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Field Report

The Characteristics of Vibrotactile Perception Threshold among Shipyard Workers in a Tropical Environment

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Abstract: The objectives of this study are to determine the prevalence of hand-arm vibration syndrome (HAVS) and the characteristics of the vibrotactile perception threshold (VPT) among users of hand-held vibrating tools working in a tropical environment. A cross sectional study was done among 47 shipyard workers using instruments and a questionnaire to determine HAVS related symptoms. The vibration acceleration magnitude was determined using a Human Vibration Meter (Maestro). A P8 Pallesthesiometer (EMSON-MAT, Poland) was used to determine the VPT of index and little finger at frequencies of 31.5 Hz and 125 Hz. The mean reference threshold shift was determined from the reference threshold shift derived from the VPT value. The results show a moderate prevalence of HAVS (49%) among the shipyard workers. They were exposed to the same high intensity level of HAVS (mean = 4.19 ± 1.94 m/s^2) from the use of vibrating hand-held tools. The VPT values were found to be higher for both fingers and both frequencies (index, 31.5 Hz = 110.91 ± 7.36 dB, 125 Hz = 117.0 ± 10.25 dB; little, 31.5 Hz = 110.70 ± 6.75 dB, 125 Hz = 117.71 ± 10.25 dB) compared to the normal healthy population with a mean threshold shift of between 9.20 to 10.61 decibels. The frequency of 31.5 Hz had a higher percentage of positive mean reference threshold shift (index finger=93.6%, little finger=100%) compared to 125 Hz (index finger=85.1%, little finger=78.7%). In conclusion, the prevalence of HAVS was lower than those working in a cold environment; however, all workers had a higher mean VPT value compared to the normal population with all those reported as having HAVS showing a positive mean reference threshold shift of VPT value.

Key words: Shipyard, Grinders, Vibrating tools, Hand-arm vibration syndrome, Tropical environment

Introduction

Hand-arm vibration (HAVS) is known in many occupations where workers come in contact with vibrating machinery and tools, which are often handheld[1]. Vibrating handheld tools are used in many different occupations such as construction, automotive and shipyards. The tools used –grinder, drill and jackhammer, jet chisel, chipping tool, nut runner, polisher, brusher, power jigsaw, sander and others –vary in type, size, weight, acceleration amplitude and frequency.

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The adverse effect of HAVS has been documented by many researchers, including worker's comfort, work performance, efficiency, safety and well-being of those who are exposed. In the worst scenario, it can lead to physiological and pathological changes[2]. Extensive exposure to HAVS can lead to a series of disorders in the vascular, sensory-neural and musculoskeletal structures of human fingers-hand-arm system, which has been collectively called hand-arm vibration syndrome (HAVS). HAVS is defined as a disorder resulting from prolonged exposure to vibration, specifically to the hands and forearms while using vibrating tools. Symptoms include numbness, tingling, and loss of nerve sensitivity[3].

In temperate and cold countries, HAVS is known as white finger disease or Raynaud's phenomenon. In the early stage of white finger disease, a tingling sensation with numbness in the fingers occurs. The fingers then become white and swollen when cold and then turn red and painful when warmed up again. The pain, tingling, and numbness in the arms, wrists and hands may interfere with sleep[3]. Cold or wet weather may aggravate the condition and actions such as picking up small objects like pins or nails becomes difficult as the feeling in the fingers diminishes and there is a loss of strength and grip in the hands[4, 5].

One of the tools used in diagnosing HAVS is the vibrotactile perception threshold (VPT) method. This method is useful in detecting a threshold shift of VPT at different frequencies after significant lengths of time exposure and acceleration magnitude to HAVS. The evaluation of VPT in the fingers is one of the basic methods for early detection of peripheral neuropathies in the upper extremities in workers who are exposed to HAVS. Although the VPT method is not a gold standard in determining the effect of HAVS, it is one the most accurate methods available for detecting a sensor-neural change compared to other methods[6–9].

Although there have been many previous studies[1, 3, 10–13] on the effect of HAVS in European countries and temperate countries concerning the relationship between the vibrating handheld tool usage and hand-arm vibration syndrome (HAVS) among various occupations, few studies have been done among those working in a hot and humid environment and the conclusion may be limited to temperate and cold environments. Therefore, research should also emphasize the characteristics of HAVS, prevalence of HAVS and VPT level among those working in a tropical climate.

The objectives of this study are to determine the prevalence of HAVS, the vibration acceleration magnitude of hand-held power tools used in the shipyard industry, the level of VPT, the reference threshold shift of VPT, the association between the reference threshold shift of VPT, complaint of HAVS and the acceleration magnitude of vibrating hand-held tools used among those working as shipyard workers in a hot and tropical climate.

Subjects and Methods

Subjects

A total of 47 healthy and fit male shipyard workers (defined as those without a history of musculoskeletal, neurological or vascular disorders, or suffering from any serious injuries of the upper extremities and routine intake of any prescribed medicines that impair neurological activity) were purposively selected from 106 shipyard workers to participate in the study (mean age of 30 ± 7.60 yr). Most of them were working as "finishing grinders" for the structure and piping sections of a shipyard in Malaysia and had been working for approximately 2 yr. The mean duration of daily use of hand-held tools is approximately 8.1 h. The majority of respondents were right handed (95.7%), while the other 4.3 % were ambidextrous. Out of 47 respondents, 43% were identified as smokers. All of them were exposed to chemicals during work (i.e., paints).

Questionnaire

Respondents were interviewed using a modified standardized HAVS questionnaire by Su[14]. Each of the respondents was briefed regarding the questionnaire and asked to fill in a consent form to participate in the study. The purpose of the questionnaire was to obtain the information regarding the individual background (demography), occupational, social and medical history, health status and also symptoms concerning HAVS. The operational case of HAVS in this study is defined as having reported any symptom (1=yes with any symptom and 0=no symptom) or clinical manifestation of whiteness of any finger, numbness or tingling sensation at the hand using a simple statement question, such as "do you have any experience or complain of tingling sensation after using your hand-held power tool?"

Hand-arm vibration measurement

A total of 47 HAV measurements were taken using the Human Vibration Meter (Maestro) with a tri-axial accelerometer (0.4–1,000 Hz) that was mounted on a hand adapter. The vibration reading is in acceleration units (m/s^2), which complies with the ISO 5349-1 standard[15]. The accelera-

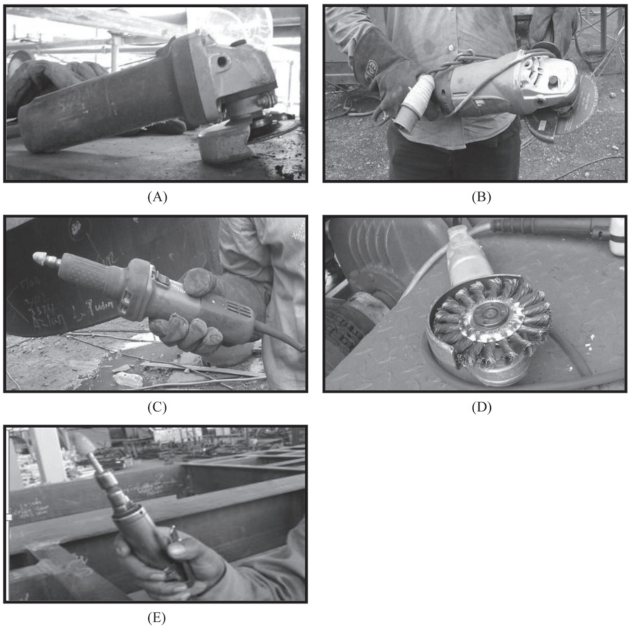

Fig. 1. Type of vibrating tool.

A) 4-inch grinder
B) 7-inch grinder
C) Pencil grinder
D) Brusher/Polisher
E) Baby grinder

tion in the three axes x, y and z was measured for at least 1 minute with an interval of 1 second for data logging. The vibration from five types of vibrating hand-held tools was measured. The tools were a 4-inch grinder, 7-inch grinder, pencil grinder, brusher and baby grinder (Fig. 1). Measurement data were recorded and then transferred into a computer for analysis using dBTRAIT32 software.

The vibration total value, a_{hv} was established by root mean squares (RMS) of frequency-weighted acceleration measured in three orthogonal axes (ISO 5349-1, 2001). Where a_{hwx}, a_{hwy}, a_{hwz} are the value of a_{hw} (frequency-weighted r.m.s. acceleration in single axis) in meters per second squared, (m/s^2). The orthogonal axes were denoted as x, y, z, respectively. The daily vibration exposure (8) was derived from the total vibration value, ahv and daily exposure duration, given as (ISO 5349-1, 2001):[15]

$$A(8) = a_{hv}\sqrt{\frac{T}{T_0}}$$

Where T is the total daily duration and T_0 is the reference duration of 8 h. The A(8) was then categorized as 1=> 2.5 m/s^2 (action value by the European Union Directive on Human Vibration (2002)[16]) and 0=< 2.5 m/s^2.

Vibrotactile perception threshold

A Pallesthesiometer (P8 EMSON-MAT®, Poland) was used to measure the vibrotactile perception threshold (VPT). The P8 Pallesthesiometer was developed according to the ISO 13091-1 standard[17]. The measuring system consisted of a vibrometer unit, a subject response button, a set of vibrotactile meter working state indicators and the vibrometer software. Prior to the VPT measurements, a pre-test was performed on the hand at the little and index finger in order to familiarize the respondents with the vibration stimuli and also the measurement procedures. The VPT measurements were taken for the index and little fingers of the dominant hand and determined at the frequencies of 31.5 and 125 Hz. The index and little finger skin temperature was measured prior to testing using a non-contacted infrared thermometer on the distal phalanx of all four digits (index finger skin temperature was 31.64 ± 1.9°C and little finger skin temperature was 31.49 ± 1.89°C). The room temperature was maintained at 29.03 ± 0.47°C and within the room temperature recommended (ISO 13091-1)[17].

Prior to VPT measurement, as recommended by ISO 13091-1[17], respondents were not allowed to consume vasoactive or neuroactive agents (e.g., smoke cigarettes, drink beverages containing caffeine) nor engage in vigorous exercise for at least one hour prior to the VPT measurement. In addition, respondents were asked to refrain from drinking alcoholic beverages and exposing themselves to hand-arm vibration for at least three (3) hours before commencing the VPT measurement. Environmental factors that were also taken into account include the temperature (20 to 30°C), and noise (less than 50 dB (A)) in the room where the measurements were conducted. The respondents were asked to keep their forearm and hand on the unit box resting the palm on a special support, which ensured the required contact between the fingertip and the probe. The center of the stimulating probe tip was located on the distal phalanx at a point midway between the center of the whorl and the fingernail. The probe was pressed by the respondent's finger with a constant force of 0.1N.

The von Bekesy algorithm was used to assess the VPT. In this method, the vibration magnitude was increased until the subject was able to perceive it. Then the respondent pressed the button held in the other hand. This caused a decrease in the vibration stimuli level until the respondent no longer perceived a vibration stimulus. Releasing the button caused the vibration level to increase again. This procedure was repeated three times by an automatic test program to establish the threshold level at a selected vibration frequency. The measurements were continued until three ascending thresholds and three descending thresholds were obtained, each with acceleration values within ± 2dB. The vibrometer software monitored the measurement, rejecting the acceleration values that differed from the mean value by more than ± 2dB.

Calculation of threshold shift

In this study, the interpretation of VPT was by calculation of the change in observed threshold from a defined reference value of 31.5 Hz and 125 Hz of the index finger of the dominant and non-dominant hand. The reference threshold shift was calculated as the difference between the observed and reference VPT (at 50th percentile value of 31.5 Hz and 125 Hz) values expressed in decibels. The calculation of the reference threshold shift is referred as below:

$$\Delta T(f_i)_{\text{ref}} = T(f_i)_{\text{obs}} - T(f_i)_{\text{ref}}$$

Where the observed VPT at the *ith* frequency, $T(f_i)_{\text{obs}}$, and the reference VPT are at the same frequency. The reference VPT was according to the provision specified in ISO 13091-2[18]. In order to determine the association with the acceleration magnitude of HAVS and reported symptoms of HAVS, the threshold shift was then categorized by coding (1 = $\Delta T(f_i)_{\text{ref}}>0$) indicating a positive reference threshold shift and 0 = $\Delta T(f_i)_{\text{ref}}\leq 0$ indicating no threshold shift). The mean value of the reference threshold shift was determined from the threshold shift difference of the index fingers measured for both the dominant and non-dominant hand. The calculation is expressed as:

$$\Delta T(f_i)_{\text{rel,M}} = \frac{1}{n}\sum_{i=1}^{n}\Delta T(f_i)_{\text{rel,i}}$$

Statistical analysis

Three statistical analysis tests were used in this study. Frequency tests (percentage, mean and standard deviation) were used to determine the socio-demographic distribution (age), occupational background (duration of employment, duration of vibrating hand-held tools used daily), prevalence of HAVS, the mean distribution of VPT at 125HZ and 31.5 Hz, mean reference threshold shift, prevalence of positive reference threshold shift and the acceleration magnitude A(8) of the hand-held power tools. One-way analysis of variance (ANOVA) was used to compare the mean difference of the six types of hand-held power tools. The association between the reference threshold shift with HAVS complaint and reference threshold shift with A(8) were determined using χ^2 2 × 2 table. The Statistical Package for Social Sciences (SPSS), version 15[19], was used in the data analysis.

Table 1. Prevalence of HAVS symptoms

Symptom	Frequency	(%)
Discoloration of the finger	0	100
Numbness	22	46.8
Tingling	3	6.4
Any HAVS symptoms	23	48.9

n=47.

Ethical clearance

The study was approved by the Ethics Committee of the Faculty of Medicine and Health Sciences, University Putra of Malaysia.

Results

The results in Table 1 show that none of the shipyard workers had any blanching of the finger indicating white finger disease. Nearly 50% reported having numbness and only three shipyard workers reported a tingling sensation (6.4%). The overall prevalence of HAVS complaint was 48.9%. The overall mean of vibration acceleration magnitude was above the EU Directive 2002[16] action value (mean = 4.19 ± 1.94 m/s^2) with no significant difference observed between the vibrating hand-held tool used by the shipyard workers (F=0.769, p=0.552). The results show that only the baby grinder did not exceed the action level set by the EU Directive (2002)[16], while the brusher machine exceeded the exposure limit of > 5.0 m/s^2 (Table 2).

The mean VPT values, as shown in Table 3, indicate that the shipyard workers have a higher VPT threshold at both 31.5 Hz and 125Hz (at index and little finger) compared to the reference VPT provided by ISO 13091-2[18]. The mean reference threshold shifts of VPT were observed having a threshold shift between 9.2 dB to 10.6 dB compared to the healthy population, as in provision of ISO 13091-2[18]. The results from Table 4 show that the mean reference threshold shift of VPT was not significantly associated with a vibration acceleration magnitude that exceeds 2.5 m/s^2. There was no significant association between those with positive reference threshold shift with vibrating hand-held tools that exceed 2.5 m/s^2. The study also showed no significant association between the mean reference threshold shift with the complaint of HAVS (p>0.05). The study showed that all of the shipyard workers who complained of having symptoms of tingling or numbness had a positive mean reference threshold shift at 31.5 Hz.

Table 2. Eight-hour time weighted average vibration magnitude, A(8) of different vibrating handheld tools

Tool	Frequency	Mean (SD)	F	*p*
4-inch Grinder[a]	34	4.17 (1.64)	0.769	0.552
7-inch Grinder[b]	3	3.95 (1.18)		
Pencil Grinder[a]	4	4.35 (2.30)		
Brusher[b]	4	5.30 (2.43)		
Baby Grinder[a]	2	2.40 (1.53)		
Overall acceleration magnitude	47	4.19 (1.94)		

a: Exceed action level of EU Directive (>2.5 m/s^2) b: Exceed exposure limit of EU Directive (>5.0 m/s^2).

Table 3. Mean reference threshold shift and tabulation of threshold shift

	Finger	Frequency	Mean (SD)	
VPT value	Index	31.5	110.91 (7.36)	
		125	117.00 (10.25)	
	Little	31.5	110.70 (6.75)	
		125	117.71 (12.29)	
Reference threshold shift	Index	31.5	10.39 (6.75)	
		125	9.20 (10.25)	
	Little	31.5	10.61 (7.36)	
		125	9.91 (10.25)	
			$\Delta T(f_i)_{ref}>0$ n (%)	$\Delta T(f_i)_{ref}\leq 0$ n (%)
Category of threshold shift	Index	31.5	44 (93.6)	3 (6.4)
		125	40 (85.1)	7 (14.9)
	Little	31.5	47 (100%)	0 (%)
		125	37 (78.7)	10 (21.3)

Table 4. Association between Mean threshold shift and A(8)

Finger	Frequency		$\Delta T(f_i)_{ref}\leq 0$ n (%)	$\Delta T(f_i)_{ref}>0$ n (%)	χ^2	*p* value
Index	31.5	Above 2.5 m/s^2	2 (19.1)	35 (74.5)	0.278	0.598
	125		6 (19.1)	31 (66.0)	0.240	0.624
Little	31.5		10 (21.3)	37 (78.7)	–	–
	125		7 (14.9)	30 (63.8)	0.577	0.447
			No symptom of HAV n (%)	Having any symptoms of HAV n (%)	χ^2	*p* value
Index	31.5	$\Delta T(f_i)_{ref}>0$	22 (46.8)	22 (46.8)	0.312	0.576
	125		20 (42.6)	20 (42.6)	0.122	0.727
Little	31.5		24 (51.1)	23 (48.9)	–	–
	125		17 (36.2)	20 (42.6)	1.823	0.177

Discussion

Prevalence of hand arm vibration syndrome

The study shows that there is moderate prevalence of HAVS among the shipyard grinders working in a tropical climate environment. Most of the symptoms observed were the feeling of numbness and some cases of tingling sensation, however, the pathological lesion of whiteness among them was not observed. The prevalence of HAVS was lower compared to previous studies among shipyard workers exposed to HAV by Jang[20] (78.2%), McGeoch[21] (62%), Lindsell[22] (98%). However, the prevalence of HAVS in this study was still high compared to the prevalence of the normal population[12, 13, 23–25]. The prevalence of tingling or numbness in fingers among an unexposed male population is 11.9%[26].

This relatively low prevalence of HAVS among respondents in this study may be due to several factors including age, duration of exposure and climate condition. The study by McGeoch[21], reported that the mean age of the respondents was 41.4 yr old, while Jang[20], reported a mean age of 36.8 yr among the shipyard workers. Both studies showed a higher age group compared to this study (mean=30 yr old). The current study has younger workers with fewer years of exposure to HAV, as similarly reported by Futatsuka in Indonesia and Vietnam (mean=31.2 yr old)[13, 23–25]. The mean duration of working exposure to HAV in this study is approximately 2 yr. The mean working exposure in this study was relatively shorter when compared to two previous studies by McGeoch[21] (mean=23.3 yr of exposure) and Jang[20] (mean=10.8 yr of exposure). There is a huge gap between this study and both previous studies in terms of job duration. This finding is similar with that reported in Vietnam, Papua New Guinea and Indonesia, which concluded that factors of climate (more than 25°C), young workers and shorter work experience play important roles in reducing the vibrating effect[12, 13, 23–25].

The final factors in this study was the climate condition[12, 13, 23–25]. Warmer work conditions, which are influenced by the local tropical climate, inhibit the development of vibration-induced white finger[13, 23–25]. Warmer conditions can initiate the vasodilatation of blood vessels, which can enhance the blood flow. This phenomenon may contribute to the prevalence of HAVS among shipyard workers that are exposed to vibrating hand-held tools in a tropical climate, unlike among populations in Europe and other northern countries and temperate regions.

Eight-hour time weighted average vibration magnitude, A(8)

This study showed that shipyard workers were exposed to a high vibration acceleration magnitude for 8 h of exposure daily but slightly less than the exposure limit recommended by the EU Directive (2002). The results indicate that the five tools used, vibrate within the same acceleration magnitude ($p>0.05$), and, therefore received the same magnitude of vibration dose. Although no significant difference of A(8) was seen in this study, the results might be limited due to the small number of shipyard workers using different grinders, such as the 7-inch, pencil, baby grinder and brusher machine, as most of them (72.3%) used a 4-inch grinder in performing grinding tasks. Dong[27], suggested that different types of tool used by the workers, emit different vibration levels that are not only significantly different in magnitude but also in frequency.

One important factor concerning the vibration level of the tools used by the shipyard workers was the state of the tool maintenance, as they were poorly maintained. From our observation, workers used their own tools rather than sharing the tools and no proper scheduled maintenance exists. Therefore, without proper maintenance, conditions, such as bearing damage or imbalance in the spindle, looseness, misalignment of the hand-held tool, will lead to a higher level of vibration[28]. In addition to the state of tool maintenance, the age of the vibrating tool might indirectly indicate the tool performance including the vibration level produced. Aged vibrating tools, without proper maintenance have more worn components compared to those in the new tool and may contribute to a higher level of vibration produced from the normal level.

Association of VPT reference threshold shift with HAV symptoms and A(8)

Although the mean acceleration magnitude was below the exposure limit of the EU Directive (2002)[16] for most of the vibrating hand-held tools except for the brusher machine, the study showed a higher level of VPT value compared to a healthy normal population, as described by 13091-2[18] for both 31.5Hz and 125Hz frequencies. In addition, there was a high prevalence of positive reference threshold shift for each frequency tested. The threshold change indicates a pattern of tactile abnormality that can be interpreted as changes of mechanoreceptor sensitivity of nerve function for both fast-adapting type 1 mechanoreceptor (FAI) and fast-adapting type 2 mechanoreceptor (FAII).

The study revealed that the frequency of 31.5 Hz was found to be more sensitive to HAVS compared to the frequency of 125 Hz with both the index and little finger having changes of 94% and 100% positive reference threshold shift, respectively, compared to the frequency of 125 Hz. This trend, indicates that exposure to HAVS will affect the sensitivity of light touch acuity first, followed by a reduction of tactile exploration such as deep touch and pain generated by FAII. The trend of early exposure of HAVS will affect the sensitivity of FAI mechanoreceptors more than it affects the FAII mechanoreceptors. This is the early sign of pathological damage of the hands among the workers who used vibrating handheld tools and, which, over time, may develop into HAVS. This damage of the finger pathological system does not occur simultaneously; however, it happens stage by stage according to the vibration magnitude (4.19 m/s^2) and duration of exposure (2 yr), as suggested by Futatsuka in concluding the possibility of subclinical dysfunction among those working in hot climates[25].

Although we are not able to see a significant association between the mean reference threshold shift and the acceleration magnitude of the hand-held vibrating tools, more than 60% of those with high acceleration magnitude had a positive mean reference threshold shift. The duration of exposure of only two years might explain the shift of only 10 dB from the normal healthy population. The reference threshold shift was also found among 100% of those that reported having symptoms of HAVS at 31.5 Hz and 87% at 125Hz. Studies have shown that within a year of exposure, a significant reference threshold shift was found within 3% of those examined (hand grip, hand and arm strength and symptoms) and the reference threshold shift increased to 14% five years later even though most of them remained symptom free[29]. Although HAV symptoms were not observed and remained undetected by those working in a tropical climate, the mean reference threshold indicated that there was a trend of tactile abnormality among the shipyard workers after a certain duration to HAV. The lack of association between HAV and its symptoms with the mean reference threshold is not a major concern as symptoms reported are primarily based on one's perception entirely, while VPT detects physiological and pathological changes that may be undetected even by the workers themselves.

Limitations of the study

In the study, the true HAVS exposure was difficult to estimate due to the mixed use of vibrating handheld tools among the shipyard workers. In a real working situation, they are exposed to more than one source of HAVS and the magnitude of HAVS each worker receives varies depending on the tools and the tasks. The exposure, A(8) was calculated based on one tool that was used by the worker during the assessment time and was not measured for other tools that were also being used at the same time. However, the actual A(8) calculation includes the magnitude and duration of each tool or 'partial vibration exposure'. The partial vibration values were combined to give the overall daily exposure value (A(8)) for that worker. The association between the mean reference threshold shift and A(8) would be better if the actual A(8) was calculated in the study, however, due to the time constraints, it was not possible to measure.

It is difficult to separate those working in a shipyard from direct exposure to chemicals. Therefore, future studies should monitor the level of chemicals with neuropathic effects, such as chemicals from paint (solvent as active ingredient) and fumes. In addition, the rate of evaporation in humid and hot climates should also be considered. It is also important that future studies evaluate the clinical examination of the hand, finger and grip strength in order to verify and determine the degree of HAVS as well as other tests, such as fork tuning, monofilament test, nerve conduction velocity, and thermal tactile tests to verify HAVS cases in a tropical climate. This study is important as it verifies the typical trend of HAVS and the mean threshold shift of VPT resulting from exposure to vibration-induced tools in a tropical and humid environment.

Conclusion

The study revealed that the prevalence of HAVS among shipyard workers in a tropical environment was lower compared to those exposed in a temperate environment. The symptom of numbness was found to be the highest complaint with none reporting having blanching or discoloration of the finger. However, physiologically, the VPT value of the workers was found to be higher than the normal healthy population; the index finger was tested at 31.5 Hz and had a total positive reference threshold shift. In addition, the trend showed that the FAI mechanoreceptor was more sensitive to vibration induced tools and was affected more than the FAII mechanoreceptors125 Hz.

Although no significant association was observed between reported HAVS and the positive mean reference threshold shift, all of those reported as having HAVS had a threshold shift of VPT at both 31.5 Hz and 87% at 125 Hz. The level of acceleration magnitude of the vibrating hand held tools used were above the action level set by EU Directive (2002)[16] and up to 60% of the workers who were exposed to an acceleration magnitude of more than 2.5 m/s^2 had a positive mean reference threshold shift.

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