

Current perception threshold and the HAVS Stockholm sensorineural scale

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Background	It is important to determine which tests of sensorineural dysfunction identify the neurological damage from hand–arm vibration exposure.
Aims	To examine the association between the hand–arm vibration syndrome (HAVS) Stockholm sensorineural scale stages and tests of peripheral neurological function including measurement of current perception threshold (CPT) and nerve conduction.
Methods	All the subjects were men who were assessed for HAVS with a medical and occupational history and physical examination to determine the Stockholm stage, CPT testing at frequencies of 5, 250 and 2000 Hz for the median and ulnar nerves and measurement of nerve conduction carried out in a blinded fashion.
Results	A total of 155 of the 157 recruited subjects agreed to take part in the study, a 99% participation rate. CPT was statistically significantly increased ($P < 0.001$) in both Stockholm sensorineural Stages 1 and ≥ 2 in comparison to Stage 0 for every frequency and nerve combination. However, CPT could not discriminate well between Stages 1 and ≥ 2 . There was no association between median or ulnar neuropathy measured by nerve conduction and the Stockholm stages. Polychotomous multinomial logistic regression indicated that the CPT measurements at 2000 Hz, corresponding to damage to large myelinated nerve fibres, were most predictive of both Stockholm Stages 1 and ≥ 2 in comparison to Stage 0.
Conclusions	Neuropathy measured by nerve conduction was unrelated to the Stockholm scale stages. CPT was increased above Stage 0 but did not distinguish well between the higher stages of the Stockholm scale.
Key words	Current perception threshold; HAVS; Stockholm sensorineural scale; vibration.

Introduction

Hand–arm vibration syndrome (HAVS) consists of vascular, neurological and musculoskeletal components [1,2]. Many workers use hand-held vibrating tools [3] and may develop HAVS [4,5].

Workers with the neurological component of HAVS usually complain of numbness and tingling in the fingers

and hands [1,6]. These symptoms, along with the presence of sensory abnormalities on physical examination, have been used as the basis for the classification system referred to as the Stockholm sensorineural scale [7]. This scale is not quantitative and therefore quantitative measures of sensorineural dysfunction might allow for a more accurate and precise determination of the neurological damage from hand–arm vibration.

Vibration perception threshold (VPT) [8] and temperature perception threshold (TPT) [9] have been the principal quantitative sensory tests used for this purpose. Together, these tests measure the main sensory nerve fibres in the fingers and hence a combination of these tests may be used clinically to identify the sensorineural component of HAVS [10,11]. Although less commonly used, current perception threshold (CPT) is a quantitative sensory test that allows all the main sensory nerve fibre types to be assessed in a simple, non-invasive manner [12,13]. The test measures CPT at frequencies of 2000, 250 and 5 Hz corresponding to the activation of large myelinated

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(Abeta), small myelinated (Adelta) and unmyelinated (C) sensory nerve fibres, respectively. Therefore, the CPT test might be useful in clinical practice to identify vibration-induced neurological damage.

Nevertheless, neurologists consider nerve conduction tests, and not quantitative sensory tests, to be the best method for evaluation of peripheral nerve function [14]. Nerve conduction tests are more objective than quantitative sensory tests, requiring no feedback or active participation from the subject other than a willingness to undergo the test. However, nerve conduction tests assess only large myelinated fibres and, while useful for measuring neuropathy proximal to the hand, are less able to detect the effects of vibration in the small anatomical area of the fingers; hence, quantitative sensory tests may be better for this purpose. A combination of nerve conduction tests and quantitative sensory tests may therefore provide more comprehensive neurological evaluation of workers exposed to hand–arm vibration.

The quantitative sensory tests in workers being assessed for HAVS involve measurement of sensory perception in the fingers. Abnormal measurements in the fingers may be due to local neurological damage or may be a distal manifestation of more proximal neurological lesions [15]. For example, carpal tunnel syndrome associated with median neuropathy at the wrist can result in increased CPTs in the fingers [16,17]. Proximal neuropathy, especially at the wrist involving the median nerve or ulnar nerve, is common in workers using vibrating tools [18,19]. Therefore, when evaluating the relationship between the CPT and the Stockholm scale as a manifestation of the distal neurological effects of vibration, it is important also to consider the effect of any proximal neuropathy.

The study that we report was carried out to determine if CPT measurements in workers exposed to hand–arm vibration predicted the stage of the Stockholm sensorineural scale after accounting for any proximal neurological lesions measured by nerve conduction tests and if so which specific frequencies were most predictive.

Methods

All the participants were men who had been exposed to hand–arm vibration at work and who were assessed for HAVS at the Occupational Health Clinic, St Michael's Hospital, Toronto, Canada. The clinical assessment consisted of an occupational and medical history and physical examination which were used to determine the stage on the Stockholm sensorineural scale [7]. In this scale, Stage 0 applies to exposed individuals with no neurological symptoms; Stage 1 applies to exposed individuals who have symptoms of numbness with or without tingling in the fingers but normal sensory examination and Stages 2 and 3 to individuals who have abnormalities on sensory

examination of the fingers. In our study, Stages 2 and 3 were combined and referred to as Stage ≥ 2 , an approach that has been used previously [19].

The nerve conduction studies were carried out in the hospital's electromyography department. All the nerve conduction studies were done by technologists certified by the Canadian Board of Registered Electrodiagnostic Technologists using Nicolet (Madison, WI, USA) Viking IV equipment according to standard methods [20]. Hand temperature was at least 32°C during testing. The neuropathies identified were sensory or mixed sensory and motor based on comparison of amplitudes, conduction velocities and latencies with their respective normal values. Each proximal neuropathy (median and ulnar) was defined as a categorical variable (yes/no) for the purposes of this study.

The CPT measurements were carried out using the Neurometer® CPT/C (Neurotron Incorporated) and the normal values established for this instrument [13]. The standard method of CPT testing has been well described [12,13] and was employed for all subjects with CPT measured at 2000, 250 and 5 Hz. The measurements were carried out on the volar surface of the tips of the index finger for the median nerve and the little finger for the ulnar nerve. The CPT measurements, nerve conduction measurements and determination of the Stockholm scale stage were all carried out in a blinded fashion.

All the analyses were done using SAS version 9.12 [21]. In the univariate analysis, categorical variables were analysed with non-parametric tests (chi-square or Fisher's exact tests). The continuous CPT variables were normally distributed at 2000 Hz but not at 250 or 5 Hz. Therefore, the 2000 Hz CPT variables were analysed with parametric tests [analysis of variance (ANOVA) and *t*-tests], whereas the 250 and 5 Hz CPT variables were analysed with non-parametric tests (Kruskal–Wallis and Wilcoxon rank sum tests). Duration of vibration exposure was also not normally distributed and its association with the Stockholm stages was analysed with the Wilcoxon rank sum test. Multivariate analysis was done using polychotomous logistic regression. The initial intent was to use polychotomous ordinal logistic regression due to the fact that the Stockholm scale is ordinal and to estimate odds ratios (ORs) for the Stockholm scale as a whole. However, this model assumes proportional odds or constancy of ORs across strata and the proportionality assumption was not met. We therefore used polychotomous multinomial logistic regression which does not require such an assumption. This type of regression estimates a separate set of coefficients for the different levels of the dependent variable in comparison to the same baseline level. Therefore, the effect of the independent variables on the odds of being at Stockholm sensorineural Stage 1 versus 0 and Stage ≥ 2 versus 0 was calculated separately. In each case, a full model was

created using all the variables found to be statistically significant in the univariate analysis and backwards elimination was then used to include variables that were statistically significant ($P < 0.05$) in the model. Additionally, any variables found to be statistically significant in any comparison of the Stockholm stages (1 versus 0 or ≥ 2 versus 0) were included in the other comparisons in the models in each hand. Goodness of fit of the models was tested with the goodness of fit chi-square test.

The participation of subjects was approved by the Research Ethics Board of St Michael's Hospital, a teaching hospital affiliated with the University of Toronto. Signed informed consent was obtained from all participants.

Results

A total of 157 men were asked to participate but two declined leaving 155 subjects in the study, a 99% participation rate. The participants had a mean (standard deviation) age of 46 (11) years. A total of 35 of the participants worked in the mining industry and the others worked in various industries, in particular various construction trades and the automotive industry. Review of the exposures by an industrial hygienist indicated that those working in mining had the highest daily exposure to vibration. The median duration of exposure to vibration of all participants was 22 years with a range of 1–47 years.

The number (per cent) of subjects at the Stockholm sensorineural scale stages was as follows: right hand: Stage 0: 51 (33%), Stage 1: 81 (52%), Stage ≥ 2 : 23 (15%) and left hand: Stage 0: 52 (34%), Stage 1: 83 (54%), Stage ≥ 2 : 20 (13%). There was a statistically significant association between being at Stage ≥ 1 in comparison to Stage 0 and both years of vibration exposure and daily vibration exposure (mining versus non-mining) in each hand.

The nerve conduction studies indicated that the percentages of subjects with neuropathy were as follows: right hand, median 35% and ulnar 6%; left hand, median 24% and ulnar 6%. The percentages of subjects with median neuropathy at the Stockholm scale Stage 0, 1 and ≥ 2 were 33, 36 and 35%, respectively, in the right hand and 27, 23 and 20%, respectively, in the left. The corresponding percentages for ulnar neuropathy were 2, 9 and 7% in the right hand and 4, 6 and 14% in the left. There were no statistically significant differences in the observed and expected numbers of cases of either median neuropathy (chi-square test) or ulnar neuropathy (Fisher's exact test) in the Stockholm sensorineural stages in either hand. In addition, there were no statistically significant differences in any of the CPT measurements in those with neuropathy of either type in comparison to those without (t -test or Wilcoxon rank sum test depending on CPT frequency).

There was a statistically significant difference between the CPT measurements in the three stages of the Stockholm sensorineural scale for each CPT frequency for the median and ulnar nerves in each hand (ANOVA or Kruskal–Wallis depending on CPT frequency; $P < 0.001$). There were statistically significant higher CPT measurements in Stage 1 versus 0 and Stage ≥ 2 versus 0 for each CPT frequency for the median and ulnar nerves in each hand (t -test or Wilcoxon test depending on CPT frequency; $P < 0.001$). However, the only CPT variable that showed a statistically significant difference in Stage ≥ 2 versus 1 was the median nerve in the left hand at 2000 Hz (t -test; $P < 0.05$) with the mean being higher in the higher stage. Therefore, the results of the univariate analysis suggested that the 2000 Hz CPT values might have the greatest association with the Stockholm sensorineural stages although this could have been a false-positive finding due to multiple significance testing. Figure 1 provides a visual display of the association between the Stockholm sensorineural stages and the mean and two standard errors of the mean of the CPT 2000 Hz measurements which, in general, show a noticeable increase in mean CPT between Stage 1 and 0 and Stage ≥ 2 and 0 but less of a difference between Stage ≥ 2 and 1.

Table 1 provides the polychotomous multinomial logistic regression results for the right and left hands. The variables considered for entry into the models were those found to be statistically significant in the univariate analysis including daily vibration exposure (mining versus non-mining), duration of vibration exposure and the CPT variables for the median and ulnar nerves at all three frequencies. In both Stockholm stage comparisons in both hands at least one 2000 Hz CPT variable was found to be statistically significant. The duration of exposure variable was statistically significant in three of the four stage comparisons and fell just short of statistical significance in the fourth. The CPT ulnar 2000 Hz variable was statistically significant in three of the four Stockholm stage comparisons, whereas the median CPT 2000 Hz variable was significant in two. The highest overall OR of 3.11 (95% CI: 1.65–5.85) was for the ulnar CPT 2000 Hz variable in the comparison of Stage 1 versus 0 in the left hand. These findings suggested that the ulnar variable was a slightly better predictor than the median variable. In both hands, only one CPT variable was statistically significant in the comparison of Stage 1 versus 0, whereas in the left hand both the ulnar and the median CPT variables were statistically significant in the comparison of Stage ≥ 2 versus 0. This suggested a progression of CPT abnormalities with progression up the Stockholm scale. Interaction terms were examined for duration of vibration exposure and each of the CPT 2000 Hz variables but none was statistically significant. The goodness of fit chi-square test was statistically significant ($P < 0.001$) for the models in each hand.

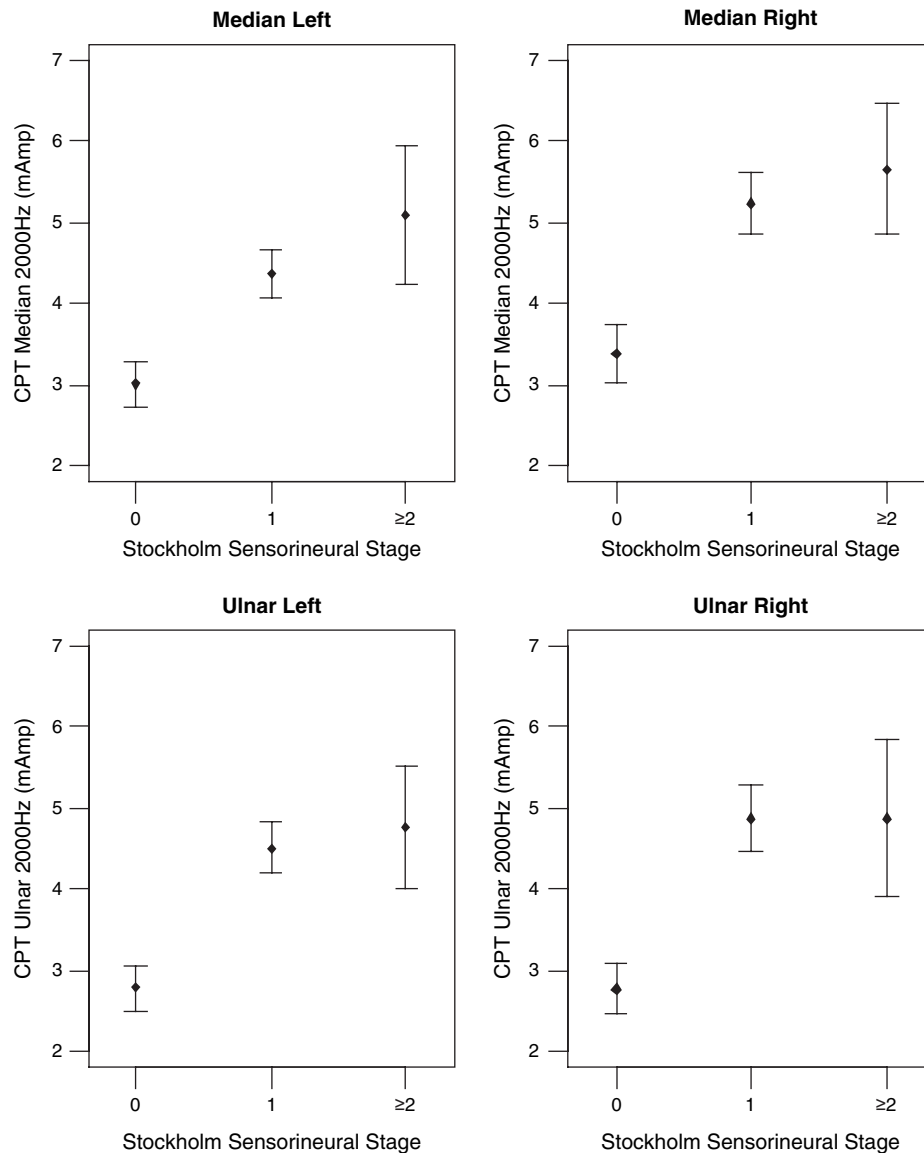


Figure 1. Relationship between the CPT 2000 Hz variables and the Stockholm sensorineural stage. The figures show the mean \pm 2 SE of the mean of each CPT 2000 Hz variable at each Stockholm sensorineural stage.

Discussion

We found statistically significant higher CPT measurements in Stockholm Stage 1 versus 0 and ≥ 2 versus 0 for each CPT frequency for the median and ulnar nerves in each hand. In contrast, neuropathy results measured by nerve conduction did not differ significantly between the Stockholm stages. Additionally, nerve conduction abnormalities were not associated with differences in CPT measurements indicating that the CPT abnormalities were not a manifestation of proximal neuropathy. Also, being at Stockholm Stage ≥ 1 versus Stage 0 was clearly associated with vibration exposure. Therefore, the CPT values at 2000 Hz appeared to be measuring an effect of vibration that was not due to proximal neuropathy.

However, CPT did not allow good discrimination between the higher stages of the Stockholm scale. The only CPT variable that showed a statistically significant difference in values between Stage 1 and ≥ 2 was the median nerve at 2000 Hz in the left hand. The logistic regression analysis indicated that the main CPT predictors of the Stockholm stages were the measurements at 2000 Hz.

Our study had several strengths. The sample size was reasonably large and all the subjects had standardized assessment and testing with attention to blinding during the data collection process. All the subjects were exposed to hand–arm vibration and it would have been useful to have had a comparison group not exposed to vibration. Also, despite the overall sample size, the subjects were

Table 1. Association between Stockholm sensorineural scale (SSN) stages and predictor variables: results of polychotomous multinomial logistic regression analysis

Side	SSN stages	Variable	OR (95% CI)
Right	1 versus 0	Vibration duration	1.04 (0.99–1.08)
		CPT median 2000 Hz	1.35 (0.82–2.22)
		CPT Ulnar 2000 Hz	2.26 (1.30–3.95)**
	≥2 versus 0	Vibration duration	1.06 (1.01–1.12)*
		CPT median 2000 Hz	1.85 (1.03–3.32)*
		CPT ulnar 2000 Hz	1.79 (0.95–3.36)
Left	1 versus 0	Vibration duration	1.04 (1.00–1.09)*
		CPT median 2000 Hz	1.51 (0.86–2.65)
		CPT ulnar 2000 Hz	3.11 (1.65–5.85)***
	≥2 versus 0	Vibration duration	1.07 (1.01–1.13)*
		CPT median 2000 Hz	2.40 (1.21–4.78)*
		CPT ulnar 2000 Hz	2.45 (1.15–5.21)*

Vibration duration: per year; CPT: per mAmp. The intercept refers to the expected value of the dependent variable in the logistic regression equation when all the other predictor variables are zero.

* $P < 0.05$, ** $P < 0.01$, *** $P < 0.001$.

distributed in three stages of the Stockholm scale which reduced the power of the univariate and multivariate tests when comparing stages. There was a very high participation rate (99%) in our study and therefore a bias was not introduced by low participation of recruited subjects.

The quantitative sensory tests usually used to grade the Stockholm scale stages are VPT and TPT [10,11]. The combination of these tests allows measurement of the main sensory fibres in the fingers that are also measured by CPT. If the CPT is to be used clinically in place of conventional tests, the diagnostic benefit needs to be demonstrated and, in this regard, the inability of the CPT to discriminate the higher stages of the Stockholm scale is not encouraging. Therefore, the CPT may not offer an advantage over currently used tests.

Previous studies of manual workers have found an association between carpal tunnel syndrome and CPT abnormalities [16,17] but we found no such associations. Both vibration exposure of the fingers and proximal neuropathy may affect CPT measurements in the fingers. Possibly in the workers in our study, the effect of vibration on the fingers was sufficiently large to eliminate any measurable effect due to proximal neuropathy.

A previous study by Lander *et al.* [19], conducted in the same setting as our study but using completely different data from subjects assessed in an earlier time period, found a statistically significant association between CPT measurements for the ulnar nerve and the Stockholm sensorineural scale. The CPT data available were categorical

(any abnormality at any frequency) which prevented evaluation of frequency-specific CPT effects [22]. Kurozawa and Nasu [23] found that the mean CPT values for the median nerve at 2000 Hz and the ulnar nerve at 2000 Hz were both statistically significantly increased in 59 men with the sensorineural component of HAVS in comparison to 20 non-exposed controls. These differences were present for subjects at every stage of the Stockholm sensorineural scale in comparison to the controls. Therefore, their results were similar to ours. However, Kurozawa and Nasu did not evaluate the potential effect of proximal neuropathy on the CPT results.

Stromberg *et al.* [24] found that nerve conduction results did not differ significantly among the sensorineural stages of HAVS. The VPT, but not the TPT, results did show a statistically significant elevation in the highest stage of the Stockholm sensorineural scale in comparison to the other stages. The VPT measures sensory thresholds in large myelinated fibres corresponding to the CPT measurements at 2000 Hz [19]. Therefore, our results were consistent with those obtained by Stromberg *et al.* [24] in terms of the type of fibres affected by vibration.

Krajnak *et al.* [25] have shown that acute high exposure of the rat tail to vibration was associated with an increase in CPT at 2000 Hz but not at 250 or 5 Hz. Hence, these acute results in animals were consistent with our results in chronically exposed workers in terms of the frequency specificity of CPT effects. Chang *et al.* [26] have shown that chronic exposure of the rat tail to vibration is associated with ultrastructural changes in myelin sheaths of large myelinated fibres and biopsies of workers with HAVS have shown similar morphological changes [27,28]. Therefore, our results, in conjunction with previous research, show coherence of evidence of damage to large myelinated nerve fibres associated with direct, local vibration exposure at the histological, animal and human level.

There is increasing evidence that carpal tunnel syndrome may also be associated with hand–arm vibration exposure [29]. This suggests that two types of neurological lesions may be associated with hand–arm vibration exposure including distal lesions in the digital nerve fibres and/or sensory receptors and more proximal lesions, in particular at the wrist involving the median nerve. The current Stockholm sensorineural scale focuses only on the distal neurological lesions.

Future research should evaluate the functional significance and the best methods of measurement of these distal neurological lesions. The CPT data in our study were continuous and future research might evaluate which specific nerves, frequencies and cutoff points for a positive test optimize CPT test performance as well as how the CPT performs in comparison to VPT and TPT. Also, the role of vibration exposure, ergonomic factors and work practices in the aetiology of the proximal neuropathies still needs to be better understood.

Key points

- Current perception threshold was increased in Stage 1 and ≥ 2 in comparison to Stage 0 of the Stockholm sensorineural scale, but Current perception threshold did not discriminate well between Stage 1 and ≥ 2 .
- The main Current perception threshold frequency affected was at 2000 Hz indicative of damage to large myelinated nerve fibres.
- There was no association between median or ulnar neuropathy measured by nerve conduction tests and the Stockholm sensorineural stages.

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Disclaimer

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Conflicts of interest

None declared.

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