present in occupational exposure. Moreover, it is essential to determine if amplification occurs at the frequency range that is linked to potential damage to the feet. Future work should also evaluate mats that have been used over a longer duration. All the mats tested in this study were new and testing was limited to 20 second trials. Future testing should also evaluate mats in the field, particularly since anti-vibration glove testing has revealed that the comparison of field and laboratory results did not produce the same ranking of gloves (Pinto et al., 2001).

4. CONCLUSIONS

The transmissibility of three commercially available anti-fatigue mats were evaluated to determine if any of the mats were capable of attenuating foot-transmitted vibration experienced during underground mining applications. None of the mats produced relevant attenuation.

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ERGONOMIC MODIFICATION AND EVALUATION OF CHAIN SAW HANDLE IN WOOD CUTTING

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1. INTRODUCTION

Human response to vibration depends on magnitude, frequency and direction of the vibration signal (Griffin, 1990). Prolonged exposure to hand-transmitted vibration (HTV) from powered processes or tools is associated with an increased occurrence of symptoms and signs of disorders in the vascular, neurological and osteoarticular systems of the upper limbs (Bovenzi, 1997). The relevance of studying hand–arm vibration in power tools for industry is highlighted by a statistical portrait revealing that 17% of European workers report being exposed to vibration from handheld tools or machinery for at least half of their working time. In the same study, about 13% of workers consider that their work affects their health in the form of muscular pain in the upper limbs (European Commission, 2002). Pocekay et al. (1995) reported that heavy workload, inadequate equipment design, high production demands and repetitive wafer-handling activities are risk factors associated with musculoskeletal disorders for semiconductor industry workers. It is also reported that a handle angle design affects wrist posture and lifting capability (Wang et al., 2000). The present study was designed to reduce vibration-induced stresses in wood cutting using a chain saw, through handle design. To achieve these objectives, the study was carried out in two phases: pilot and main experiments.

2. PILOT EXPERIMENT

The pilot experiments were performed prior to main investigations, to record the postural angles of wrist, forearm and index finger and the vibration levels.

2.1. Angular Deviations of Wrist and Forearm

Two healthy male participants participated in the experiment. A twin axis goniometer (SG65) and single axis torsiometer (Q150) goniometers were attached to the left hand with die cut medical grade double sided adhesive tape (T350). The participant was asked to hold the tool for comfortable posture, and then to operate the tool for one minute.

2.2. Transfer of Vibration to the Hand-Arm System

Data acquisition was made possible using tri-axial transducer (Model No. SEN041F made by PCB Piezotronics, New York, USA) that was connected to NI card. The transducer was placed as required by ISO 5349-2 (2001). The setup supported a sampling rate of 1024 per second. A LabVIEW code was written for the recording of Vibration levels.

2.3. Results - Pilot Experiment

<u>Angular deviation</u>

From Figure 1, it was found that the torsion angular deviations were high for both left and right hands. Deviations of the wrists were also large in the radial/ulnar directions, with left wrist deviation larger than the right.

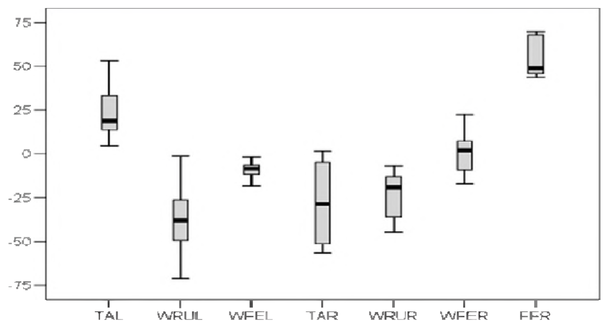


Figure 1. Torsion Angle, left (TAL) & right (TAR) Wrist Radial/Ulnar Angle, left (WRUL) & right (WRUR), Wrist Flexion/Extension Angle, left (WFEL) & right (WFER) Finger Flexion Angle (FFR)

<u>Vibration Levels</u>

The analysis for vibration was done using MATLAB. The vibration of the chain saw was high, but the component vibration in three directions (X, Y & Z) can be reduced by making new handles of different material having high vibration damping properties.

3. MAIN EXPERIMENT

Based on the findings of pilot experiment, three different angled handles were used for the investigations, with 30°, 60°, and 90° inclinations in the downward direction from the horizontal axis. Four healthy male subjects participated in the main experiment. Vibration levels were recorded in three directions (X, Y and Z) at the wrist position with the old and new designs of handles. Observations were recorded as in the pilot experiment.

4. RESULTS AND DISCUSSION

In Figure 2, it can be seen that the deviation in the torsion angle was lowest for the 30° handle and highest for the original handle (180°), during chain saw operation. For the wrist radial/ulnar angle, the 30° and 90° handles have similar angular deviation, and these were the minimum values of radial/ulnar deviation among all handles tested. The angular deviation for radial/ulnar of the 60° handle was greater than that of both the 30° and 90° handles, but was less than that of the original handle.

Figure 2. Postural angles for modified and original handles.

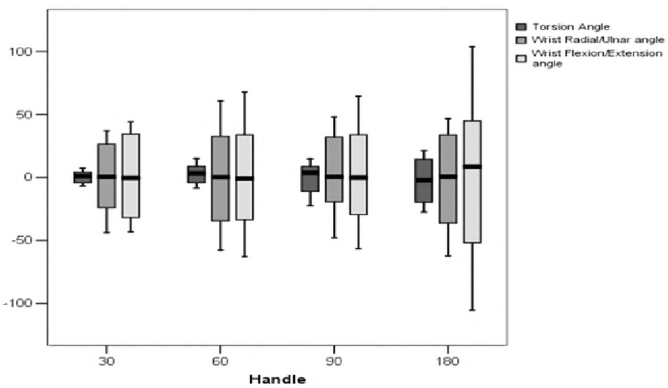
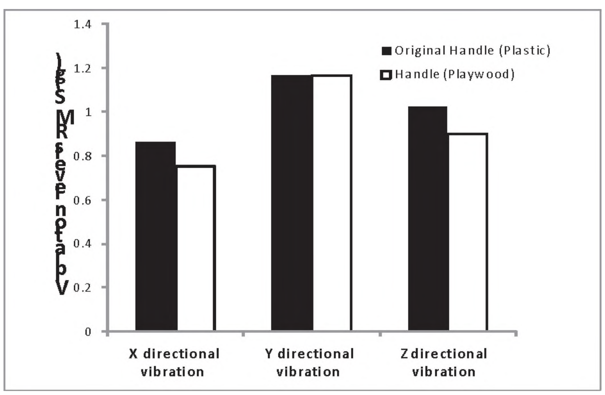


Figure 3. Vibration levels for original and new handles



Vibration levels were also observed to be lower with new design of handles than the old design. The results in Table 3 showed the levels of vibration produced in the new handle were lower in X and Z directions. Reduction in handle vibration levels can be attributed to the new handle material. The old handle was plastic, and the new handle was made of cross-ply laminated plates; vibration absorption of laminated plates is greater than that of the plastic. The similar studies were done with different power tools in previous research (Xu et al. 2009; Dong et al. 2003; Chang et al. 2000; Vergara et al. 2008; Rimell et al. 2008).

Similar findings on wrist angle deviations were described by Okunribido & Haslegrave (1999), who performed a study on the effect of handle design for cylinder trolleys. Chung & Wang (2001) also found that modifying the grasp handle on a pod in wafer-handling tasks induced less ulnar deviation, but significantly greater radial deviation. They further found that radial deviation could be reduced by tilting the handle angle from 90° to between 30° and 45°. The wrist radial deviation problem was thus improved. The results by ANOVA showed that only the minimum value for the flexion/extension angle was significant ($p<0.01$).

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Characterization of Frequency-Dependent Responses of Sensory Nerve Function to Repetitive Vibration

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1. INTRODUCTION

Both epidemiological (1) and experimental studies (2) suggest that the ISO 5349 frequency weighting curve may not place enough weight on exposure to mid-range vibration frequencies (i.e., 100-500 Hz). Data from rat vibration studies demonstrated the risk of developing vibration-induced vascular dysfunction is greater in rats exposed to vibration at 125 or 250 Hz than in rats exposed to vibration at 62.5 Hz (3). Vibration also affects peripheral nerve function. However, the frequency-dependent effects of vibration on injury to the peripheral nervous system have not been examined. The goal of this study was to characterize the frequency-dependent effects of repeated vibration exposures (i.e., 10 days) on peripheral nerve function and biology.

2. METHODS

2.1. Exposure

Male Sprague-Dawley rats [Hla:(SD) CVF rats; 6 weeks of age at arrival; Hilltop Lab Animals, Inc, Scottdale, PA] were used in this study. Animals were maintained in an AALAC-accredited vivarium under a 12:12 LD cycle (lights on 0700 h) with food and water available *ad libitum.* Rats were acclimated to the laboratory for 1 week prior to the beginning of the experiment.

On the first day of the experiment, rats were restrained in Broome style restrainers. Each rat had their tail secured to a platform as previously described (4). Rats (N=6/group) were exposed to vibration at 62.5, 125 or 250 Hz (49 m/sec^2 r.m.s.), restraint-control, or cage control conditions for 10 consecutive days. Restraint-control rats had their tails secured to a platform mounted on isolation blocks. Cage control rats were maintained in their home cages. Following the last exposure, rats were anesthetized using pentobarbital (100 mg/kg, i.p.) and euthanized by exsanguination 10 days following the exposure.

Tail nerves and dorsal root ganglia (DRG, from the L5-6 regions of the spine) were dissected and frozen for analyses of transcript expression or for immunohistochemistry. An additional segment of the nerve was embedded in JB4, sectioned and stained for histological analyses.

All procedures were approved by the NIOSH Animal Care and Use committee and were in compliance with CDC and NIH guidelines for the care and use of laboratory animals.

2.2. Current Perception Threshold (CPT)

Aβ, Aδ, and C fiber functions were assessed using transcutaneous electrical stimulation at 3 different frequencies (2000, 250 or 5 Hz to test different fiber types). Thresholds were measured prior to vibration or restraint exposures on days 1 and 9 of the study.

To perform the CPT, a stimulating electrode was attached near the C18 region of the tail and a dispersing electrode was attached approximately 1cm above that. Electrical stimulation was gradually increased (0.5 amp increments at 2000 Hz and 0.1 amp increments at 250 and 5 Hz) until the rat flicked its tail.

2.3. Gene Expression

Changes in gene expression were measured in the ventral tail nerve and DRG using total rat genome arrays to identify candidate genes (Illumina Rat Expression Arrays) and changes were verified using quantitative PCR as previously described (3).

2.4. Morphology

Segments of the ventral tail nerve were embedded in JB4 and 2 μm transverse sections were cut on a microtome. Sections were stained with Sudan Black to assess changes in myelinated nerve number and myelin thickness. Other sections were stained with methylene blue to count infiltration of mast cells. Frozen segments of nerve were sectioned and immunostained for albumin to determine if vibration resulted in edema in nerves.

2.5. Data Analyses

CPT data were analyzed using 2 (day) x 5 (treatment) ANOVAs, with subjects added as a random variable. Histological and gene data were analyzed using 1-way ANOVAs. Differences with $p < 0.05$ were considered significant.

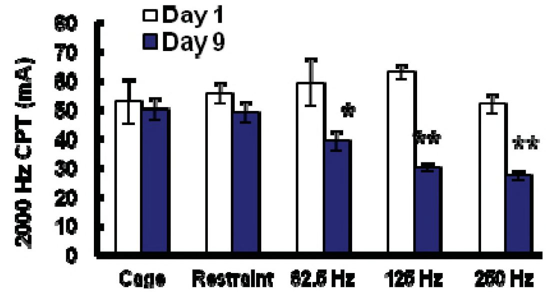

Figure 1. On day one there were no differences in the 2000 Hz CPT in rats. However, after 9 days of vibration exposure at any frequency there was a reduction in the 2000 Hz CPT as compared to day 1 (* less than day 1, p < 0.05; **less than day 9 cage and restraint CPTs, p < 0.05).

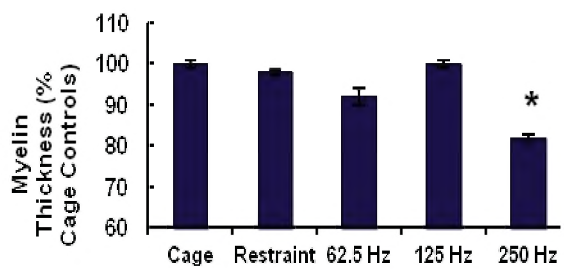

Figure 2. Myelin thickness was significantly reduced in nerves collected from rats exposed to vibration at 250 Hz (* less than cage and restraint controls, p < 0.05).

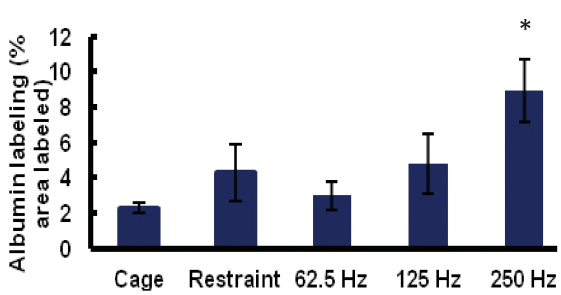

Figure 3. These data represent the percent of area in the ventral tail nerve that was labeled with albumin. Vibration at 250 Hz resulted in a significant increase in albumin staining in the nerve. (*greater than cage and restraint control rats, p < 0.05).

3. RESULTS

There were no significant changes in the CPTs at 250 or 5 Hz. However, between days 1 and 9, there was a significant decrease in the 2000 Hz CPT in rats exposed to vibration at all frequencies (Figure 1).

There were few significant changes in gene expression in either the tail nerve or DRG after 10 days of vibration exposure. However, nerves from rats exposed to vibration at 250 Hz displayed a significant reduction in myelin thickness (Figure 2) and an increase in the area stained for albumin (Figure 3). These changes in swelling and myelin thickness were not accompanied by a change in the number of myelinated nerves or a change in the number of mast cell.

4. DISCUSSION AND CONCLUSIONS

- After 9 days of vibration exposure, rats displayed an increased sensitivity to 2000 Hz stimuli during the CPT. This suggests that in vibrated rats, Aβ fibers are more sensitive to electrical stimulation. Changes in perception thresholds are early indicators of injury.
- Myelin thickness and albumin staining (i.e. edema) were altered in nerves from rats exposed to vibration at 250 Hz, but not at the other frequencies.
- These data suggest that there are frequency dependent changes in peripheral nerves after 10 days of vibration exposure. However, vibration at all frequencies appears to have an effect on Aβ nerve function
- These data are consistent with previous findings suggesting that greater weight should be given to mid-range frequencies (100-500 Hz) in the ISO 5349 frequency weight curve.

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FREQUENCY WEIGHTING OF HAND-TRANSMITTED VIBRATION FOR EVALUATING COMFORT

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1. INTRODUCTION

The purpose of this research is to establish a suitable frequency-weighting curve for comfort evaluation with regard to hand-arm vibration using the category judgment method (Guilford, 1954). Many frequency-weighting curves based on biodynamic responses or on epidemiological data for hand-arm vibration exposure have been proposed by many researchers, as shown in Figure 1. It is not clear which frequency-weighting curve is best for establishing relationships between frequency-weighted r.m.s. acceleration and hand-arm vibration comfort. Therefore a psychological experiment has been performed to investigate the effectiveness of the frequency weightings in Figure 1 to predict comfort.

2. APPARATUS AND METHOD

2.1. Apparatus

A shaker with a power amplifier (VA-ST-03, IMV Corp.) and signal processing unit (F2 SPU, IMV Corp.) were used in the experiments. All vibration stimuli were generated on the handle, and the frequency-weighted r.m.s. vibration acceleration was feedback controlled by the F2 SPU controller and computer.

2.2. Method

A series of 15 vibration stimuli (three times for five levels of vibration stimuli, respectively), each of which was randomly ordered, were applied in the X_h axis to the right hand of each subject, who was seated in a relaxed posture. All vibration stimuli had a duration of five seconds with a two-second pause between them. The vibration load was applied in the direction of the X_h axis with a predetermined stimulus program input into the vibrator, and then applied to the subject grasping the vibrating handle. The grasping force was about 2-3 N. The diameter of handle was 0.03 m and the length was 0.12 m. The subjects were issued verbal responses to each vibration stimulus, selecting from five evaluation categories using the designated numeric value (1 to 5) for each category (Maeda and Shibata, 2008).

The subjects were exposed to vertical vibrations before being asked to choose a numerical category to indicate their best perceived level of comfort during each stimulus. The creation of this assessment scale, including the aforementioned categories, enabled not only the clarification of the relationship between the vibration stimuli and the degree of comfort but also the connection between the r.m.s. acceleration frequency-weighted according to Figure 1 and the corresponding comfort categories.

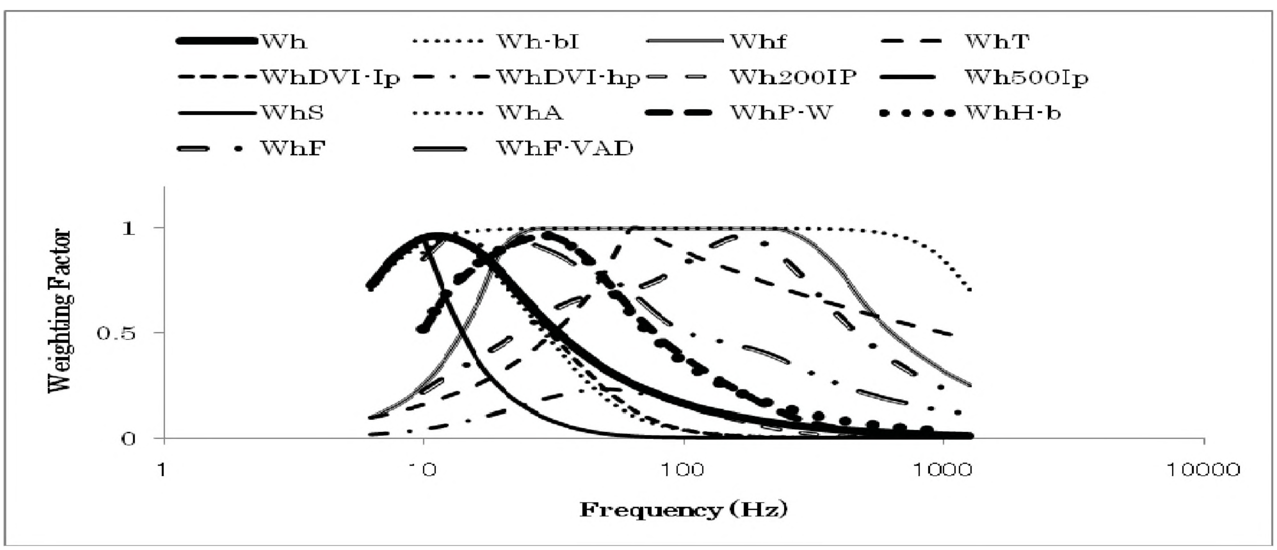

Figure 1. Comparison of frequency weighting curves (for explanations see Table 1).

The experiments were conducted using random signals for the stimuli over a frequency range of 1-1000 Hz, similar to the ISO 5349-1 standard evaluation range.

In addition, in order to clarify the individual characteristics of the different spectra, varying degrees of high and low frequency components were used. The stimuli consisted of three kinds of signals, designated: stimulus F, with a flat PSD from 1 to 1000 Hz; stimulus H, with a PSD that became 20 dB higher at 1000 Hz than at 1 Hz, and; stimulus L, with a PSD 20 dB lower at 1000 Hz than at 1 Hz. The signals were modified using the W_h frequency weighting of ISO 5349-1:2001, and the frequency-weighted r.m.s. accelerations were adjusted to be equal. In addition, the magnitudes of the signals were varied over a range of five steps to make 15 kinds of stimuli with accelerations of 0.28, 0.56, 1.12, 2.48 and 4.48 m/s^2 r.m.s. These stimuli were selected from the specific vibration magnitudes of hand-held vibration tools. Each one of these signals was used three times, comprising a total of 45 stimulus applied in random order, each for a duration of five seconds with a two-second pause between stimuli. Each subject in the experiment experienced all stimuli. This meant that each subject was exposed to a total of 225 seconds of vibration, which even when the exposure time is considered, is in the acceptable range for the ISO 5439-1:2001.

2.3. Subjects

The experiments were performed with twelve healthy subjects, six males and six females, with mean ages of 23.2 and 24.5 years, respectively. All of the subjects were non-smokers. None of the subjects had been exposed to high magnitudes or long periods of hand-arm vibration occupationally or in their leisure time activities. The experiments were approved by the Research Ethics Committee of the Japan National Institute of Occupational Safety and Health. All the subjects underwent an explanation of the test procedure and gave their written informed consent to participate in the study.

3. RESULTS

The category judgment method can establish the relationship between the frequency-weighted r.m.s. acceleration according to the frequency weighting curves shown in Figure 1 and the corresponding categories representing each degree of comfort for hand-arm vibration. In order to clarify the effectiveness of the frequency-weighting curve for evaluating the hand-arm vibration comfort, the effectiveness was quantified in terms of the square root of the sum of the squared differences between the least square line of the category judgment results and the experimental data (i.e., r.m.s. errors), as shown in Table 1 (Maeda and Griffin, 1994).

Table 1. Effectiveness (the r.m.s. errors) obtained from the frequency-weighting curves as shown in Figure 1.

Frequency-Weighting Curve	R.M.S. Error
Wh (ISO 5349-1)	1.963
Wh-bl (band-limiting component of Wh)	6.167
Whf (Finger vibration power absorption)	5.441
WhT (Epideiological data)	5.775
WhVDI-lp (Wh with 24dB/Oct low-pass filter at 50 Hz)	2.680
WhVDI-hp (Wh with 24dB/Oct high-pass filter at 50 Hz)	2.925
Wh200lP (VDI 2057 200 Hz)	2.245
Wh500lp (VDI 2057 500 Hz)	2.017
WhS (Biodynamic Response of Shoulder)	3.599
WhA (Biodynamic Response of Arm)	2.729
WhP-W (Biodynamic Response of Palm and Wrist)	1.966
WhH-b (Biodynamic Response of Hand back)	1.945
WhF (Biodynamic Response of Finger)	5.426
WhF-VAD (Finger of Vibration Absorption Density)	2.979

4. DISCUSSION

From the results for r.m.s. errors in Table 1, the most suitable frequency-weighting curves for evaluating hand-arm vibration comfort are WhH-b, Wh, and WhP-W. From Figure 1, the shapes of the weighting curves WhH-b, Wh, and WhP-W are almost same. But, the weighting factors are a little greater than the ISO 5349-1:2001 weighting factors. Although the frequency-weighting curves Wh-bl, Whf, and WhT are suitable for evaluating the hand-arm vibration syndrome, the r.m.s. errors of these frequency- weighting curves are large. Therefore, these weighting curves are not suitable for evaluating hand-transmitted vibration comfort. From this experiment, it is clear that the frequency-weighting curve of the current standard, ISO 5349-1:2001, is suitable for evaluating hand-transmitted vibration comfort.

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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.

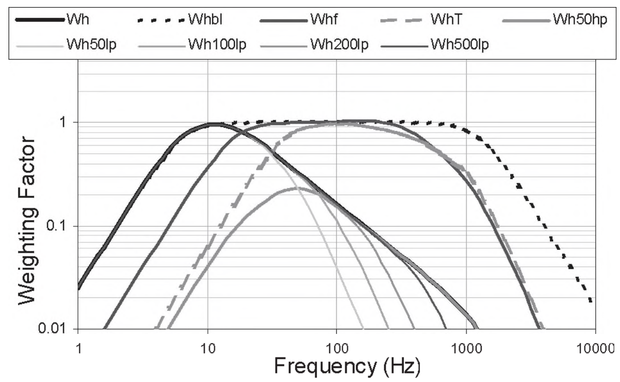

Figure 1. Candidate frequency weightings.

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.

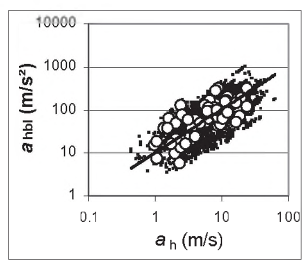

Figure 2a. a_{hbl} vs a_h

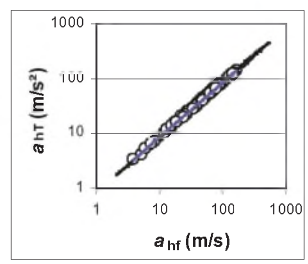

Figure 2b. a_{hf} vs a_{hT}

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

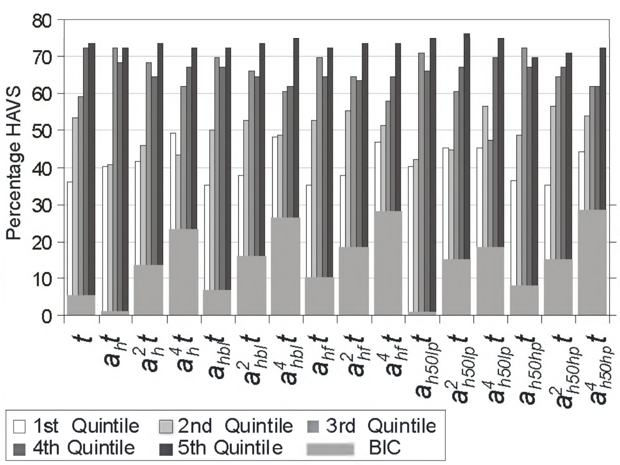

Figure 3. Prevalence of HAVS by vibration magnitude quintiles and BIC values for candidate weightings.

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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Posture-Related Change in Frequency Weightings Derived from Vibration Power Absorption of the Hand-Arm System

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1. INTRODUCTION

Workers use various hand-held power tools in a variety of hand-arm postures during their operation. However, the evaluation method of effects of exposure to hand-arm vibration (HAV) on health, specified by ISO5349-1(2001), does not consider the effects of hand-arm posture on frequency weightings.

Frequency weightings derived from total power absorption of the hand are shown to correlate well with the ISO weightings based on subjective sensation or discomfort (Dong et al., 2006). The aim of this study is to examine the effects of hand-arm postures on the frequency weightings derived from the vibration power absorption (VPA) of the hand. To calculate the VPA-based frequency weightings, the mechanical impedance was measured for twelve male subjects exposed to a random vibration along the Z_h axis. This study considered five arm posture conditions that consist of two elbow postures (horizontally stretched straight and bent by 90 degrees) in combination with three forearm postures (pronated, neutral, and supinated).

2. SUBJECTS AND METHOD

2.1. Apparatus

The single-axis hand-arm vibration test system used in this study included an electro-dynamic shaker (VE-100S; IMV Corporation, Osaka, Japan) that can generate Z_h axis vibration. A handle instrumented in the system had a circular cross-section with a diameter of 40 mm and an effective grip length of 100 mm. It was connected to the shaker shaft so that the centerline axis of the handle was vertically oriented. This handle consisted of the handle base and measuring cap, between which two piezoelectric single-axis force sensors (9212; Kistler Inc., Winterthur, Switzerland) were sandwiched along the centerline of the handle, to measure the grip force acting between the base and the measuring cap. Signals from these two force sensors were summed up to obtain the total grip force. Also an accelerometer (356A12; PCB Piezotronics, Inc., New York, USA) was secured to the center of the measuring cap to measure the vibratory acceleration at the handle. The push force applied to the handle through the hand was measured by using a force plate.

2.2. Subjects

The experiments were performed with twelve healthy male subjects in their twenties. None of the subjects had any experience of exposure to high levels or long periods of hand-arm vibration occupationally or in their leisure time activities. The right hand was used for the test.

All the subjects underwent an explanation of the test procedure and gave their written informed consent to participate in the study. The experiment was approved by the Research Ethics Committee of Japan National Institute of Occupational Safety and Health.

2.3. Method

The vibration signal used in the experiments was a pseudo-random vibration in the frequency range of 10 Hz to 1,250 Hz with a flat power spectrum density (PSD) of 1.0 $(m/s^2)^2/Hz$, which corresponds to an unweighted acceleration magnitude of 35.2 m/s^2 (r.m.s.).

Table 1. Hand-arm postures considered in this study.

Posture index	Elbow	Forearm
BP	Bent	Pronated
BN	Bent	Neutral
BS	Bent	Supinated
SP	Straight	Pronated
SN	Straight	Neutral

As summarized in Table 1, this study considered five hand-arm postures by combining three forearm postures with two elbow postures. Three forearm postures considered in this study included 1) pronated posture in which the forearm was rotated by 90 degrees with the palm facing inferiorly, 2) neutral posture in which the forearm was maintained so that the palm faced medially, and 3) supinated posture in which the forearm was rotated by 90 degrees with the palm facing upward. The elbow was either stretched straight with the forearm and upper-arm horizontally maintained, or bent by 90 degrees so that the upper-arm was vertically maintained. During the measurements, the subjects were asked to keep the hand-arm untouched to the body.

The subjects with these postures were exposed to Z_h axis hand-arm vibration. Mechanical impedances in the Z_h direction were measured at the finger and at the palm side. The total BR parameters of the entire hand were obtained by summing up the BR parameters measured at the both sides. The subjects were asked to grasp the handle with a grip force of 30N in combination with a push force of 50N. The dynamic force and acceleration in the Z_h direction were measured at the measuring cap of the handle. The data gathering was performed with a data acquisition system (Type3109; Brüel & Kjær; Nærum, Denmark).

The results obtained in this study were analyzed and were expressed at the one-third octave band center frequencies ranging from 10 to 1,000 Hz. For each measurement, data collection lasted 30 seconds.

2.4. Calculation of VPA-based weighting factors

The driving-point mechanical impedance (DPMI) at the hand-arm system is defined as a ratio of the dynamic force V(ω) to the vibration velocity V(ω):

$$DPMI(\omega) = F(\omega)/V(\omega) \quad (1)$$

According to the normalization technique used in a previous study (Dong et al., 2006), the VPA-based frequency-weighting factor W_{VPA} can be given as a function of the frequency in the following equation:

$$W_{VPA}(\omega) = 0.958 \cdot \frac{\omega_{ref}}{\omega} \cdot \sqrt{\frac{\mathrm{Re}[DPMI(\omega)]}{\mathrm{Re}[DPMI(\omega_{ref})]}} \quad (2)$$

where ω_{ref} is the frequency of the reference impedance. In this study, the impedance magnitude at 12.5 Hz was taken as the reference.

3. RESULTS

Under elbow-bent posture, no significant difference was observed for effects of forearm postures on the MI at frequencies from 10 to 25 Hz and from 160 to 250 Hz. At frequencies ranging from 40 to 125 Hz, forearm pronation was statistically significant for the neutral / supinated forearm posture ($p<0.01$). In contrast, the neutral forearm posture was significant for the forearm pronation and supination. Under elbow-stretched posture, difference in the MI was significant in between the pronated and neutral forearm posture at frequencies of 10-25 Hz ($p<0.01$), 63-100 Hz ($p<0.01$), 315-400 Hz ($p<0.01$), and 630-1,000 Hz ($p<0.05$). Under pronated forearm posture, the MI measured with the elbow-bent posture was observed to be significantly different from that with the elbow-stretched posture in the frequency bands, 1-20 Hz ($p<0.01$), 32 Hz ($p<0.05$), 63-125 Hz ($p<0.01$), and 250 Hz ($p<0.05$). Also under neutral forearm posture, the MI measured with elbow-bent posture was significantly different from that with the elbow-stretched posture in the entire frequency range of 10-1,000 Hz ($p<0.01$), except in the frequency bands of 20, 125, and 160 Hz (Figure 1).

Under the elbow-stretched postures, the VPA-based weighting factors were significantly lower than the ISO weighting factors at frequencies ranging from 12.5 to 1,000 Hz ($p<0.01$). These basic trends observed in VPA weightings were consistent with the different forearm postures. Under the elbow-bent posture, in contrast, the VPA weightings were significantly higher than the ISO weightings at frequencies ranging from 20 to 80 Hz ($p<0.01$). These results were consistently observed, regardless of the forearm postures. The VPA weightings followed the ISO weighting well in the entire frequency range (Figure 2).

4. DISCUSSION

VPA-based frequency weightings were affected by elbow postures, compared to the effect of forearm postures. Particularly at frequencies up to 80 Hz, where the weighting factors are relatively sensitive to calculation of weighted acceleration values, VPA weightings were significantly higher under elbow-bent postures and were significantly lower under elbow-stretched postures. Based on the analogy of the VPA weightings to ISO weightings (Dong et al., 2006), vibration dose of workers operating vibrating tools with their elbow relatively stretched might be overestimated. In contrast, workers operating vibrating tools with their elbow bent might have vibration exposure more than that evaluated according to the ISO-weighted acceleration. Epidemiological study will be needed to validate our results from the medical aspect.

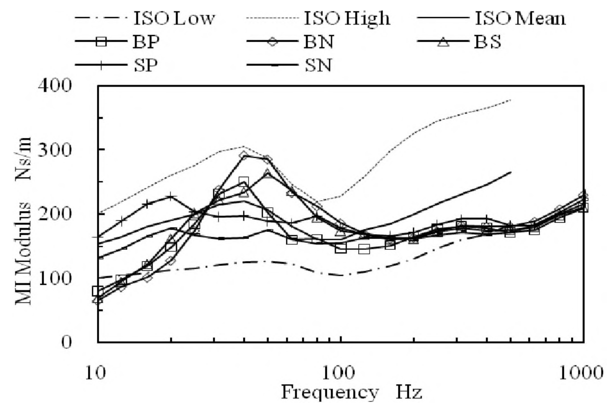

Figure 1. MI modulus under various arm posture.

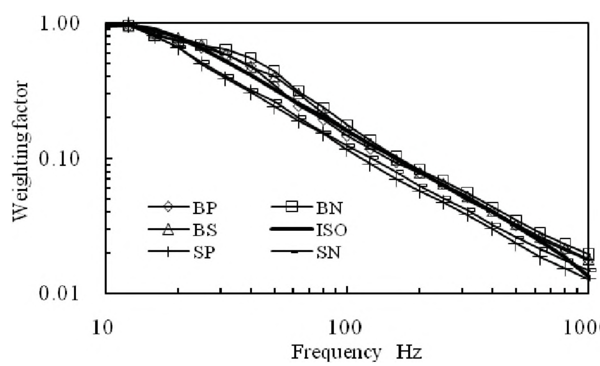

Figure 2. VPA-based frequency weightings.

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VPA-BASED WEIGHTING CURVE: PRELIMINARY ASSESSMENT OF GENDER DIFFERENCE

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1. INTRODUCTION

The UNI EN ISO 5349-1:2004 weighting curve (WC) is the standard risk assessment of HAV.[1] This made use of subjective sensation data reported by Miwa on vibration perception in 1967 performed on ten subjects.[2] Risk assessment is generally done following the cited standard, even if the foundation of the weighting curves has been criticized by some authors.[3] This means, from a pragmatic point of view, that any revision of this standard should preserve the weighting curve, eventually modifying it in order to cope with various vibratory conditions. Recently, an alternative method to compute WC has been proposed,[4,5] which is based on Vibration Absorbed Power (VPA) measurements. These authors found a resonance frequency for the hand-arm system around 31.5 Hz through VPA and MI (Mechanical Impedance) measurements. In the present work, where the range 10-60 Hz was explored, two frequencies immediately before and after that peak, i.e. 30 Hz and 33 Hz, were examined. The aim of this study is to derive weighting factors from VPA measurements and establish the possibility of a gender difference.

2. METHODS

36 young subjects were enrolled, equally divided by genders (18 men: age 26.4±2.5 years, weight 75.4± 10.5 kg, height 178.1±6.2 cm); 18 women: age 25.6±4.4 years, weight 58.9±7.3 kg, height 167.3±8.2 cm). Nine pure sinusoidal vibration signals (10, 20, 30, 31.5, 33, 40, 50 and 60) were generated by a vibration exciter (RMS SW 1508, Germany). Subjects were positioned as described in UNI EN ISO 10819. The grip force was set to 50 N.

The exerted force was constantly shown to the subject. An adapter with a load cell (FGP Sensor & Instruments, FGPXFL212R, France) and an accelerometer (PCB, SEN026, U.S.A.) were fixed to the palm of the hand. Acceleration and force signals were recorded by a real time 32 channel analyzer (OROS, OR38, France) at a sampling rate of 2,500 samples per second.

VPA evaluation is the product of force and velocity. Force was measured directly by means of palm mounted load cell, the velocity was estimated by numeric integration of the palm acceleration along the z-axis. For comparison purpose, MI was derived from VPA measurements through the following equation:[5]

$$P(\omega_i) = \mathrm{Re}[Z(\omega_i)] \cdot \left(\frac{A(\omega_i)}{\omega_i} \right)^2 \quad (1)$$

VPA frequency weighting evaluation has been done following the scientific, [4] and technical literature:[1]

$$\mathrm{W}_{VPA}(\omega_i) = 0.958 \frac{\sqrt{P(\omega_i)}}{A(\omega_i)} \Big/ W_{VPA\_Max} = 0.958 \frac{\sqrt{P(\omega_i)}}{V(\omega_i) \cdot \omega_i} \Big/ W_{VPA\_Max} \quad \textbf{(2)}$$

where $P(\omega_i)$, $A(\omega_i)$ and $V(\omega_i)$ are frequency mean power absorption, acceleration and velocity, respectively, while W_{VPA_Max} is the W_{VPA} maximum attained in the investigated frequency range and assumed as the reference value.

3. RESULTS

VPA data are reported in Figure 1. Absorbed-power based frequency weighting curves WVPA and MI curves were computed for both genders and compared with UNI EU ISO 5349-1:2001 and the literature (Figures 2 & 3).[6]

Referring to the male and female VPA data (Figure 1 a and b, respectively), we may observe that up to 20 Hz the relative behaviours are almost the same, and within the intrinsic statistical variation. Within the range 30 to 33 Hz, the male notch response is more pronounced than that of the females. At both outer frequencies, the male curve is higher and drastically drops at 31.5 Hz. This local minimum is also evident for females, though less pronounced than for the other gender. Above the range 30 to 33 Hz, and up to 60 Hz, the curves for both genders are close one to the other with the male curve beneath the female one.

Concerning gender differences (Figure 2), the female's WVPA curve is almost similar to that of male subjects up to 20 Hz. From 20 Hz up to 60Hz, the male curve is, with no-statistical significance, under the relative female curve. Within the more deeply investigated frequency range, we found for both genders two analogous peaks at 31.5 Hz, with approximately the same maximum absolute value. Clearly, the relative weight of these peaks is higher for male subjects then for females, though the curves are within each other's error margins. Both curves are below the ISO curve.

Concerning MI curves (Figure 3), a small gender difference is evident, with the resonance peak for females at a lower frequency (31.5Hz) than for males (33 Hz). By comparison with the literature,[6] the published resonance behaviour is less evident and more damped than in the present data.

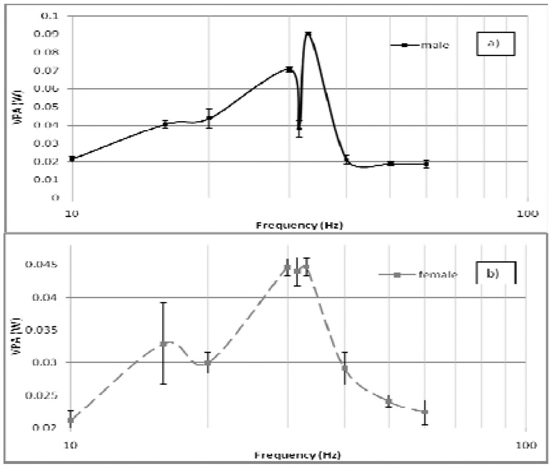

Figure 1. Male (a) and female (b) VPA curves. Data are mean values for each gender group ± standard error. Note that the vertical scales are different.

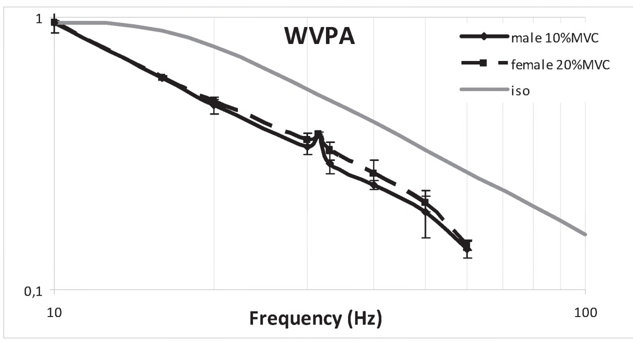

Figure 2. Weighting curves WVPA derived from the VPA curves for both genders. In this case, the ISO curve is taken as a reference curve. Data are mean values evaluated on each gender group ± standard error

4. DISCUSSION AND CONCLUSIONS

By comparing MI curves with those of Dong et al [6] (see Figure 3), we may notice that their profiles are almost similar for all frequencies but from 30 to 33 Hz where the presence of a peak at 31.5 (female) or 33 Hz (male) is evidence of resonance behaviour. The explanation for this discrepancy is twofold: firstly, the resonance behaviour is enhanced in our study by increasing the sampling rate within the 30 to 33 Hz frequency range; secondly, our experimental set-up allowed a direct assessment of palm acceleration and force, instead of those at the handle, which, in turn, gave more accurate measurements. Moreover, we can exclude any influence of the adapter dynamics on the sharp resonance in our results, since a previous accurate transducer calibration procedure guaranteed an absolutely flat frequency response in the range 5 to 100 Hz.

A possible physiological explanation comes from the observation of the Meissner corpuscles behaviour, which have a maximal sensitivity just at that frequency.

By comparing male versus female VPA curves, we may observe that the females curve is below that of the males. Presumably this is due to the higher effort for female subjects to exert the same 50 N grip force. This, in turn, causes different muscle stiffness and consequently a different absorbed power.

Concerning the weighting WVPA curves depicted in Figure 2, we may notice that the normalization procedure adopted in equation (2) decreases the relative curve dynamic, rendering both female and male curves closer to each other. The sharp peak observed at 31.5 Hz in the VPA curves is also evident in the WVPA curves but much smaller. Anyway, the most important conclusion about the WVPA curves is that they are both clearly below the ISO standard curve. This conclusion addresses the most important aim of the present research, which is to prevent vibration injures in the work environment for both genders.

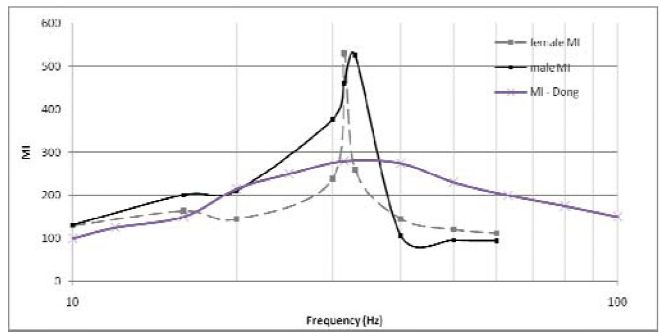

Figure 3. MI curves derived from the VPA curve for both genders. In this case, the curve from Dong et al. is taken as a reference curve.[6]

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REPETITIVE SHOCK VIBRATION RISK ASSESSMENT FOR GUNSHOTS

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1. INTRODUCTION

UNI EN ISO 5349-1:2004 states that it only temporary applies to shock or transient vibration [1]. This is so because data processing to produce root mean square (rms) acceleration is prone to underestimate effects of shocks. ISO/TS 15694:2004 has been proposed for studying these particular vibration exposures [2]. We have made use of this standard in the present work for processing measures of typical shock vibration such as those of firearms. Given the fact that in the cited standard [2] there are several suggestions of data post processing, those suitable for enhancing exposure assessment with respect to 5349 [1] have been adopted in present work. The selection of firearms has been done with regard of those mostly used by Italian police (including Carabinieri).

2. METHODS

We measured triaxial acceleration on the butt of three Beretta firearms (92FSB, PM12 and AR70/90) with an accelerometer (PCB SEN 026, sensitivity 10mV/g,) mounted in an adaptor (Figure 1). The adaptor was made in conformity with the prescription of UNI EN ISO 10819 [3]. Measurements were performed on seven male right-handed operators; since the full magazine holds 15 rounds (see Table 1) it nearly equals the weight of the 92FSB, and is a non marginal portion of the other weapons mass. In order to restrain mass variation during measurements, they have been done with the magazine always fully loaded. The firing distance was 10 m.

Table 1. Characteristics of the measured weapons.

	92 FS	M12	AR70/90
Length	217 mm	Fixed stock: 660 mm	998mm
Barrel lenght	125 mm	200 mm	450 mm
Unloaded Weight	970 g	3480 g	4070 g
Rate of Fire	Single shot	550 rounds/min	670 rounds/min
Muzzle velocity	365 m/s	380 m/s	920 m/s
Magazine	15 rounds	32 rounds	30 rounds
			

The signal was acquired and analyzed by an OROS OR 38. The sampling frequency (5.12 kHz) was selected for wide frequency range.

Figure 1. Adaptor with triaxial accelerometer.

Analysis and processing have been done with MatLab software. The processing rms and root mean quad (rmq) parameters proposed in [2] with a computation time window of either 3 or 30 seconds. The frequency weighting of the acceleration signal was either that of the UNI EN ISO 5349-1 (Figure 2), or the flat weighting of ISO/TS 15694 (Figure 3). All signals were processed in 1/ 3 octave bands.

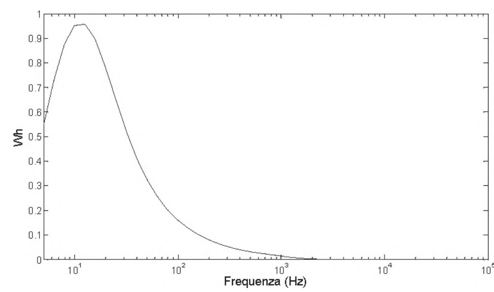

Figure 2. UNI EN ISO 5349-1 W_h weighting curve.

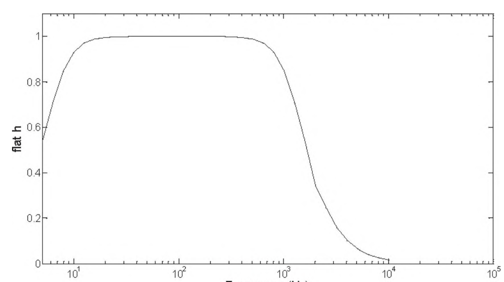

Figure 3. ISO/TS 15694 W_f flat weighting curve.

3. RESULTS

Firing with firearms, as it is expected from impulsive events, encompasses a far larger frequency range than usual vibration exposure. This is evident from Figure 4, which highlights the fact that high frequency acceleration is very relevant. This fact should be kept in mind when selecting

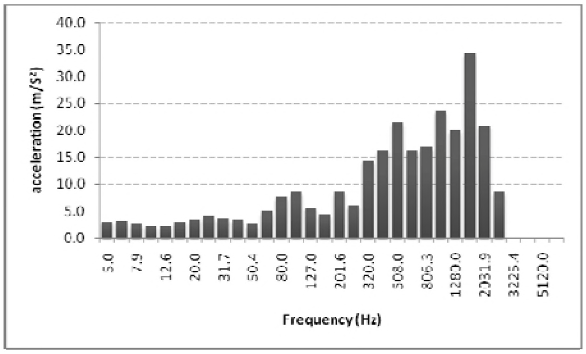

Figure 4. Acceleration versus frequency in 1/3 octave bands.

the weighting curve for that kind of exposure. Post processing gave exposure indicators reported in Table 2. As proposed in ISO /TS 15694, the rms and rmq were evaluated with two weightings: W_h and W_f. filters. Evaluation was done for 2 time windows: 3 and 30 seconds.

Table 2. Indicators assessing exposure evaluated as root mean square weighted by Wh (rms_{Wh}) and Wf (rms_{Wf}), and root mean quad weighted by Wh (rmq_{Wh}) and Wf (rmq_{Wf})

	# sec	rms_{Wh} (m/s^2)	rms_{Wf} (m/s^2)	rmq_{Wh} (m/s^2)	rmq_{Wf} (m/s^2)
92FS	3	10.74±1.15	65.48±4.42	3.85±0.48	10.51±0.86
	30	5.86±0.67	36.20±2.89	1.58±0.21	4.15±0.43
PM12	3	1.94±0.11	21.83±0.15	0.67±0.07	3.16±0.1
	30	0.98±0.04	11.02±0.45	0.24±0.02	1.130±0.05
AR90	3	4.4±0.3	81.0±4.7	0.9±0.08	12.6±1.1
	30	1.86±0.31	37.8±3.7	0.26±0.06	4.0±0.6

In addition, the maximum number of rounds per day was computed, respecting the European limit value for exposure to mechanical vibration (5.0 m/s^2). Tables 3A and 3B show these data for different exposure indicators and weighting curves.

4. DISCUSSION AND CONCLUSIONS

It is evident, from Table 2, that a wide range of values are covered by different indicators. The influence of various factors can be deduced. Widening the time window reduces the indicator value, as expected. But the effect of the fourth power (rmq) is not that of enhancing the exposure assessment. Instead it depresses it. This can be attributed to the impulsive shot and its very short time duration, which implies a wide spectrum in frequency domain and acceleration values below 1 m/s^2 in low frequency bands. Hence the double squaring reduces the result and this sums up to a total less than that for the simple square. This is not compensated by the weighting in the high frequency range for W_h. With a flat weighting, the exposure indicator recovers, but stays well below the rms. From this point of view, the flat weighting curve W_f seems to be better, giving equal weight to a larger range of frequencies. Hence it increases the exposure indicator value. This aspect is even more interesting because the rise in value is present even in rmq, showing that the frequencies involved are well beyond those cut by the W_h curve, as is evident from Figure 4. The indicator to be used seems to be rms_{Wf}.

Table 3 A-B. Number of admissible rounds fired per day not exceeding the European limit, using root mean square (A) and root mean quad (B) indicator.

A	**Max 5 m/s^2**	rms_{wh} (m/s^2)		rms_{wf} (m/s^2)	
		3 s	30 s	3 s	30 s
92FS (single shot 0.1 sec)	T_e	1.6	5.5	0.04	0.14
	Rounds per day	976	3300	26	86
PM12 (single shot 0.1 sec)	T_e	50.1	195.4	0.39	1.6
	Rounds per day	30035	117265	236	927
AR7090 (single shot 0.15 sec)	T_e	9.8	54	0.03	0.1
	Rounds per day	3903	21626	11	53
B	**Max 5 m/s^2**	rmq_{wh} (m/s^2)		rmq_{wf} (m/s^2)	
		3 s	30 s	3 s	30 s
92FS (single shot 0.1 sec)	T_e	12.6	75.5	1.7	10.9
	Rounds per day	7580	45280	6532	1020
PM12 (single shot 0.1 sec)	T_e	419.6	3296.7	18.7	146.8
	Rounds per day	251753	1978024	11236	88056
AR7090 (single shot 0.15 sec)	T_e	222	2749	1.2	11.6
	Rounds per day	88654	1099471	475	4655

Not having any definite indication of what the real danger is from that kind of working activity, it is reasonable to adopt a conservative restriction on the daily number of rounds that can be safely fired.

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INVESTIGATION OF THE RELATIONSHIP BETWEEN VIBRATION EMISSION AND IN-USE VIBRATION FOR ELECTRICAL TOOLS

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1. INTRODUCTION

The Health and Safety Executive has a programme of research with the Health and Safety Laboratory (HSL) investigating the relationship between manufacturers' declared vibration emission, HSL measured emission and vibration measured during real, or simulated real use for different categories of tool. Current research investigates the emission test codes for electric hand-held tools defined in the BS EN 60745 series of standards.

The work described here investigates the repeatability and reproducibility of the BS EN 60745 series of test codes for tools that are considered to represent the greatest health risk from hand-arm vibration exposure: hammers, angle grinders, saws and drills. Individual reports for two of the test codes are published (HSE Research Reports RR717 and RR754) and two are in press.

2. EQUIPMENT AND METHODS

Triaxial hand-arm vibration measurements were made at the prescribed hand locations on each tool using three single axis piezoelectric accelerometers bolted to a mounting block. The blocks were fixed to the tool handle(s) using either a plastic cable tie and tensioning gun system or cyano-acrylate glue. Data from the accelerometers was collected and processed using a real-time frequency analysis system giving frequency-weighted vibration total values for each measurement location. Five consecutive measurements were made for each of three operators on each tool. The overall arithmetic mean, a, was obtained from the mean vibration total values for the three tool operators. A value for the individual tool deviation, K, was also calculated according to the provisions of BS EN 12096:1997 Annex B.2, where a single tool is used to declare the vibration emission. Following the emission tests, in-use measurements were made using the same accelerometer mounting locations. Operating conditions were chosen to represent typical use of the tool under test.

For comparison purposes, the data were summarised in terms of the tool manufacturers' declared vibration emission, the HSL measured vibration emission and the HSL measured field vibration. BS EN ISO 20643:2008 (ISO 20643:2005) requires that test codes produce values indicative of the upper quartile of real-world use, therefore field data is presented here as upper quartile values. For each test code investigated, tools used were anonymised and assigned an alphabetic identification.

3. RESULTS

3.1. Hammers (BS EN 60745-2-6:2003+A2:2009)

Figure 1 illustrates summary vibration data values for each hammer with a rotary drilling mode when drilling into concrete. Data for hammers in a chiseling or breaking application were also obtained but are not illustrated here.

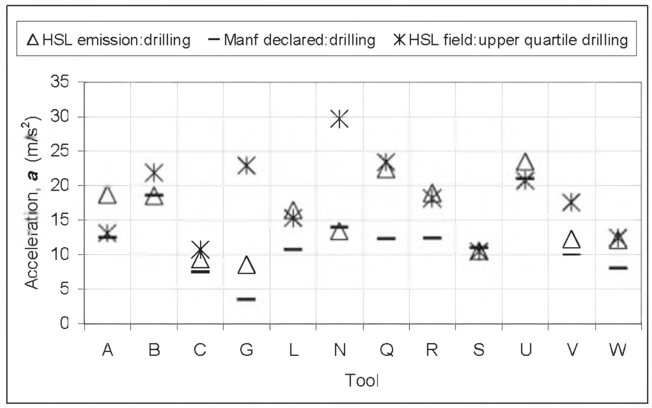

Figure 1. Vibration from hammers (drilling application).

3.2. Angle grinders (BS EN 60745-2-3:2007)

Figure 2 illustrates summary vibration data for angle grinders. Manufacturers' declarations have been assumed to be single axis. All HSL data displayed are triaxial. Field data include both grinding and cutting operations. All emission data were produced using an out of balance aluminium disc.

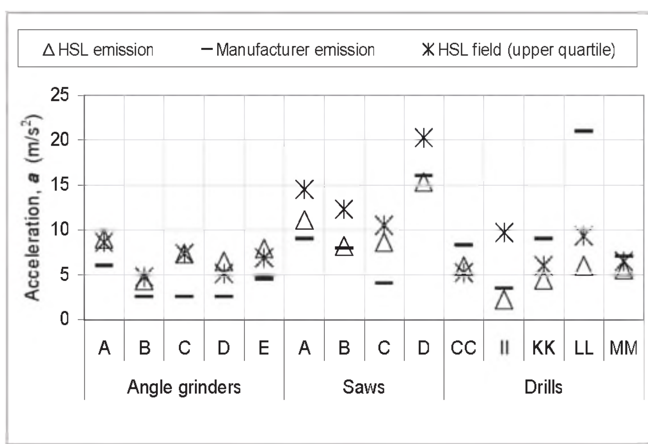

Figure 2. Vibration from angle grinders, reciprocating saws and drills.

3.3. Reciprocating saws (BS EN 60745-2-11:2003)

Figure 2 also illustrates summary vibration data for reciprocating saws. This tool type was tested cutting metal and wood. HSL emission data is at the highest handle for the highest value activity. HSL upper quartile data is for all field activities.

3.4. Drills (BS EN 60745-2-1:2003)

Figure 2 also includes vibration data for drills drilling into metal. Data for impact drilling into concrete, wet diamond core and dry diamond core drilling were also obtained but are not illustrated here.

4. DISCUSSION AND CONCLUSIONS

Manufacturers' declared vibration emissions from test codes such as the BS EN 60745 series and its predecessors were not primarily designed for the assessment of human vibration exposure. However, anecdotal evidence suggests that with the lack of any other information, manufacturers' declared emissions are routinely used in this fashion, and this is actively encouraged by UK and European workplace exposure legislation. BS EN ISO 20643:2008 (ISO 20643:2005) introduced the requirement that results from emission test codes should produce "*vibration emission values and uncertainties corresponding to the upper quartile of vibration magnitudes resulting from intended uses of the machinery*". As Table 1 shows, this requirement has not yet been met.

Table 1. Summary of BS EN 60745 test code investigations.

	Hammers	Angle Grinders	Saws	Drills
Repeatable (HSL C_v < 0.15)	Yes	Yes	Yes	Yes
Reproducible (HSL $\boldsymbol{a} \leq$ manf. $\boldsymbol{a}+\boldsymbol{K}$)	33-40%*	60-100% †	50-75%*	9-100%*
Manf. emission representative of HSL field upper quartile	27%	0-80%†	0%	0-80%*
HSL emission representative of HSL field upper quartile	65-83%*	100%	25%	20-100%*

*Dependent on operating mode. Manf. = anufacturers'

†Dependent on whether single axis or triaxial emission declaration

It is not always clear from tool instruction manuals which versions of standards the manufacturers have used for vibration emission declaration. This means it is difficult to be certain whether data is single axis or triaxial, as was the case here for angle grinders. A recent revision to the European Machinery Directive (2006/42/EC) requires manufacturers to use the latest versions of the standards, in which triaxial measurements are required. Hence in future, all vibration declarations should be triaxial; tool manuals should identify which standard has been used.

Both the manufacturers' declared vibration emissions and the HSL measured emission values under-estimated exposures when compared to HSL field upper quartile values, but HSL data compare more favourably. Several factors were found likely to influence manufacturers' declared and HSL measured emissions, including:

- operating mode of the tool, e.g. drill II was capable of drilling metal, dry diamond core drilling, and impact drilling concrete, producing emissions of 2.2-15.9m/s^2;
- orientation of the tool during use, e.g. hammers produced about 30% more measured vibration when drilling vertically compared to drilling horizontally;
- accelerometer location on the tool, e.g. angle grinder measured vibration ranged from 15.1m/s^2 to 6.0m/s^2 at the outer and inner edges for the same tool handle.

The BS EN 60745 standard series still allows for a fair comparison between tool emission values. However, declared emissions are not always reproducible and may fail to warn users of the potential workplace vibration hazard.

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Assessment of Hand-Arm Vibration Exposure by Means Estimation Methodologies: Comparison Between Vibration Databases (ISPESL) and Information Provided by Tool Manufacturers

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1. INTRODUCTION

1.1. State of Implementation of Directive 2002/44/EC

Legislative Decree 81/2008 (Consolidated Act on Safety at Work) makes it compulsory to assess workers' exposure to risk through direct measurements, reference to accredited databases (ISPESL) or using emission values supplied by producers. Application of the direct measurement method is not always necessary or appropriate, due to: 1) the practical difficulty of identifying measuring conditions deemed to be representative of all actual working situations, 2) economic reasons, with the taking up of resources and time, 3) the high degree of relative uncertainty, and 4) the dearth of expert professionals in this field (Nitti et al., 2008). In this paper, we set out to cross-check and compare data obtained using the two methods, in order to gauge their reliability and to outline the pros and cons of both.

1.2. ISPESL Vibrations Database

Italian Regions (in particular Tuscany) and ISPESL have acted and are continuing to act to maintain the uniform nature of databases and insert them in a specialist Italian portal. This has led to the availability, since 1 December 2005, of a database that contains information on the vibration levels of about 1,300 work tools and 800 vehicles. The database can be consulted at the ISPESL website. As far as the ISPESL vibrations database is concerned, at least the following characteristic elements are specified: type of equipment (grinders, drills, etc.), category of equipment (rated power or size characteristics), power supply type (e.g. pneumatic, hydraulic, electric, internal combustion engine), properties of anti-vibration protection devices (handles, etc.), specific working conditions at time of measurement, speed of use (rpm, opm, etc.), type and properties of processed material.

1.3. Vibration Emission Data Supplied by Manufacturers

The first generation of harmonized technical standards on vibration emissions had been designed to satisfy the relative Essential Safety Requirements of the Machinery Directive, and to make possible comparisons between similar machines, i.e. those belonging to the same 'family'. These objectives have only been partly achieved, since the need to obtain measurements with a high degree of accuracy, repeatability and reproducibility has partly overshadowed the more important aim of informing users of residual risks. It is currently possible to compare machinery belonging to the same family, based on emission values. One of the aims of the present paper is to gauge the usefulness of these emission values. At present, however, declared emission values are often not representative of vibration levels under actual working conditions, sometimes being higher but more frequently lower.

When direct measurements and emission values are unavailable, it is possible to conduct an assessment using emission values of similar equipment, after applying correction factors given in Technical Report CEN TR 15350 for the type of equipment, for example, and the power level and supply (electrical, pneumatic or internal combustion engine). A second aim of the present paper is to gauge the reliability of this estimation method. Testing carried out by some experts in the sector, albeit limited to some families of equipment and small samples, had shown a substantial consistency between values estimated on the basis of adjusted emission values and values measured under practical operating conditions, or at least results falling within the typical accuracy range that can be obtained with measurements (Kaulbars, 2006). A study on a large scale sample of tools found that, in general, the manufacturers' declared emission data tended to underestimate the measured values under simulated workplace conditions, and adjusted emission data (after applying correction factors) tended to overestimate them (Rimell et al., 2008).

2. METHODS

Vibration emission values obtained from several difference sources - direct measurement, manufacturers' declarations, and with correction factors recommended by the CEN TR 15350 applied - were collated, cross-checked and compared. These data were analyzed, so as to describe, summarize and report on the important characteristics. The statistical Z test of means was applied to subsets of data reported by the ISPESL Database, and to relevant emission values, both adjusted (correction factors applied) and not, to compare relevant populations. Finally, linear regression analysis was done between measured vibration exposure values and declared vibration emissions, in order to test the reliability of declared values for use in ranking tools.

3. RESULTS

Vibration emission data have a statistical distribution which, as a whole, is plausibly similar to a log-normal distribution for a population of tools, and for a single type of tool. Vibration emission values from the ISPESL Database, particularly when values are available for the specific tool (in terms of type of equipment, power supply, brand, model, attachment and type of work) prove to be more reliable than estimating based on manufacturers' declared emission values, even if corrected by the factors recommended by CEN TR 15350.

Main reasons are: 1) declared emission values are often measured on a single-axis, not necessarily dominant, or for only one handle, not necessarily worst case; 2) manufacturers' data are often derived from tests performed in the laboratory and on new tools, thereby not reflecting real work conditions; 3) ISPESL Database values take into account more variables than those of the declared emission data: specific working conditions, speed of use, type of accessories, type and properties of processed material; and 4) ISPESL Database values are collected from independent sources.

With regard to the correlation between measured exposure values and manufacturers' declared vibration emission values, good correlation coefficients were generally obtained (between 0,729 and 0,977). This confirms the overall suitability of the method to compare, classify and choose equipment based on emission values declared by manufacturers, at least in the same machine family (same type of equipment and same power supply).

The declared vibration emission values, when adjusted by the correction factors, were more accurate than non-adjusted emission values. Adjusted emission values over-estimated vibration emissions by 27% on average, and under-estimated in 42% of cases. The unadjusted emission values under-estimated vibration emissions by 16% on average, and under-estimated in 73% of cases.

The correction factors used for emission values for some types of equipment were observed to be inadequate - for example, for chainsaws and electric sanders - resulting in exposure risks being under-estimated by adjusted emission values. In contrast, correction factors appeared to be adequate for concrete breakers, pneumatic drills, electric percussion and non-percussion drills, air sanders and polishers. And yet exposure risks for this group of tools were generally over-estimated by adjusted emission values, although under-estimates still occurred in 6% - 36% of cases.

4. DISCUSSION AND CONCLUSIONS

Vibration emission values from the ISPESL Database for specific tools were found to be more reliable than estimations based on manufacturers' declared emission values, or the values adjusted by correction factors. Vibration emission values declared by manufacturers, when suitably adjusted, appeared to be less reliable than the ISPESL Database values, and not conservative in a number of cases. Therefore, these values cannot be considered suitable for estimations to fulfil legal obligations.

On the other hand, the overall correctness of comparing, classifying and choosing equipment according to emission values declared by manufacturers, at least within the same family of equipment (same type, power supply) is confirmed. In the future, the accuracy of this method is expected to improve, as reference standards used to determine emission values are revised according to the new harmonized type B standard EN20642. Moreover, it will likely become possible to reliably compare and classify equipment which belongs to different families, and may be subject to different reference technical standards.

The ISPESL Database will also be extended to other physical agents (Nicolini et al., 2010). ISPESL and the Regions intend to create an Italian portal for hosting databases in four areas - noise, vibration, electromagnetic fields and artificial optical radiation. These databases are expected to include information such as certification and emission values of working equipment, risk levels measured in the field, scientific bibliography, laws and standards. The goals of this initiative are to: 1) estimate worker exposures, 2) expand and implement the current ISPESL vibration database, 3) enable identification of lower-risk equipment in the database, 4) publish examples of best practices - results, pros, cons and costs, and 5) facilitate choice of personal protective equipment based on attenuation values supplied.

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IMPACT OF EUROPEAN DIRECTIVE 2002/44/EC ON THE RISK OF DEVELOPING HAND-ARM VIBRATION SYNDROME IN GREAT BRITAIN

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1. INTRODUCTION

European Directive 2002/44/EC (OJEU, 2002) – implemented in Great Britain through The Control of Vibration at Work Regulations 2005 (CoVR) (HSE, 2005) – requires control of the risk from occupational exposure to hand-arm vibration (HAV) by:

- identifying and keeping under review, risks from vibration and the adequacy of controls;
- minimizing exposures and the attendant risks; and
- providing information and training for vibration exposed workers.

Requirements are consistent with earlier Health & Safety Executive (HSE) guidance for industry as supported by general health and safety law. The CoVR, using the methods of ISO 5349-1 (2001), lowered the exposure action value, set a limit value a little above the earlier action level, and made health surveillance mandatory for high exposures.

Employers have achieved large reductions in exposure to HAV through their choice of machinery, materials and production methods, and by reduction in the time spent using powered hand-tools. Reduced exposure has been assisted by the increased availability of powered hand-tools with reduced vibration emissions and the reduced the availability of powered hand-tools with high vibration emissions. Vibration information supplied with powered hand-tools is important for selecting low vibration machines but remains a source of confusion for employers.

Trends in risk from HAV since 1994 are reported here, based on work for the HSE with employees, employers, suppliers and their vibration advisers. Work has included inspection of workplaces, investigation of reportable cases of hand-arm vibration syndrome (HAVS) and activities to raise awareness of risks from HAV and their control.

2. HSE INTERVENTIONS ON HAVS

2.1. HSE's Workplace Interventions

A HSE sponsored study in the mid 1990s found that about 5 million people were exposed to HAV at work in Great Britain. About 40% of exposures were estimated to be above the CoVR exposure action value; half of these were above the exposure limit value. HSE anticipated difficulty for some employers to comply with the exposure limit value, and it did not become binding in some cases until July 2010. HSE offered to work with industry from 2005 – 2010 if compliance with the limit appeared difficult. HSE has sought compliance with all requirements of the CoVR (other than the exposure limit value) from their introduction in July 2005. To support compliance, HSE has updated its guidance on good practice, publicised case studies of successful management of exposure to vibration and challenged poor control of vibration risk.

2.2. HSE's Interventions With Suppliers and Others

The EC Machinery Directive (MD) (OJEU, 2006) addresses free trade and includes provisions to ensure that products for use in the workplace present minimum risks from vibration. HSE's inspections under this Directive have been designed to complement workplace interventions under the CoVR, by:

- advising that standards, which presume to conform with the vibration requirements of the MD, should promote low vibration by design, and provide information which enables use without risk from vibration; and
- researching the usefulness of declared vibration values.

In other areas, the HSE have:

- worked with the Faculty of Occupational Medicine of the Royal College of Physicians, UK (FOM) to produce a syllabus for training of medical professionals in health surveillance for HAVS;
- audited the quality of health surveillance provision; and
- intervened with other stakeholders such as consultants, suppliers of anti-vibration gloves, and suppliers of other products marketed as aids to risk management.

3. RESULTS

3.1. Rates of Injury

Industrial Injuries Disablement Benefit (IIDB) is paid for disabling cases of HAVS in specified industries and for Carpal Tunnel Syndrome (CTS) associated with exposure to vibration. Yearly totals of newly assessed IIDB payments for HAVS and CTS since 1995 are shown in Figure 1. New payments for HAVS have fallen slowly since 2004 but fell by over 60% between 2001 and 2004. Payments for CTS have varied slowly with a peak in 2003. It is too soon to see any impact of the CoVR because of the long latency of HAVS. Since 2007, IIDB has been paid for CTS not associated with vibration and for the neurological part of HAVS – payment was originally for vascular injury only.

It should be noted that employers' liability insurance makes more awards over a broader industry base, and for lesser injury, than the IIDB scheme.

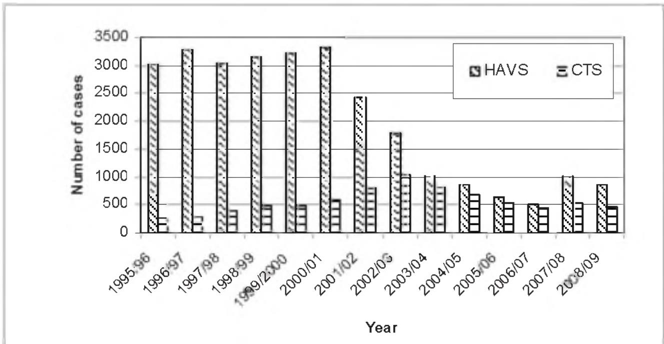

Figure 1. New IIDB Payments for Vibration Injury

3.2. Trends in Workplace HAV Controls

Employers' changes in process and re-negotiation of specifications to reduce HAV have usually been commercially rewarding in their own right. For example, use of laser-profiling machines have produced more accurate components with little need for rework and eliminating most of the exposure to HAV. Changing to non-metallic materials has reduced cost and weight of the product and fettling of plastic involves little exposure to HAV. Re-negotiation of product specifications to avoid time-consuming (cosmetic/finishing) re-work has reduced HAV exposure for the manufacturer and cost for the customer. Changing from powered hand-held tools to hand-guided machinery has brought ergonomic and production benefits alongside reduction in HAV exposure.

Employers' rationalisation of powered hand-tools and avoidance of unnecessarily high vibration models has greatly reduced HAV exposure. In 1995, there could be a factor of six between the HAV emissions of competing tools whereas now, HAV emissions are usually similar.

Many providers of health surveillance have received training according to the HSE/FOM HAVS syllabus since 2005 but there are still frequent examples of poor quality service. Large companies have generally made provision for health surveillance but many small companies have not. Health surveillance has helped set priorities for management of high risk and to prevent further cases of non-disabling HAVS – commonly reported in employees approaching retirement. Health surveillance has identified HAVS cases in some industries not previously associated with the injury.

Employers who have found it difficult to achieve control of vibration risk have usually put too much emphasis on quantification of exposure and too little on taking proven steps to manage the risk. Employers' dissatisfaction with manufacturers' declared vibration emissions has often been cited as the reason for measuring employee HAV exposures even though risk was frequently evident, alternative production methods could have been introduced and manufacturers' data generally helped compare the vibration hazard of competing tools.

There have been few cases where it has not been reasonably practicable to comply with the exposure limit value. Limiting exposure duration has often been necessary and is an example of where knowledge of the range of HAV magnitudes is necessary – possibly requiring measurement.

3.3. Supply of Lower Vibration Equipment

Where use of powered hand-tools has continued, it has often been possible to re-equip with lower vibration models. Action has often been reinforced by most of the main suppliers of powered hand-tools running campaigns promoting their lower vibration models. Hire companies are influential in the UK market and have increased the supply and use of low vibration tools by avoiding and discontinuing supply of unnecessarily high vibration tools.

Companies hiring out power tools (amongst others) have lobbied manufacturers for supply of good vibration information, including declarations representative of workplace emissions. A specification for test codes to achieve this was agreed in 2005 and reinforced by the recast MD in 2006. Improvements in the representation of workplace HAV have been seen in recently revised Standards, but weaknesses remain and vibration declarations remain unreliable for use in estimating likely workplace exposures.

4. CONCLUSIONS

Directive 2002/44/EC provided a renewed focus for control of risks from HAV in Great Britain, using an established and effective approach. It encouraged more use of vibration information provided under trading legislation.

Control of exposure to HAV has been seen to be achievable despite large uncertainties in both the vibration emissions of powered hand-tools and in employees' HAV exposures.

Investment by employers', power-tool manufacturers' and others' in compliance with legislation based on ISO 5349-1 appears to have reduced risk from HAV, but it is too soon to see an impact on the incidence of HAVS.

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CURRENT STATUS OF HAND-ARM VIBRATION SYNDROME IN CHINA – OCCURRENCE, LAWS, AND MEASURES OF PREVENTION AND CONTROL

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1. INTRODUCTION

China is the most populated country in the world, and is rapidly becoming one of the most industrialized countries as well. Many workers in China are exposed to occupational hazard factors (OHF), and hand arm vibration (HAV) is a continuing OHF for millions of workers. The use of vibrating hand tools may contribute to Reynaud's Syndrome, vibration-induced white finger (VWF), musculoskeletal injuries, neuropathies, cardiovascular effects, psychosocial stress, and mental disorders. Monitoring and detecting hand-arm vibration syndrome (HAVS) is complex, and may require specialized equipment which is not typically available to employers at workplaces, or even at some occupational hygienic institutes. Therefore, many workers exposed to HAV are not identified, monitored, examined, or diagnosed.

Aware of these problems, China now is building systems, using technical and procedural methods, to monitor HAV and related factors, conduct medical surveillance among workers, provide diagnosis and treatment of HAVS, and implement preventative measure.

This paper presents several reports of HAV exposures in China, and then outlines regulations to prevent and control HAVS, as well as the new national prevention and control program for occupational diseases.

2. PREVALENCE OF HAVS AND SOME DIAGNOSTIC REPORTS

Clinical manifestations of multiple sensory neuropathy disorders are expected to occur when a worker is exposed to hand-arm vibration for a long time. These disorders include hand-arm (mainly the elbow and wrist) bone proliferation, joint features of the hand-arm muscles and tendons disorders, and nerve trunk entrapment syndromes. Joint damage, VWF, Dupuytrens contracture and hand-arm muscle atrophy are commonly observed.

2.1 Vibration-Induced White Finger (VWF)

Since 1979, China has carried out VWF investigations of different types of work in various regions in ten provinces and cities in China. These investigations show that VWF has prevalence rates around 10%-60%[1], but may be as high as 80% or more for some types of work. In both southern and northern regions of the country, VWF was found in workers but a significant difference in occurrence between regions was observed. Workers averaged 33.8 years old, and averaged of 9.2 years of service. These studies also showed hand swelling, cold hands, and hand sweating were common early clinical symptoms for workers exposed to hand-arm vibration. Episodes of finger blanching happened most frequently before 0900h (where daytime air temperature ranged from 9-22 ℃) [2].

2.2 Joint Damage

Studies were conducted to investigate joint damage in exposed workers. Studies examined changes in x-ray images. For example, Song Hanlin, et al.[3] examined the changes of hand-bone x-rays for 143 workers who used vibrating hand-held tools. The results showed that 68.5% of workers had x-ray image changes. The extent of damage was related to the vibration exposure duration, and vibration exposure area on the hands and arms. Also, it appeared that the basis of joint pain and activity disorder pathology was articular surface hyperosteogeny, subchondral sclerosis, and joint space narrowing.

2.3 Hand Tendon Contractures

In 1982, Chang Jizeng et al.[4] investigated a group of polishing and grinding workers. Among them, 41.2% had hand tendon contractures, while the control groups had none. There were significant differences between the two groups ($P<0.01$). Liu Changting[5] examined the rivet, shovel mill, and cleaning workers, and found that hand tendon contracture rates were 18.8%, while the control group rate was 2.6%. Again, there were significant differences between the two groups ($P<0.01$).

Figure 1. Hands of workers exposed to HAVS.

Figure 1 shows the hand tendon contractures of several workers from an ironware plastic company. The workers were not able to straighten their fingers, and they suffered sharp pain [6].

2.4. HAVS Prevalence in Coal Miners

In 2009, there were more than 1.5 million coal miners in China. Most of them worked underground and were exposed to HAV. A research project investigated HAVS, using the mine workers as the exposure group, and workers in other industries and not exposed to vibration as the control group. Results showed there were significant differences between the two groups in prevalence of hydroarthrosis ($chi^2 = 7.6$, $p < 0.01$), osteoporosis ($chi^2 = 2.72$, $p < 0.05$), and osteomyelitis ($chi^2 = 4.39$, $p < 0.05$). Edema and avascular necrosis of the ossa carpi were found only in the exposed group. Hydroarthrosis and edema occurred most in the early stages of vibration exposure. This can be useful in diagnosing HAVS. Changes in the wrist joint also occurred in the early stages of vibration exposure, and could be seen on an MRI.

3. OCCUPATIONAL HEALTH LAWS AND STANDARDS

In October 1985, China published and implemented the national standard (GB4865-85): "*Local Vibration of Occupational Disease Diagnostic Criteria and Principles*". This national standard has played a positive role in promoting work on prevention and control of vibration disease.

In 2001, after enactment of the "*Law on Occupational Disease Prevention and Contro*l of P.R.China", China released several additional national standards, including "*Diagnostic Criteria of Occupational Hand-Arm Vibration Disease*" (GBZ 7-2002), "*Requirements for Vibration Hazards Reduction of Hand-Held Machines at the Workplace*" (GB/T 17958-2000), and "*Measurement and Evaluation of Vibration Transmissibility of Gloves at the Palm of the Hand*" (GB/T 18703-2002).

Recently, China further enacted "*Occupational Exposure Limits for Hazardous Agents in the Workplace. Part 2: Physical Agents*" (GBZ 2.2-2007), and adjusted the requirements of exposure limits for hand-transmitted vibration. Also issued in 2007 was the latest hand-transmitted vibration measurement standard (GBZ/T 189.9-2007): "*Measurement of Hand-Transmitted Vibration in the Workplace*". When taken together, these regulations and standards provide the basis for conducting hand-arm vibration monitoring, and for the evaluation and control of workplace hazards.

Recently, studies have been conducted to evaluate quantitative methods to assess sensations of vibration, pain, touch, and temperature. In particular, vibrotactile perception at the fingertips has been studied.

More research is being done on hand numbness, pain, sensory dysfunction, peripheral nerve injury, as well as on vibration perception thresholds and their clinical significance for assessing HAVS. Considerable progress has been made in acquiring experience and developing more consistent views[7].

Even though significant progress is being made in the field of HAV in China, more work needs to be done. There is an opportunity now for further revisions and improvements in China's national occupational hygiene and diagnosis standards, based on current interest and active participation in international standard-setting and research activities.

Therefore, the Chinese *National Prevention and Control Program for Occupational Diseases 2010-2015* has plans to: revise national standards for occupational hygiene to protect the health of workers exposed to HAV; prevent and control factors contributing to HAV; revise national diagnosis standards for early diagnosis of HAVS, based on adverse health effects of workers exposed to HAV; enhance monitoring capacity and warning levels of workplace factors that contribute to HAVS; enhance medical surveillance for workers exposed to HAV; develop occupational health risk assessment, prediction and control methods for management of HAVS; improve tools, equipment, and personal protective equipment through technical innovation and research; strengthen communication of knowledge and information for prevention and control of HAV factors; and improve treatment technologies for HAVS, especially in the use of Chinese traditional medicine.

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COMPENSATION OF HAND-ARM VIBRATION SYNDROME IN CANADA

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1. INTRODUCTION

Hand-arm vibration syndrome (HAVS) describes the vascular, neurological and musculoskeletal pathology that may arise after sufficient exposure to hand-transmitted vibration (Noel B, 2000). Though HAVS was first recognized a century ago (Loriga G, 1911), the literature suggests that it remains highly prevalent yet under-recognized (Palmer K et al., 1999, NIOSH 1989; Bernard et al., 1998). There exists a paucity of literature on HAVS in Canada, especially with respect to prevalence estimates for the condition, its recognition, and the compensation experience for HAVS claimants. To date, the only study addressing prevalence and compensation of HAVS in Canada was published by Patterson in 1986, who identified 1585 accepted claims for vibration white finger (HAVS) in the 64 years spanning 1920 to 1984 (Patterson C., 1986). A recent report from Quebec suggested under-recognition of HAVS in that province, though data were limited (Turcot et al., 2007). The objective of this study was to provide a summary of the current compensation experience for HAVS in Canada, by reviewing and comparing workers' compensation board policies, adjudication procedures and recent claims data for HAVS in Canada's ten provinces and three territories.

2. METHODS

The Compensation Boards in each province and territory were contacted to request the criteria used for the adjudication of HAVS claims in their jurisdiction. The Boards were also asked to provide the number of accepted HAVS claims in their jurisdiction for the most recent years available in their statistical records. In cases where the Board in question had no prescriptive policy with respect to entitlement criteria or diagnostic testing modalities for HAVS, an effort was made to speak with assessing physician(s) to further delineate the diagnostic approach used for HAVS in that province.

3. RESULTS

Eleven of the 12 compensation boards in Canada responded to our request for information. The initial entitlement criteria used for HAVS claims varies widely by province/territory. Six of the 12 provinces/territories require at least two years of exposure immediately preceding the onset of vascular disease before a claim is considered. In British Columbia, at least 1,000 hours of exposure is required as an initial entitlement criterion, while in the North West Territories and Nunavut (NWT & Nunavut) a claimant must have had at least 3,500 hours of exposure before their claim is considered. The other provinces and territories either do not specify initial entitlement criteria, or simply require confirmation by a specialist (i.e. sufficient exposure in the opinion of the assessing specialist).

With respect to the testing modalities used for diagnosis and impairment rating for HAVS, these also vary widely across jurisdictions. All compensation boards seem to use some form of vascular testing to confirm the presence and severity of cold-induced vasospasm and to rule out other underlying vascular pathology. The most commonly used tests are Doppler examination of the upper extremities (four jurisdictions), plethysmography (four jurisdictions) and thermometry (three jurisdictions). With respect to the neurological component of HAVS, electromyography/nerve conduction studies are used in at least four provinces/territories (British Columbia, Ontario, Quebec and the NWT & Nunavut). Testing for the musculoskeletal aspects of HAVS (using grip strength) is specified by two compensation boards: Ontario and the NWT & Nunavut.

Claims data were available from 10 of the 12 compensation boards in Canada; the province of Newfoundland and Labrador was unable to identify specific HAVS claims from their current record-keeping methods, while the NWT and Nunavut Workers' Safety and Compensation Commission did not respond to our request. There were 457 HAVS claims identified in Canada during the three year period of 2003-2005. The largest number of accepted claims was in Ontario (328) followed by Quebec (87) and British Columbia (28). The average number of accepted claims per year was 152 in the entire country, with 71.8% of these occurring in Ontario.

4. DISCUSSION

This study found considerable variation in the entitlement criteria and assessment procedures used for the adjudication of HAVS claims across Compensation Boards in Canada. The study also found the number of accepted HAVS claims in Canada to be low, compared to prevalence estimates in other comparable industrialized countries. Finally, the results showed the number of accepted claims to vary widely by province/territory.

The most common initial entitlement criterion for HAVS used by Compensation Boards in Canada is the requirement of at least two years of exposure immediately preceding the onset of vascular disease. Two Boards specify the specific number of hours required; 1000 hours in British Columbia and 3500 hours in NWT & Nunavut. The basis for these entitlement criteria is not clear, but may be based on a study by Miyashita et al. which reported that symptoms of HAVS did not typically appear until after 2000 hours of exposure in a group of forestry workers (Miyashita et al., 1982). However, latencies between exposure and the development of HAVS have been reported to range anywhere from six weeks to 14 years (Gemme et al., 1997). The wide variation in latencies reflects exposures of different magnitudes and frequencies, neither of which is addressed in the initial entitlement criteria used by workers' compensation boards in Canada. While more detailed exposure assessments may occur later in the adjudication process, current Board policies may exclude potentially affected workers from consideration (for example, those with less than 2 years of exposure to high levels of vibration).

Perhaps the most pertinent finding of this study was the small number of accepted HAVS claims in Canada compared to prevalence estimates for HAVS in other comparable industrialized countries. A Medical Research Council survey of 1997-1998 gave an estimate of 288,000 prevalent cases of HAVS in Great Britain (Palmer et al., 1999). In the United States, there were an estimated 1.45 million workers exposed to HAV in 1983 (NISOH 1989), fifty percent of whom could reasonably have been expected to have developed HAVS (Bernard et al., 1998), providing an estimate of 725,000 prevalent cases in the U.S. Using these approximate prevalence estimates while accounting for differences in population, one could postulate between 72,000 to 144,000 prevalent cases of HAVS in Canada. With only 457 accepted claims identified in Canada over the period of 2003 to 2005, significant under-recognition and/or under-reporting is suggested.

Not all compensation boards include HAVS as a specific diagnosis for statistical record keeping purposes, so it is possible that the study was affected by outcome misclassification, resulting in under-estimation of the actual number of HAVS related claims. If this were the case, the number of misclassified HAVS claims would have to be significant to account for the degree of under-reporting suggested by this study. The difference in concentration of claims by province (71.8% of all claims were in Ontario) may be attributable to the fact that Ontario is the only province that has a university-affiliated hospital-based clinic dedicated to the detailed clinical assessment of workers with HAVS in the country. This may result in higher recognition and reporting of HAVS in Ontario. Also, some provinces may have a lower prevalence of occupational HAV exposure. But the construction industry is present in every province, so that cases would be expected in every province.

This study identified wide variation in assessment procedures used for HAVS claimants across the country. In particular, there does not appear to be any clear case definition for HAVS in any of the Board Policies, and many jurisdictions only recognize one or two of the three systems affected in HAVS. While the vascular component of HAVS is recognized by every Board, the neurological component of HAVS is recognized by less than half, and the musculoskeletal components by even fewer. This reflects the complexity of HAVS diagnosis; at present, no single test (vascular, neurological or musculoskeletal) has a demonstrated sensitivity and specificity to allow it to be used as a stand-alone diagnostic tool for compensation purposes. As such, diagnosis must necessarily be based on the overall clinical presentation of each individual worker, with the overall conclusion with respect to the presence and severity of each component of HAVS being made by an experienced occupational medicine physician after carefully considering the worker's history, physical examination and as many objective test results. While such an approach precludes application of an algorithm for diagnosis, it does not mean that a more loosely based case definition cannot be developed and applied across jurisdictions.

In summary, this study suggests under-recognition and/or under-reporting of HAVS in Canada. The results also show significant variation in the compensation experience for HAVS across the Canadian provinces and territories, calling for refinement of the entitlement criteria, case definition and assessment procedures used for the adjudication of HAVS compensation claims in Canada.

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Review of Legal Suits Involving Hand-Arm Vibration

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1. INTRODUCTION

While Carpal Tunnel Syndrome is a household word, Hand-Arm Vibration Syndrome has been largely unknown to the American industrial community until recently. Increased awareness of vibration-induced trauma to the upper extremities has led to an increased number of legal suits filed on behalf of workers over the past decade. Additional reasons for the increase in legal suits include overall awareness of ergonomic hazards in the workplace, passage of standards of the United States and in Europe, and increased worker awareness of the symptoms of Hand Arm Vibration Syndrome.

The legal community's increased awareness of the potential hazards of hand vibration exposure is also related to the possibility of significant settlements, particularly in areas that are not covered by no-fault workers compensation. This presentation will outline the characteristics of these lawsuits, the medical issues involved, and the strategies of both defense and plaintiff attorneys as noted in a particular occupational medicine practice. Specific lawsuits will not be referenced, in order to protect employee and company confidentiality.

2. LAWSUIT CHARACTERISTICS

As would be expected, most legal suits have involved industries where the use of intensely vibrating hand-held tools is still required. While legal claims have been made in many industries ranging from energy to manufacturing companies, the most common suits have been in the maritime and railroad industries. This is not surprising, as these industries are not covered by limits in workers compensation, thus allowing for higher settlements. Furthermore, these two industries have been often been less progressive in accepting vibration as workplace hazard, and have often denied outright that vibration is a hazard at all.

It is interesting to note, in contrast, that hearing loss programs have been in place since the 1970's, that noise is well accepted as a hazard and is closely monitored by periodic testing, and that there is a strong emphasis on noise protective equipment. Analogous programs for vibration exposures are, for the most part, nonexistent in the same companies.

Unfortunately, the observation has been made that it takes one or two multi-million dollar losses from such cases, to bring about modification of safety policies to include vibration prevention as part of safety program. A legal claim of this kind does, however, require the establishment of causal relationship between the employment tasks and the alleged medical pathology.

A number of particular medical patterns have been noticed in these cases. It is common to see that individuals with upper extremity complaints are often initially diagnosed with carpal tunnel syndrome or other entrapment disorders, as well as with various tendinopathies of the upper extremities. It is not uncommon to see multiple surgeries performed, before the patient and his insurance providers appreciate the nature of the residual medical symptoms and problems. Often, patients undergo surgery with only partial relief of the symptoms, as the pathology from hand-arm vibration syndrome is simply not appreciated by their treating practitioners.

In reviewing the medical records, vibration is often not noted as part of the occupational work history by either the primary provider or the surgeons. In addition, there is wide-spread lack of physician knowledge or appreciation for vibration-related upper extremity traumas. In many States, compensation schedules do not include an official specific statute for this condition to determine permanent partial disability ratings.

The most common medical presentation is carpal tunnel syndrome plus lateral epicondylitis, followed by residual numbness in the fingers, hand weakness and various levels of Raynaud's symptoms. While some cases tend to try to include cervical pathology as additional claims, these larger claims are rarely successful, as there are usually alternative explanations, such as direct trauma or degenerative changes that explain the neck pathology.

Confounding factors that may cause similar neurological or vascular symptoms may be present in the worker such as diabetes, collagen vascular disease or other neuropathies, but often the severity and progression of disease is more than one would expect from the confounding factors alone. Furthermore, one can never ignore smoking as a contributory factor. Of interesting note, it appears that females doing similar jobs with high vibration exposure have been noted to develop symptoms considerably faster and earlier then their male counterparts.

3. LEGAL STRATEGIES

For a successful lawsuit, the plaintiff strategy must not only establish the diagnosis, but must also establish that there is sufficient exposure history from the nature and duration of the employee's occupation.

Furthermore, it must be ascertained that there are not alternative or additional factors, in terms of other diagnoses, that would explain the same condition. In addition, non-work-related vibration exposures need to be ruled out.

The more difficult cases involve workers who have had similar vibration exposures from employment with various companies in the course of their careers. Attribution of causal factors and allocation of responsibilities among the various jobs worked can often be difficult. One cannot simply rely on the medical evidence to establish the causal relationship.

There must also be strong evidence that the vibration exposure has been long enough and sufficient to cause the pathology observed, taking into account the current standards. This involves thorough, reliable and accurate tool testing by someone qualified to perform this task in a defensible manner.

Often in a case for damages, multiple diagnoses are claimed to be caused by, and related to the job, to accentuate the level of disability. This requires not only employment of physicians knowledgeable in vibration-related pathologies, but also engineering expertise with the skills and experienced to determine levels of vibration exposure. On-site inspection by both medical and generic experts is often very helpful in evaluating the case.

Defensive strategy revolves around finding alternative explanations for the pathology, from other medical conditions, from non-work-related exposures, or by establishing that the diagnoses are not correct. It is helpful in establishing a medical defense to find evidence of alternative medical diagnoses that can cause similar medical presentation and symptoms. Establishment of alternative medical diagnosis or explanation can often lead to dismissal or minimization of damage is in such cases. This requires a thorough investigation of the injured worker's entire medical and work history, as well as medical testing.

While contesting limited work history and vibration exposure in the course of employment can be difficult, time-consuming and costly, it can be a very effective way of dismissing the claims, if it can be shown that insufficient vibration exposure had actually occurred. In contrast, simply denying that vibration can cause problems has not proven to be effective defense and can often lead to further problems, for example, the employer may be charged to have failed to proper warn the workers of the vibration hazard. Similarly, the claims of lack of knowledge also have not proved to be effective, in light of the plethora of the literature available concerning this problem.

4. CONCLUSION

Injury claims from hand-arm vibration are becoming more common. It appears some companies are initially led to believe that they can summarily dismiss these lawsuits as an initial strategy based on internal and external counsel. This strategy only seems to cost time and money, but the problem remains.

In the absence of strong regulatory control of vibration exposure for workers, these lawsuits provide a strong incentive for companies to modify their policies and workplace practices toward this hazard, to avoid legal entanglements in the future.

These legal suits may therefore have had a beneficial effect for the working population in general, as many companies are finally finding that it is more cost-effective to provide prevention and a proper work environment than to continue to fight or lose lawsuits.

The growth in the number of these claims in the future will be affected by awareness of the problems. But growth in claims may be mitigated by the decreasing number of workers exposed the high levels of hand-arm vibration. Fortunately, while the number of jobs requiring high vibration exposure to the upper extremities is decreasing, awareness of the problems is increasing, standards concerning vibration exposure are improving, and industries are more commonly accepting the value of ergonomic prevention. Therefore, these legal cases should become less frequent in the future.

Glove Use and Education in Workers with Hand-Arm Vibration Syndrome

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1. INTRODUCTION

Hand-arm vibration syndrome (HAVS) is an occupational disorder with vascular, neurological and musculoskeletal symptoms in the upper extremity developing after exposure to hand-transmitted vibration. The literature is relatively silent with respect to actual experiences of workers regarding training and education related to the use of gloves in the prevention of occupational diseases such as HAVS.

There is some evidence that anti-vibration gloves, certified according to International Standards, effectively prevent and limit the development of HAVS (Jetzer et al., 2003, Mahbub et al., 2007). The use of work-appropriate gloves not only benefits the employee by improving comfort, reducing fatigue and protecting against disease, but also benefits the employer by improving productivity and decreasing health-related expenditures associated with employee illness (Jaeger, 2006, Garner, 2001, Shibata and Maeda, 2008). It is important to educate workers regarding appropriate glove use as a preventive measure.

Despite the aforementioned benefits of wearing gloves, many workers exposed to hand-transmitted vibration are not compliant with their use. Reasons include bulky glove designs, loss of dexterous movements, decreased ability to manipulate workplace objects, and decreased comfort (Jaeger, 2006, Akbar-Khanzadeh et al., 1995). Furthermore, without appropriate glove education, some employees may use gloves inappropriately. In terms of glove provision, the high costs of specialized gloves and the need for frequent replacement may deter employers from supplying such appropriate safety equipment (Jaeger, 2006, Shibata and Maeda, 2008). The literature is silent regarding the current state of glove use and education for workers who have developed HAVS.

The objective of this study is to describe the current education practices related to glove use and the relationship between glove use education and glove use compliance

2. METHODS

The study was approved by the Research Ethics Board at St Michael's Hospital and the University of Toronto.

2.1. Questionnaire

A self-administered questionnaire was developed for this study with input from the inter-professional research team at the St. Michael's Hospital Occupational and Environmental Health Clinic (SMHOEHC). The questionnaire was 7 pages in length, including a total of 38 questions exploring the following themes: participant demographics, workplace characteristics, workplace exposures, protective glove characteristics, glove use compliance, provision of glove use education, and glove supply characteristics.

2.2. Participants

Participants included consecutive patients presenting to SMHOEHC in Toronto, Ontario for investigation of HAVS. On arrival at the Clinic they received information about the study and the questionnaire to complete. Data collection occurred from March to May 28, 2010, inclusive.

2.3. Data Analysis

One hundred and two of 106 HAVS questionnaires distributed were returned, resulting in a response rate of 96%. Of those 102, 9 were excluded due to incomplete responses or multiple conflicting responses making the questionnaire responses invalid. A total of 93 were used for data analysis.

The data were entered and analyzed using SPSS version 16.0. Frequencies and percentages were calculated on all binary and categorical data. Descriptive statistics were thus performed to: (1) determine percentage of workers presenting with HAVS that wear gloves; (2) determine when education was received by workers; (3) determine methods of education provision to workers; (4) determine content of information provided to workers, and; (5) determine workers' perceived barriers to glove use. To determine if any correlations were present between education of workers and glove use, a Pearson chi-square test (Fisher's Exact test) was performed.

3. RESULTS

The mean age for HAVS workers was 50 years and all were male. Forty two percent were not working at the time of questionnaire completion, 72% lived in urban regions, and 67% had been employed for more than 20 years. Seventy one percent were employed in the construction sector, and 13% in the electrical sector. Eighty seven percent worked in unionized workplaces. Of those not working, 20% noted that their HAVS was the reason they were not working.

Eighty-eight percent reported the presence of a workplace joint health and safety committee, 87% reported receiving occupational health and safety training, and 97% reported receiving Workplace Hazardous Materials Information System (WHMIS) training.

3.1. Glove Use and Education

Eighty seven percent of HAVS participants have worn protective gloves at some point during their career. Sixty seven percent reported wearing some type of gloves when exposed to workplace hazards, however, 87% of these workers did not wear the most protective form of anti-vibration glove.

A minority of workers received protective glove use education either in school (7%) or work (45%). Predominantly, glove education was provided prior to work initiation (60%), but the second most common time for education provision was more than one year after employment started. Employers were primarily responsible for educating these employees with the most frequent method of delivery being seminars (37%) or videos (25%). The two most common components of education were tasks necessitating glove use (31%), appropriate glove type for a given task (26%), and glove disposal (19%).

3.2. Barriers to Glove Use

The perceived barriers to glove use include, in descending order: lack of supply, decreased comfort, and feelings of restraint and bulkiness. Ninety two percent of patients with HAVS stated employers were responsible for supplying gloves, and 25% of HAVS participants did not receive gloves having requested them from their employer.

3.3. Correlation Between Glove Use and Education

Pearson chi-square analysis revealed a statistically significant relationship between workplace education and glove use; those who reported wearing gloves were more likely to report having received education ($p<0.005$).

4. DISCUSSION AND CONCLUSIONS

The findings suggest that most workers received basic occupational health and safety training, and training related to hazardous workplace materials. This may be partly due to the fact that the majority of workers worked in unionized environments. Glove education and training was reported by a minority of workers. The reported delivery methods for training and education varied with the two most common being seminars and videos. Seminars have the potential to allow hands-on training with the workers being able to ask questions. This method would facilitate the opportunity to try on different types of gloves and determine appropriate glove size. Attention to such details might increase workers' use of appropriate gloves.

The barriers workers reported to glove compliance included discomfort and difficulty using the gloves because of restraint and bulkiness. These are similar to what others have reported (Jaeger, 2006; Akbar-Khanzadeh et al., 1995). However, the workers raised the additional issue of lack of availability of gloves. This may be a problem with glove availability at the worksite as well as being readily available at local stores. Both these factors would impede workers from using the appropriate anti-vibration gloves. It also raises the question of who is responsible for supplying workers with their protective equipment. This may vary depending on the jurisdiction. On a positive note, workers who reported receiving training were more likely to report the use of gloves. Whether this is totally due to the training and education they received or whether it reflects other facilitative aspects of their workplace is not known. A workplace that provides training and education may also be more likely to supply gloves and encourage their use than organizations that do not provide education and training. While it is not possible to be certain, it does suggest that the provision of education and training is associated with improved glove use.

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POSTER PAPERS

CLINICORADIOLOGIC CHARACTERISTICS OF SHOULDER PAIN AMONG PATIENTS WITH HAND-ARM VIBRATION SYNDROME

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Federal State Scientific Institutional «Ekaterinburg Medical Research Center for Prophylaxis and Health Protection in Industrial Workers», Ekaterinburg, Russia

The main reason for forced change of profession and disablement of patients with HAVS is progressive pathology of the musculoskeletal system including pathology of the shoulder. Neuro-orthopedic examination and radiography of shoulder joints were made for 41 patients with HAVS. The average age of patients was 43.4± 0.6 years. Almost all patients (95.1%) had shoulder pain, on the right side - 16 (39.0%), and on the left side - 14 (34.1%). Pain during abduction of the shoulder in the range of 160 - 170° was found in 35 patients (85.3%), and during abduction of shoulder in the range of 60 - 120° in 7 patients (17.1%). Pain during resistance abduction was found in 19 patients (46.3%). Symmetrical ambilateral myofibrosis was often apparent in the supraspinous muscle (70.7%), in the infraspinatus muscle (60.9%), in horizontal portion of trapezius muscle (75.6%), and in the deltoid muscle (46.3%). In 85.4% of cases, localized pain was revealed in the projection of the acromioclavicular joint. During radiography of shoulder joints, acromioclavicular arthrosis was diagnosed in 91.7% of patients, and sclerosis of the greater tubercle of the humeri in 83.3%. Calcinosis of the chondral labium of the glenoid cavity was detected in 50% of patients on the right side and in 33% of patients on the left side. In 16.7% of cases, cystic formations were detected in the head of humerus. Acromioclavicular arthrosis and rotator cuff tear are frequently detected among patients with HAVS.

PAIN SYNDROME FROM EXPOSURE TO LOCAL VIBRATION

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Local vibration damages sensory nerve fibers, causing demyelination in the distal or proximal parts of nerves. Excessive cooling and physical stress increase the risk of injury to neural structures. Neuropathic and nociceptive mechanisms were determined in the development of the pain syndrome in various diseases of the peripheral nervous system. The first step for studying the neuropathic component of pain was DN4 questioning in 2 groups. Group 1 contained 190 miners working in an iron ore mine for more than 5 years. Group 2 contained 44 patients with HAVS. Those who scored 4 or more on DN4 were questioned with Pain Detect (PD). Twenty-seven (14.2%) miners and all patients with HAVS scored 4 or more on DN4. The prevalence of responses with scores 4 or more was significantly higher ($p < 0.05$) in group 2. We obtained a reliable difference in the scores over 18 on PD between patients with HAVS and a group of miners ($p < 0.045$). In the group of miners, we found a weak correlation between scores on the DN4 and PD (level of significance - 0.54), while in the group of patients with HAVS, we found a direct correlation between positive results on the existence of a neuropathic component of pain (DN 4) and scores for PD.

INTERNATIONAL COMMISSION ON OCCUPATIONAL HEALTH SCIENTIFIC COMMITTEE ON VIBRATION AND NOISE

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The International Commission on Occupational Health (ICOH) is an international non-governmental professional society whose aims are to foster the scientific progress, knowledge and development of occupational health and safety in all its aspects. It was founded in 1906 in Milan. Today, ICOH is the world's leading international scientific society in the field of occupational health with a membership of 2,000 professionals from 93 countries. The mission of the ICOH Scientific Committee is to facilitate the process from research to practice and from practice to research. The Committee is planning position papers on the main themes: medical surveillance, screening and prevention of workers exposed to hand-arm vibration; noise in the entertainment industry, and; whole body vibration and shock measurement, health effects and prevention. Professionals sharing the Scientific Committee's mission are welcome to join. To be a member of the Committee, ICOH membership is required and can easily be obtained: see www.icohweb.org.

EFFECTIVENESS OF TWO SYSTEMS OF DAMPING HANDLES FOR VIBRATION ATTENUATION

Enrico Marchetti[1], Raoul Di Giovanni[1], Angelo Tirabasso[2], Pietro Nataletti[1], Alessandro Lunghi[1], and Federica Morgia[1]

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We studied two damping handles suitable for substitution for the standard handles on existing electric tools. The handles employ two different principles for reducing vibration at the hand of the worker: uncoupling, and mass. Given the difference in performance of these two damping systems, we studied also a protocol for simulating "in field" measurements for after-market handles. The experimental position was an extended arm forming an angle of 90° with the standing body. The signal on z axis was provided by an RMS SW 1508 vibration exciter with a mount for connecting handles, which had a flat frequency spectrum between 6.5 and 1250 Hz, and rms acceleration of 5 m/s^2. The system did not have any mechanical resonance. Measurements were done with an accelerometer lodged in an adapter positioned between the hand and handle. Grip force was monitored (to be kept constant), and transmissibility was evaluated. Handles with and without damping systems have been tested. A comparison shows that there is damping but, while at high frequency it is good for both handles, at low frequency it is poor for one of them. The transmissibility assessed with the flat signal and the signal of a typical tool (drill) showed coherent behaviour. The two handles tested did not perform in the same way: one only shifts the frequency, the other dampens effectively. The testing system is suitable for more general use. We will improve the protocol for simulating "in field" measurement.

USE OF AIR BLADDER TECHNOLOGY APPLIED TO TOOL HANDLES TO REDUCE EXPOSURE TO HAND-TRANSMITTED VIBRATION

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Air bladders made from bonded sheets of urethane thermoplastic films have successfully been used in anti-vibration gloves to attenuate vibration transmitted to the hands from vibrating machine handles and work pieces. This poster presents the results of using a form of this technology, adapted for use on machine tool handles. The presentation describes the structural form of the handle bladders and how they are attached to the machine handles. Two applications are presented: use on the steering wheel of a military off-road vehicle, and use on the non-trigger side handle of a horizontal pneumatic grinder. Procedures outlined in ISO 5349 and ISO 10819 are used for the vibration measurements. With regard to the grinder tests, the results of the vibration measurements are presented with and without an auto-balance bearing, with an unbalanced ISO disc, with a new and unused grinder wheel, and with a badly worn and unbalanced grinder wheel.

EVALUATION OF ANTI-VIBRATION GLOVE TRANSMISSIBILITY WITH CHIPPING HAMMER

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Chipping hammers are widely used for demolition tasks in industries. Due to their heavy weight, faster speed and greater vibration as compared with other power hand tools, there is a greater risk of musculoskeletal injury in the hand-arm system. In long-term repetitive use of such power tools, musculoskeletal injuries may lead to several cumulative trauma disorders, e.g., carpal tunnel syndrome, vibration-induced white finger, etc. However, investigations have shown that vibration hazards can be controlled and their risks can be minimized by certain precautions taken by the operator. The objective of this study was to control vibration generated by a chipping hammer. A pilot experiment was conducted to evaluate the risk while operating a chipping hammer, and for different positions of the hand-arm system. Vibration recording was done using a tri-axial accelerometer and LABVIEW code. The FFT analysis was done using MATLAB. The results revealed vibration levels were high, and there was much vibration transfer from tool body to hand. Some vibration reduction technique was needed. Nine pairs of different types of anti-vibration gloves were studied to assess reductions in vibration transferred to the hand-arm system. All the experiments were done as per the pilot experiment. Results indicated that gloves made of natural rubber blend (Pair-1), natural rubber silver lined (Pair-2) and leather (Pair-5) were the best among the nine pairs of evaluated gloves for reducing vibration transmitted to the hand-arm system.

CHANGES IN VIBRATION AND MECHANICAL PERFORMANCE OF HIGH SPEED AIR TURBINE DENTAL HANDPIECES DURING CLINICAL USE

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The vibration levels of high speed air turbine dental handpieces were tracked throughout actual clinical use cycles until handpeice failure. Other mechanical performance characteristics, such as sound emission and turbine balance, bearing resistance, stall torque, and power were also tracked to study the influence of wear on mechanical performance. Three types of air turbines, i.e., OEM, aftermarket, and refurbished turbines, were considered, in order to understand differences in handpiece configurations. Four commonly-used handpieces were chosen, based on widespread use in dental practices within the United States. Nine handpieces of each design were divided into three groups of three, with each group randomly assigned to incorporate OEM, aftermarket, or refurbished turbines. The 36 handpieces were randomly distributed to participating dental practitioners for clinical use. Measurements for vibration and the other mechanical performance characteristics were taken before distribution, as a baseline, and at intervals of 150 clinical use cycles until handpiece failure. Baseline results show differences between handpieces and between the three turbine groups of each handpiece. Preliminary results suggest that mechanical wear of the turbine influences vibration and mechanical performance.

ASSESSMENT OF DAILY EXPOSURE TO VIBRATION WITH A DEDICATED MEASUREMENT INSTRUMENT AND SOFTWARE TOOL

Daniel Vaucher de la Croix[1], Charles Gagne[2], Luc Pellerin[2], and Christine Aujard[1]
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Directive 2002/44/EC addressing the risks arising from exposure to vibration at the work place has been transcribed into national laws in European Member States. This Directive deals with the determination of limits and action values for daily exposure to vibration. Two physiological domains are addressed: “hand-arm” and “whole-body”, the acceptable statutory values of which are specified in the Directive. The experimental protocol, as well as indicators relevant for assessment, are defined in ISO 5349-2 and ISO 2631-1. The equivalent frequency-weighted acceleration shall be measured on 3 axes, x, y and z, the bandwidth of which is defined for each domain. In 2008, 01dB-Metravib introduced a new portable instrument perfectly meeting the requirements of this statutory application. A blind metrological instrument connected to a tri-axial accelerometer can be installed on site. The instrument is remotely controlled by the operator using a wireless remote control of the Pocket PC type. This remote control can be used to manage measurement configurations (“whole-body”, hand-arm”), to start acquisitions (immediate, delayed mode) and to collect measured data for post-processing and archiving purposes. This presentation focuses on metrological and operational advances associated with this new instrument and describes a real case study dealing with the assessment of daily exposure to vibration. The results obtained based on the case study in Québec highlight possible differences between European Directive 2002/44/CE and local equivalent standards in Canada.

FUNDAMENTAL STUDY OF VIBROTACTILE PERCEPTION THRESHOLD ON JAPANESE - NEW MEASUREMENT EQUIPMENT FOR VIBROTACTILE PERCEPTION THRESHOLD

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The purpose of this research is to report in detail on a newly-developed measuring instrument complying with ISO 13091-1 (2001). The specifications of the new measurement equipment are shown in Table 1. Using a built-in printer, this measurement equipment can print records of all results that are specified by the standard. Moreover, the response level and the probe contact force can be recorded at the same time. This report presents the first device in Japan based on the ISO13091-1(2001) and JIS B7763-1(2009) standards.

Table 1. Main specifications of the new measurement equipment

■Stimulus frequencies -
3.15, 4.0, 5.0, 20, 25, 31.5, 100, 125, 160 Hz
■Skin-stimulator contact -
Method B (with surround), surround 10 mm, Surround force 2 ±0.3 N
■Stimulating probe -
Contact area 6 mm diameter, probe contact force 1 N±0.3 N
■Psychophysical algorithm -
Variant of up–down, or von Békésy
■Skin surface condition -
Thermistor thermometer (resolution 0.1°C)

Canadian Acoustical Association

Minutes of the Board of Directors Meeting
Mississauga, Ontario
07 May 2011

Present: Christian Giguère (chair), Dalila Giusti, Bradford Gover, Tim Kelsall, Rich Peppin, Ramani Ramakrishnan, Frank Russo

Participating by Videoconference: Stan Dosso, Roberto Racca, Clair Wakefield (in Victoria); Hugues Nélisse, Jérémie Voix (in Montréal); Sean Pecknold (in Dartmouth).

The meeting was called to order at 10:00 a.m. Minutes of the Board of Directors meeting of 12 October 2010 were approved as published in the December 2010 issue of *Canadian Acoustics*. *(Moved R. Peppin, seconded R. Ramakrishnan, carried).*

President's Report

Christian Giguère reported that it has once again been a busy half-year for the CAA.

The main priority remains the transition to online membership and database management capabilities (discussed below as an extension to the Secretary's report). In addition to planning of CAA annual conferences, the CAA has continually been liaising with other organizations regarding participation in or co-sponsorship of their meetings (discussed below under CAA Conferences, and Other Business). These activities are part of the ongoing effort to maintain and increase the visibility and relevance of the CAA.

Christian also reported that he is now in his fourth year as President of the CAA, and plans to seek re-election in the fall of 2011, but would prefer to "pass the torch" by 2012.

Secretary's Report

Bradford Gover reported that routine processes of the Association are proceeding normally, despite the delays associated with implementing the online membership system.

Routine mailings, bank deposits, annual filing correspondence, membership database management and other secretarial operational issues were handled as usual. The secretarial account balance was $651 as of early May. Anticipated expenses for the remainder of the fiscal year are not likely to exceed this amount.

Invoices for 2011 membership dues were delayed, and sent only in mid-April. Due to difficulty in processing some payments last year, some of the 2011 invoices included outstanding fees for 2010. The current tally of membership does not yet include all expected renewals for 2011, but projecting the number of renewals based on previous years, the membership is essentially on par with 2009. This is evidence of a strong core membership, and is in line with the membership count in the recent past.

Category	Paid as of 7 May 2011	Projected 2011	Paid Sept 2009
Member	109	256	245
Emeritus	2	2	1
Student	23	60	60
Sustaining	23	50	42
Direct	5	2	4
Indirect	18	18	22
Total	**178**	**401**	**374**

Efforts will continue to collect payment of 2011 dues, and to get back on track with respect to invoicing schedules.

(*Acceptance of the report moved by R. Peppin, seconded T. Kelsall, carried.*)

Regarding invoicing schedules, it was suggested that the "fees due" date be moved, to facilitate payment of membership dues for the upcoming year at the October conference. The plan is that starting this year, membership will be invoiced for 2012 dues sometime in September, with the payments due on 1 November 2011.

(*Acceptance of the proposal moved by D. Giusti, seconded T. Kelsall, carried.*)

Rich Peppin noted continued interest in establishing a “Life Member” process, in which a member could pay an increased fee in one calendar year, and not have to pay again thereafter. The Board agreed to consider the idea, and to gather information on how this is handled in other organizations.

The Board also discussed the notion of a “Fellow” designation for members. This would be a merit-based title that could be awarded by a committee to recognize contributions to the CAA and its goals. Frank Russo agreed to work with Stan Dosso and Rich Peppin to define Terms of Reference for implementing the concept, and for the required committee that would administer it.

Regarding the new online system for membership management and fees payment, it was decided to proceed as rapidly as possible, with a goal of having the system in place by fall.

Treasurer’s Report

Dalila Giusti distributed a brief report summarizing the current financial situation.

Dalila indicated that the CAA finances are in reasonable shape, with nothing new to report. Revenues from membership dues and journal advertising are continuing to be collected.

The interest earned on investments is covering award expenses, as planned. At the 2010 Conference, $5450 was distributed in awards, compared to $7800 earned in interest. Dalila reported that not all planned student travel subsidy funds were awarded since numerous applicants did not provide receipts for expenses they were claiming. It is to be made clear to applicants that receipts are mandatory.

(*Acceptance of the report moved by B. Gover, seconded S. Pecknold, carried.*)

Editor’s report

Ramani Ramakrishnan reported that production and distribution of the journal *Canadian Acoustics* has been proceeding normally. Ramani thanked Rich Peppin for his successes in handling advertising for the journal.

One continuing concern regarding the journal is the cost of mailing paper copies, particularly outside of Canada. On a trial basis, starting with the June 2011 issue, a pdf version is to be offered to subscribers outside of Canada, to keep mailing costs down.

Ramani reminded the Board that he is planning to step down as Editor in Chief as of October 2012. He would like to use the time until then to assist the transition to a replacement. Any individuals interested in being considered as the next editor are asked to contact Ramani.

CAA Conferences – Past, Present & Future

<u>2010 Victoria:</u> Conference Chair Stan Dosso provided the Board with a final report that indicated the conference was highly successful from a technical, attendance, and financial point of view. There were 110 technical papers and 3 keynote lectures presented over 2.5 days. The conference attracted 162 registrants, and 16 organizations took part in the Exhibition. The conference was run entirely by volunteers, and qualified for a “carbon friendly” designation. Net proceeds from the conference were $19,376. The Board thanked Stan and the entire 2010 Conference Organizing Committee for their successful efforts.

<u>2011 Québec City (12-14 October):</u> Conference Chair Christian Giguère reported, on behalf of the organizing committee, that the organization of the conference is on schedule and proceeding well. The venue (Hôtel Château Laurier Québec) and logistics are finalized, and the website is up and running. Technical co-chairs Jérémie Voix and Hugues Nélisse reported that planning for technical sessions and keynote lecturers is well underway. Watch for the latest information in *Canadian Acoustics*, and on the website.

<u>Subsequent meetings:</u> Christian Giguère reported on the continuing difficulty of attracting a convener for the 2012 conference. One location which is being considered is Winnipeg. He will follow up in the next few weeks and get back to the Board.

Awards

Frank Russo reported that certificates and cheques for 2010 prizes were recently sent out. All award coordinators have agreed to stay on for 2011, although there is the need for a substitute coordinator for the Shaw Postdoctoral Prize, due to a conflict of interest. Frank is working to identify a suitable substitute. The deadline for most 2011 awards has already passed (April 30), and a number of applications have apparently been received.

There was discussion of the proposed monetary value of two new student awards approved in principle by the Board at the last meeting: one in the field of "Architectural Acoustics", and in the field of "Psychological Acoustics". Frank will work with others to identify a proposed award structure that will keep the total award pay out less than the interest earned on investments, and also respect any pre-existing constraints on award values.

Acoustical Standards Committee

Tim Kelsall reported that the new CAA Acoustical Standards Committee has now had two meetings, the most recent being last October in Victoria during the CAA conference. Efforts are being made to synchronize meetings and activities with CSA S304 Occupational Noise Technical Committee. The next meeting of both committees will be 19 May 2011, with a subsequent meeting in Québec City in October, during the annual CAA conference.

Efforts continue to formalize the transfer from CSA to CAA of the Z107.10 standard "Guide for the use of Acoustical Standards in Canada". In addition, discussions are underway with key stakeholders regarding the as-yet-uncertain future of the Z107.9 standard "Standard for Certification of Noise Barriers".

CAA Website

Sean Pecknold has been routinely updating the website. There is nothing special to report regarding website content, other than the need to keep the membership application page current as the online functionality becomes available.

Other Business and Issues

There were several items of other business:

- The CAA is an official sponsor of the 12th International Conference on Hand-Arm Vibration (HAV), to be held in Ottawa 13-17 June 2011. The proceedings of HAV 2011 are published as the June issue of *Canadian Acoustics*. The Board received an update regarding the status of the conference and discussed worst-case financial projections that could possibly impact the costs to the CAA of production and mailing of the proceedings issue. The Board will remain in close contact with HAV organizers and will continue to monitor the situation.
- The Board discussed how we can continue to co-operate and co-sponsor conferences and events with other professional associations.
- The Board once again discussed the idea of creating an "Education Coordinator" to compile and maintain a compendium of Canadian university training programs related to acoustics. Progress on this has been made sporadically in the past, and Jérémie will follow up with key persons.

Adjournment

Meeting adjourned at 2:45 pm. (*Moved by D. Giusti, seconded T. Kelsall, carried*).


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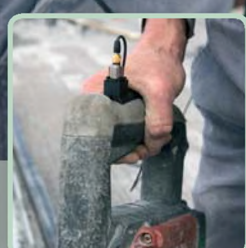

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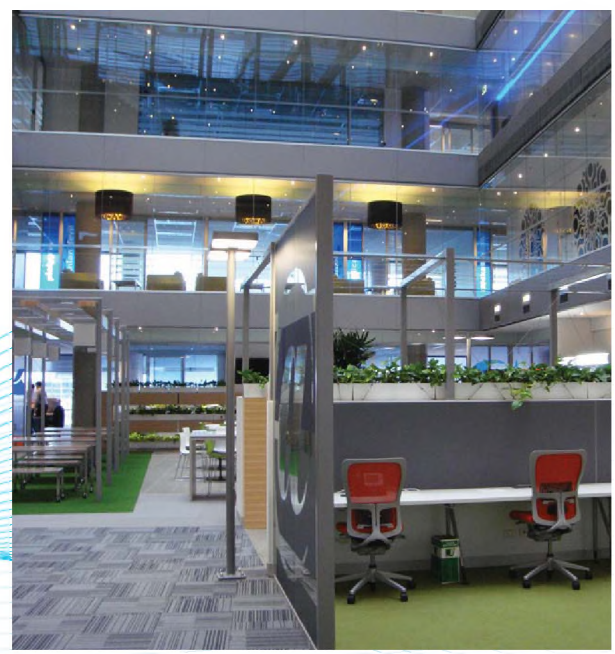

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POSITION OPEN - Assistant Editor, Canadian Acoustics Journal

The current Editor-in-Chief, Ramani Ramakrishnan, will be stepping down in 2012. A new Editor will be elected during the Annual General Meeting (AGM) in October 2012 and will become the new Editor-in-Chief from 2013 onwards. CAA is looking for an Assistant Editor who will work with Ramani Ramakrishnan and will be trained to be the next Editor. He or she will be nominated during the 2012 AGM and it is hoped that the membership will vote him/her to be the Editor-in-Chief.

The current proposal is to aid in the smooth transition from Ramani Ramakrishnan to the new Editor.

Interested person should contact either the president, Christian Giguère or Ramani Ramakrishnan.

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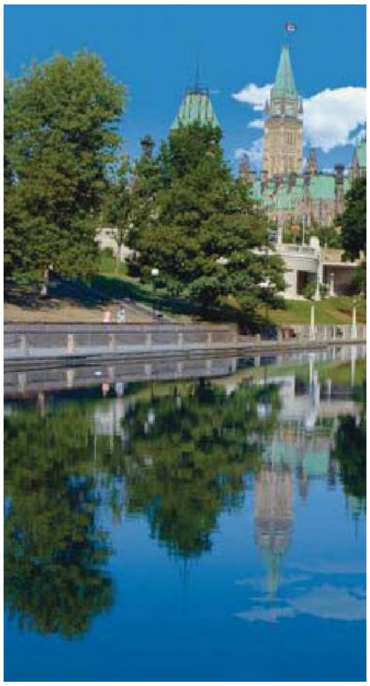

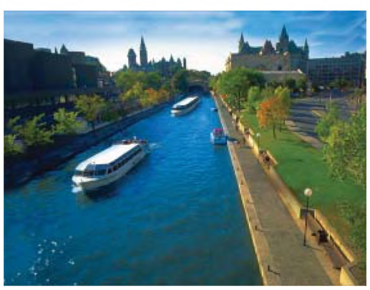

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PRIZE ANNOUNCEMENT • ANNONCE DE PRIX

Prize

Edgar and Millicent Shaw Postdoctoral Prize in Acoustics
Alexander G. Bell Graduate Student Prize in Speech Communication and Hearing
Eckel Graduate Student Prize in Noise Control
Fessenden Graduate Student Prize in Underwater Acoustics
Raymond Hetu Undergraduate Student Prize in Acoustics

Prix

Prix Post-doctoral Edgar et Millicent Shaw en Acoustique
Prix etudiant Alexander G. Bell en Communication orale et audition (2^{E} ou 3^{E} cycle)
Prix etudiant Eckel en Controle du bruit (2^{E} ou 3^{E} cycle)
Prix etudiant Fessenden en Acoustique sous-marine (2^{E} ou 3^{E} cycle)
Prix etudiant Raymond Hetu en Acoustique (1ER cycle)

Deadline for Applications:
April 30th 2011

Date limite de soumission des demandes:
30 Avril 2011

Consult CAA website for more information
Consultez le site Internet de l'ACA pour de plus amples renseignements
(http://www.caa-aca.ca)

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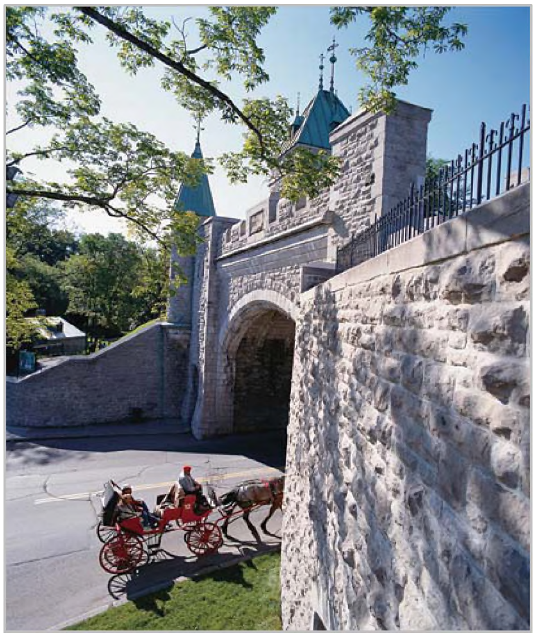


Porte (Gate) Saint-Louis
(Photo: Yves Tessier, Tessima)

— THIRD ANNOUNCEMENT —

ACOUSTICS WEEK IN CANADA

Quebec City, October 12-14, 2011

Acoustics Week in Canada 2011, the annual conference (the Canadian Acoustical Association, will be held in Quebe City from October 12 to 14. This premier Canadia symposium in acoustics and vibration will take place i beautiful Old Quebec, a UNESCO world heritage treasu with European appeal. You surely will not want to miss th event. The conference will include three days of plenar lectures and technical sessions on all areas of acoustics, meeting of the Acoustical Standards Committee, the CA Annual General Meeting, an Exhibition of acoustic equipment, materials and services, the Conference Banque an Award ceremony and other social events.

Venue and Accommodation – The conference will be held at **Hôtel Château Laurier Québe** The hotel is conveniently located on the Plains of Abraham at the heart of all major attractions of O Québec. It is only a few steps from Grande Allée Historic Street, well-known for its restaurant boutiques and nightlife. The Parliament Buildings, the Old City walls and Porte (Gate) Saint-Louis a only a five-minute walk from the hotel. The Hôtel Château Laurier Québec boasts 289 rooms and suite modern conference facilities with 17 meeting rooms and banquet services, a fitness room, an indoor po and landscaped outdoor garden with spas, and an inner courtyard. You will enjoy four-star bilingu services rooted in a rich francophone tradition.

A block of Standard ($134/night + taxes) and European ($114/night + taxes) style rooms is bein offered at special conference rates based on single or double occupancy. Additional adults will be a extra $20/night. Wireless internet access is complimentary with each room. Indoor parking available for an overnight charge of $19/day. Hotel reservations must made by congress participan no later than September 11 by phone (1-800-463-4453), fax (1-418-524-8768), ema (reservation@vieuxquebec.com) or online (http://www.vieux-quebec.com/en/laurier/). NOTE: It important to quote the event **group code ACA5007** when booking. Availability of rooms in th conference block is on a first come first serve basis. Do not delay booking your room!

Participants are strongly encouraged to stay at Hôtel Château Laurier Québec. Staying at the conference hotel will place you near your colleagues and all conference activities, and help make the meeting a financial success to the benefit of future activities of the Canadian Acoustical Association.

Hôtel Château Laurier Québec

Plenary Lectures and Technical Sessions – Three plenary lectures are planned in areas of broad and relevant appeal to the acoustical community, highlighting the regional expertise and distinctiveness. Technical sessions will be organized in all areas of acoustics, including the following:

- Aeroacoustics
- Building and Architectural Acoustics
- Noise Control
- Acoustical Materials
- Environmental Noise
- Speech Sciences
- Hearing Sciences
- Bioacoustics
- Musical Acoustics
- Active Noise Control
- Vibrations
- Hearing Protection
- Signal Processing
- Underwater Acoustics
- Education in Acoustics
- Acoustical Standards
- Case Studies in Acoustics

Paper Submission – The abstract deadline is June 15, 2011. The two-page summaries for publication in the proceedings issue of *Canadian Acoustics* are due by August 1, 2011. Detailed instructions with submit link are given on the conference website.

Standards Committee – The Joint Meeting of the CAA Acoustical Standards Committee and the CSA Technical Committee on Occupational Hearing Conservation will be held on the evening of Wednesday October 12, 2011.

Exhibition and Sponsorship – The conference will show case an exhibition of acoustical equipment, products and services on Thursday October 13, 2011. If you or your company is interested in participating in the Exhibition or sponsoring technical sessions, coffee breaks, lunches or social events, all of which being excellent promotional opportunities, please contact the Exhibition Coordinator.

Registration – Details of registration fees and the registration form will be available soon on the conference website.

Student Participation – Student participation is strongly encouraged. Travel subsidies and reduced registration fees will be available. Student presenters are eligible to win prizes for the best presentations. The deadline for application is August 1, 2011.

Rue (Street) Saint-Louis (Photo: Luc-Antoine Couturier)

Local Organizing Committee:

Conference Chair: **Christian Giguère** cgiguere@uottawa.ca

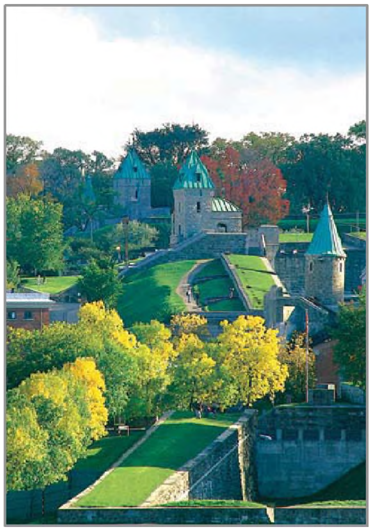
Technical Co-Chairs: **JérémieVoix** jeremie.voix@etsmtl.ca
Hugues Nelisse hugues.nelisse@irsst.qc.ca

Exhibition Coordinator: **André L'Espérance** a.lesperance@softdb.com

Logistics: **François Bergeron** francois.bergeron@rea.ulaval.ca
Jean-Philippe Migneron jean-philippe.migneron.1@ulaval.ca

Webmaster: **Nicolas Ellaham** nellaham@uottawa.ca

Conference Website: www.caa-aca.ca/conferences/quebec2011



Murs (Walls)
(Photo: Brigitte Ostiguy)

— TROISIÈME ANNONCE —

SEMAINE CANADIENNE D'ACOUSTIQUE

Québec, 12 au 14 octobre 2011

La Semaine canadienne d'acoustique 2011, le congrès annuel de l'Association canadienne d'acoustique, se tiendra à Québec du 12 au 14 octobre prochain. Cet événement de premier plan dans le domaine de l'acoustique et des vibrations, tenu au cœur d'une ville si pittoresque et joyau du patrimoine mondial de l'UNESCO, en fera encore cette année un colloque à ne pas manquer. Il comprendra trois jours de séances plénières et sessions scientifiques, une réunion du Comité de normalisation en acoustique, l'Assemblée générale annuelle de l'ACA, une exposition d'équipement, produits et services en acoustique, un banquet, la remise annuelle des prix et d'autres activités sociales.

Lieu du congrès et Hébergement – Le congrès se tiendra à l'**Hôtel Château Laurier Québec**, exceptionnellement situé sur les plaines d'Abraham et au cœur de tout ce qui fait le charme de Québec pour votre plus grand plaisir. L'hôtel n'est qu'à quelques pas de la rue Grande-Allée, bien connue pour ses restaurants, boutiques et boîtes de nuit. La colline parlementaire, la porte Saint-Louis et l'enceinte du Vieux-Québec ne sont qu'à 5 minutes à pied. L'Hôtel Château Laurier Québec compte 289 chambres et suites, un ensemble de 17 salles de réunion et de banquet, une salle de conditionnement physique, une piscine intérieure, un jardin extérieur avec spas et une cour intérieure.

Un bloc de chambres en style standard (134$/nuit + taxes) et européen ($114/nuit + taxes) est offert à des taux préférentiels en occupation simple ou double. Des frais de 20$/nuit sont applicables pour tout adulte supplémentaire. L'accès Internet haute vitesse sans fil est gratuit dans les chambres. Le stationnement intérieur est offert au tarif de 19$ par jour. Les réservations devront être effectuées individuellement par les congressistes au plus tard le 11 septembre par téléphone (1-800-463-4453), télécopieur (1-418-524-8768), courriel (reservation@vieuxquebec.com) ou en ligne (www.vieux-quebec.com/fr/laurier). N.B. Il est très important de préciser le **code de groupe ACA5007** de notre événement lors de votre réservation.

Hôtel Château Laurier Québec

Fontaine de Tourny (Photo: La Maison Simons)

La disponibilité des chambres du bloc à taux préférentiels est sur le principe du premier arrivé, premier servi. Ne tardez donc pas à réserver votre chambre !

Les congressistes sont vivement encouragés à héberger à l'Hôtel Château Laurier Québec. Cela vous permettra de mieux côtoyer vos collègues durant votre séjour et de bénéficier pleinement de toutes les activités du congrès. Demeurer à l'hôtel du congrès contribue aussi au succès financier de l'événement et profitera aux prochaines activités de l'Association canadienne d'acoustique.

Séances plénières et sessions scientifiques – Trois présentations plénières dans des domaines d'intérêt général en acoustique sont prévues, mettant en évidence l'expertise régionale. Des sessions scientifiques seront organisées dans tous les domaines de l'acoustique, y compris :

- Aéroacoustique
- Acoustique architecturale et du bâtiment
- Contrôle du bruit
- Matériaux acoustiques
- Bruit environnemental
- Sciences de la parole
- Sciences de l'audition
- Bioacoustique
- Acoustique musicale
- Contrôle actif du bruit
- Vibration
- Protection auditive
- Traitement du signal
- Acoustique sous-marine
- Enseignement de l'acoustique
- Normes acoustiques
- Études de cas en acoustique

Soumissions – La date d'échéance pour la soumission des résumés de communication est le 15 juin 2011. Les articles de deux pages pour le numéro spécial des actes de congrès dans l'*Acoustique canadienne* sont dus le 1 août 2011. Voir le site du congrès pour de plus amples renseignements.

Comité de normalisation – La réunion conjointe du Comité de normes de l'ACA et du Comité technique de l'ACNOR en Préservation de l'ouïe en milieu de travail aura lieu mercredi le 12 octobre 2011 en soirée.

Exposition technique et Commandite – Le congrès comprendra une exposition d'équipement, produits et services en acoustique le jeudi 13 octobre 2011. Si vous ou votre entreprise êtes intéressés à réserver un table pour cette exposition technique ou commanditer des sessions scientifiques, pauses-cafés, repas ou événements sociaux, lesquels présenteront tous d'excellentes occasions promotionnelles, veuillez communiquer avec le coordinateur de l'exposition technique.

Inscription – Les modalités d'inscription au congrès et le formulaire d'inscription seront bientôt disponibles sur le site internet du congrès.

Participation étudiante – La participation étudiante est fortement encouragée. Des subventions de voyages et des frais d'inscription réduits seront offerts. Des prix seront décernés pour les meilleures présentations étudiantes lors du congrès. La date limite d'inscription au concours est le 1 août 2011.

Rue (Street) Grande-Allée (Photo Travel Pages)

Comité organisateur:

Président:	**Christian Giguère** cgiguere@uottawa.ca
Comité scientifique:	**Jérémie Voix** jeremie.voix@etsmtl.ca **Hugues Nelisse** hugues.nelisse@irsst.qc.ca
Exposition technique:	**André L'Espérance** a.lesperance@softdb.com
Logistique:	**François Bergeron** francois.bergeron@rea.ulaval.ca **Jean-Philippe Migneron** jean-philippe.migneron.1@ulaval.ca
Site internet:	**Nicolas Ellaham** nellaham@uottawa.ca

Site Internet du congrès: www.caa-aca.ca/conferences/quebec2011

INSTRUCTIONS TO AUTHORS FOR THE PREPARATION OF MANUSCRIPTS

Submissions: The original manuscript and two copies should be sent to the Editor-in-Chief. The manuscript can also be submitted electronically.

General Presentation: Papers should be submitted in camera-ready format. Paper size 8.5" x 11". If you have access to a word processor, copy as closely as possible the format of the articles in Canadian Acoustics 39(1) 2011. All text in Times-Roman 10 pt font, with single (12 pt) spacing. Main body of text in two columns separated by 0.25". One line space between paragraphs.

Margins: Top - 0.75"; bottom - 0.75" minimum; sides - 0.75".

Title: Bold, Times New Roman 14 pt with 14 pt spacing, upper case, centered.

Authors/addresses: Names and full mailing addresses, 10 pt with single (12 pt) spacing, upper and lower case, centered. Names in bold text.

Abstracts: English and French versions. Headings, 12 pt bold, upper case, centered. Indent text 0.5" on both sides.

Headings: Headings to be in 12 pt bold, Times-Roman font. Number at the left margin and indent text 0.5". Main headings, numbered as 1, 2, 3, ... to be in upper case. Sub-headings numbered as 1.1, 1.2, 1.3, ... in upper and lower case. Sub-sub-headings not numbered, in upper and lower case, underlined.

Equations: Minimize. Place in text if short. Numbered.

Figures/Tables: Keep small. Insert in text at top or bottom of page. Name as "Figure 1, 2, ..." Caption in 9 pt with single (12 pt) spacing. Leave 0.5" between text.

Line Widths: Line widths in technical drawings, figures and tables should be a minimum of 0.5 pt.

Photographs: Submit original glossy, black and white photograph.

Scans: Should be between 225 dpi and 300 dpi. Scan: Line art as bitmap tiffs; Black and white as grayscale tiffs and colour as CMYK tiffs;

References: Cite in text and list at end in any consistent format, 9 pt with single (12 pt) spacing.

Page numbers: In light pencil at the bottom of each page. For electronic submissions, do not number pages.

Reprints: Can be ordered at time of acceptance of paper.

DIRECTIVES A L'INTENTION DES AUTEURS PREPARATION DES MANUSCRITS

Soumissions: Le manuscrit original ainsi que deux copies doivent être soumis au rédacteur-en-chef. Le manuscrit peut être aussi acheminé par voie électronique.

Présentation générale: Le manuscrit doit être soumis avec mise en page en format de publication. Dimension des pages, 8.5" x 11". Si vous avez accès à un système de traitement de texte, dans la mesure du possible, suivre le format des articles dans l'Acoustique canadienne 39(1) 2011. Tout le texte doit être en caractères Times-Roman, 10 pt et à simple (12 pt) interligne. Le texte principal doit être en deux colonnes séparées d'un espace de 0.25". Les paragraphes sont séparés d'un espace d'une ligne.

Marges: Haut - 0.75"; bas - minimum 0.75" ; côtés,- 0.75".

Titre du manuscrit: Caractères gras, Times New Roman 14 pt,avec espace interligne de 14 pt, lettres majuscules, texte centré.

Auteurs/adresses: Noms et adresses postales. Lettres majuscules et minuscules, 10 pt à simple (12 pt) interligne, texte centré. Les noms doivent être en caractères gras.

Sommaire: En versions anglaise et française. Titre en 12 pt, lettres majuscules, caractères gras, texte centré. Paragraphe 0.5" en alinéa de la marge, des 2 cotés.

Titres des sections: Tous en caractères gras, 12 pt, Times-Roman. Premiers titres: numéroter 1, 2, 3, ..., en lettres majuscules; sous-titres: numéroter 1.1, 1.2, 1.3, ..., en lettres majuscules et minuscules; sous-sous-titres: ne pas numéroter, en lettres majuscules et minuscules et soulignés.

Équations: Minimiser le nombre et les numéroter. Insérer directement dans le texte les équations très courtes.

Figures/Tableaux: De petites tailles. Les insérer dans le texte au haut ou au bas de la page. Les nommer "Figure 1, 2, 3,..." Légende en 9 pt à simple (12 pt) interligne. Laisser un espace de 0.5" entre le texte.

Largeur des traits: La largeur des traits sur les schémas techniques doivent être au minimum de 0.5 pt pour permettre une bonne reproduction.

Photographies: Soumettre la photographie originale sur papier glacé, noir et blanc.

Figures numérisées: Doivent être au minimum de 225 dpi et au maximum de 300 dpi. Les schémas doivent être en format bitmap tif. Les photos noir et blanc doivent en format tif sur une échelle de tons de gris et toutes les photos couleurs doivent être en format CMYK tif.

Références: Les citer dans le texte et en faire la liste à la fin du document, en format uniforme, 9 pt à simple (12 pt) interligne.

Pagination: Au crayon pâle, au bas de chaque page. Ne pas paginer si le manuscrit est envoyé par voie électronique.

Tirés-à-part: Ils peuvent être commandés au moment de l'acceptation du manuscrit.

The Canadian Acoustical Association
l'Association Canadienne d'Acoustique

Application for Membership

CAA membership is open to all individuals who have an interest in acoustics. Annual dues total $80.00 for individual members and $35.00 for Student members. This includes a subscription to ***Canadian Acoustics***, the Association's journal, which is published 4 times/year. New membership applications received before August 31 will be applied to the current year and include that year's back issues of ***Canadian Acoustics***, if available. New membership applications received after August 31 will be applied to the next year.

Subscriptions to *Canadian Acoustics* *or* Sustaining Subscriptions

Subscriptions to ***Canadian Acoustics*** are available to companies and institutions at the institutional subscription price of $80.00. Many companies and institutions prefer to be a Sustaining Subscriber, paying $350.00 per year, in order to assist CAA financially. A list of Sustaining Subscribers is published in each issue of ***Canadian Acoustics***. Subscriptions for the current calendar year are due by January 31. New subscriptions received before August 31 will be applied to the current year and include that year's back issues of ***Canadian Acoustics***, if available.

Please note that electronic forms can be downloaded from the CAA Website at **caa-aca.ca**

Address for subscription / membership correspondence:

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Phone ____________ Fax ____________ E-mail ____________

Address for mailing Canadian Acoustics, if different from above:

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Areas of Interest: (Please mark 3 maximum)

1. Architectural Acoustics
2. Engineering Acoustics / Noise Control
3. Physical Acoustics / Ultrasound
4. Musical Acoustics / Electro-acoustics
5. Psychological / Physiological Acoustic
6. Shock and Vibration
7. Hearing Sciences
8. Speech Sciences
9. Underwater Acoustics
10. Signal Processing / Numerical Methods
11. Other

For student membership, please also provide:

__________ __________ __________ __________

(University) *(Faculty Member)* *(Signature of Faculty Member)* *(Date)*

I have enclosed the indicated payment for:
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[ ] $88 including mailing to USA,
[ ] $95 including International mailing

[ ] Sustaining Subscriber $350.00
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(Signature) (Date)

Mail application and attached payment to:

Executive Secretary, Canadian Acoustical Association, PO Box 74068, Ottawa, Ontario, K1M 2H9, Canada

l’Association Canadienne d’Acoustique
The Canadian Acoustical Association

Formulaire d’adhésion

L'adhésion à l'ACA est ouverte à tous ceux qui s'intéressent à l'acoustique. La cotisation annuelle est de 80.00$ pour les membres individuels, et de 35.00$ pour les étudiants. Tous les membres reçoivent ***l'Acoustique Canadienne***, la revue de l'association. Les nouveaux abonnements reçus avant le 31 août s'appliquent à l'année courante et incluent les anciens numéros (non-épuisés) de ***l'Acoustique Canadienne*** de cette année. Les nouveaux abonnements reçus après le 31 août s'appliquent à l'année suivante.

Abonnement pour la revue *Acoustique Canadienne* et abonnement de soutien

Les abonnements pour la revue ***Acoustique Canadienne*** sont disponibles pour les compagnies et autres établissements au coût annuel de 80.00$. Des compagnies et établissements préfèrent souvent la cotisation de membre bienfaiteur, de 350.00$ par année, pour assister financièrement l'ACA. La liste des membres bienfaiteurs est publiée dans chaque issue de la revue ***Acoustique Canadienne***. Les nouveaux abonnements reçus avant le 31 août s'appliquent à l'année courante et incluent les anciens numéros (non-épuisés) de ***l'Acoustique Canadienne*** de cette année. Les nouveaux abonnements reçus après le 31 août s'appliquent à l'année suivante.

Pour obtenir des formulaires electroniques, visitez le site Web: **caa-aca.ca**

Pour correspondence administative et financière:

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Cocher vos champs d'intérêt: (maximum 3)

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