Nagoya J. Med. Sci. **57 (Suppl.)**. 27 ~ 41, 1994

CLINICAL ASSESSMENT OF HAND-ARM VIBRATION SYNDROME

PETER L. PELMEAR[1] and ROBERT KUSIAK[2]

[1]*Department of Occupational and Environmental Health, St. Michael's Hospital, Toronto, Ontario, Canada,* [2]*Health and Safety Policy Branch, Ministry of Labour, Toronto, Ontario, Canada*

ABSTRACT

The clinical assessment of patients thought to be suffering from hand-arm vibration syndrome (HAVS) requires the use of multiple vascular and sensory tests. In a family physician's office, Adson's, Allen's and cold water immersion of the hands are the only feasible vascular tests, while the sensory tests have to be limited to assessing impairment of skin sensitivity and manipulative dexterity. This paper reviews the laboratory tests deemed to be useful in a hospital or clinic facility, and reports on the investigation of 364 patients exposed to hand-arm vibration who were examined in Toronto, Canada during the period 1989–92. A statistical clustering algorithm was used to categorise 138 male subjects according to the results of their diagnostic tests. From the cluster analysis, four vascular and four sensorineural categories of impairment were recognised in patients suffering from HAVS. The Stockholm vascular classification stages and the four vascular clusters were found to correspond. The Stockholm sensorineural classification (Stages 1, 2, and 3) correlated with clusters formed from the sensory tests evaluating the sensitivity of the nerve endings and the distal digital branches of the median and ulnar nerves. When the myelinated nerve fibres were affected, as detected by abnormal Tinel's, Phalen's, and nerve conduction tests, an additional cluster group emerged. The subjects with abnormal nerve conduction test results constituted a distinct group with increased impairment, so there is a need for them to be categorised separately i.e. as a Stage 4. It is suggested that a Stage 4 be included in the Stockholm sensorineural classification.

Key words: Hand-arm vibration syndrome, Stockholm classification, Clinical assessment, Clinical tests

INTRODUCTION

The diagnosis of hand-arm vibration syndrome (HAVS) is based initially on a history of hand-arm vibration (HAV) exposure and the exclusion of other causes of Raynaud's phenomenon i.e. Primary Raynaud's phenomenon (Raynaud's disease or constitutional white finger), and Secondary Raynaud's phenomenon from local trauma to the digital vessels, thoracic outlet syndrome, drugs, peripheral vascular disease, and collagen diseases, including scleroderma. The diagnosis of HAVS is confirmed and the severity assessed by stage from the results of laboratory tests.[1–4]

In a family physician's office, the only feasible vascular tests are (1) Adson's,[5] to determine thoracic outlet obstruction (2) Allen's,[6] to check the effectiveness of the circulation in the superficial and deep palmer arches, and (3) immersion of the hands in cold water to stimulate blanching. Often the latter will be unsuccessful because central body cooling is usually required in addition to hand cooling. The sensory tests which are feasible for the family physician to use to detect diminished skin sensitivity are pin prick, cotton wool, or monofilament hairs (von Frey or Semmes-Weinstein); together with callipers for two-point discrimination.

To confirm the diagnosis and grade the severity, sophisticated tests in clinics or hospital

Correspondence: Dr. Peter L. Pelmear, Department of Occupational & Environmental Health, St. Michael's Hospital, 30 Bond Street, Toronto, Ontario M5B 1W8, Canada

departments will be required. The vascular tests should include most or all of the following, i.e. Doppler and Duplex studies (to check the patency and the blood pressure ratios in the peripheral vessels), plethysmography (to evaluate the pulse waves before and after cold stress), finger systolic pressure measurement (to compare the blood pressure of an affected digit pre- and post-cold stress with the thumb, which is not usually affected), and cold water provocation tests (immersion of the digits in water for 2 to 10 minutes with recording of skin temperature) to note any reactive hyperaemia while immersed, and delay in recovery afterwards.

The sensorineural tests should include depth sense and two-point discrimination using von Frey or Semmes-Weinstein monofilament hairs, callipers, or plastic blocks with split levels and widening grooves,[7] and one or more of the following subjective tests i.e. (1) finger tip vibration threshold measurement (8 to 500 Hz with vibrometer instrumentation[8]), (2) thermal hot/cold perception (using Minnesota thermal discs[9] or instrumentation[10]), and (3) current perception threshold (detection of a 0 to 10 milliamperes current at 5, 250 and 200 Hz[11]). Objective nerve conduction tests[12] should be undertaken to confirm the presence and severity of the neuropathy, which in HAVS patients often affects both median and ulnar nerves.[1]

MATERIALS AND METHODS

A laboratory designated to the evaluation of the vascular and sensorineural effects of HAV on workers was established in Toronto, Ontario in 1988 and the case data has been entered in a computer database. The medical assessment included completion of a history questionnaire; a medical examination of the upper torso, cardiovascular and central nervous systems; and multiple clinical and laboratory tests (including urine and blood analyses to identify any systemic diseases). The vascular test results included in the computer database were Adson's, Allen's, doppler pressure measurements (arms and digits), digital plethysmography (pre- and post-cold stress), Digimatic systolic pressures, and digit temperature recording (cooling to 10°C for 10 minutes). The neurological test results recorded included two-point and depth sense aesthesiometry, grip strength, vibrotactile sensation, current perception neurometry, and nerve conduction latency and velocity. For each subject, the type of tools used, the mean vibration levels, and the exposure time were recorded.

METHODOLOGY

A Stockholm staging (history) for each hand, based upon the history information alone, was recorded. Following a review of all the test results the hand severity impairment was regraded and the Stockholm staging (diagnostic) was recorded.

Adson's test[5] was conducted in the traditional manner with the head rotated to both sides to determine thoracic outlet obstruction, also Allen's test[6] to evaluate arterial circulation at or distal to the wrist.

Photocell Plethysmography — tracings from all digits of both hands were obtained in the warm state, and the test was repeated following 2 minutes immersion in water at 10°C. The tracings are interpreted as showing abnormality (mild, moderate, severe) or no abnormality pre- and post-cold stress.

Finger Systolic Pressure (FSP) Test — this test was performed according to the procedure suggested by Nielsen and Lassen.[13] The blood pressure of the middle or worst finger was recorded at 30°C, then again following 5 minutes ischaemia at 10°C. The reference digit used was the thumb. A $FSP\%_{10}$ of 60% or less was used as the discriminating threshold between normal and abnormal as suggested by Bovenzi.[14] If the result was normal at room temperature the patient was wrapped in a cooling blanket at 10°C for 15 minutes and the test repeated.

Cold Water Immersion Test — thermocouples were attached to the tips of each digit to record the threshold skin temperatures for 5 minutes. The hands were then immersed in a cold water bath for 10 minutes and a sphygmomanometer was inflated around each wrist for the initial 5 minutes. In order to monitor reaction while immersed and during the recovery phase, the skin temperatures of the digits were recorded throughout the immersion period and for a further 15 minutes following immersion. The data from the thermocouples was continuously recorded using a portable temperature recorder, and a digital computer output with graphs was produced for analysis. In the normal subject after the sphygmomanometer cuff is released, there is a reactive hyperaemia while immersed, and rapid recovery following immersion. As vasospasm to cold increases in severity there is less hyperaemic reaction, and recovery is increasingly prolonged.[15]

All the following sensory tests were conducted after a vibration free interval of 16 hours. Depth sense aesthesiometry and two-point discrimination was conducted using the technique of Carlson et al..[7] Grip strength was measured by means of a dynamometer. Tinel's[16] and Phalen's[17] tests were used to detect median nerve compression neuropathy.

Vibrotactile Perception Threshold Test — this test was conducted using a Bruel & Kjaer Vibrometer type 1800/WH 1763 with hand switch. The 5 mm tip was counterbalanced so as to exert a uniform pressure of 0.5 Newtons on the test finger (middle) and the perception threshold at the 8, 16, 31.5, 65, 125, 250, and 500 Hz frequencies was recorded using the technique advised by the manufacturer and Lundborg et al..[18]

Current Perception Threshold Test — using a neurometer (supplied by Neurotron Inc., Baltimore, Maryland.) and the method described by Katims et al.,[19] a constant alternating current of 0 to 10 mA intensity at 5, 250 and 2000 Hz was transmitted to the index and little fingers of both hands to determine the detection threshold. Normative values are used for a computerized method of grading the severity of any median and ulnar nerve neuropathy.[20]

Nerve Conduction Test — the electrodiagnostic tests were conducted with a TECA TD5 Electromylograph using a standard protocol. The latency of the sensory and motor components of the median and ulnar nerves was determined across the wrist, then the motor latency from above the elbow. Subsequently, the motor conduction velocity in the forearms was derived. The results reflect the state of the largest most rapidly conducting myelinated fibres, both motor and sensory.

SUBJECT SELECTION AND ANALYSIS

The results obtained from 364 subjects examined during the period 1989—1992 have been analysed. All subjects who had been exposed to significant hand-arm vibration away from work; who had suffered significant injuries or disease — cardiovascular, neurological, rheumatoid, connective tissue, Dupuytren's contracture, or constitutional white finger (Raynaud's disease); those on cardiovascular medication; those who had the cold water immersion test prior to the use of the portable temperature recorder in February 1990; or who were female were excluded, leaving 173 men available for analysis.

The current perception threshold test was introduced as an additional sensory test in October 1990, much later than the others, so the cluster analysis of the sensory test results do not include these results. For the cluster analysis by the SAS FASTCLUS procedure, the results from each hand were used separately. The diagnostic tests were normalised to have means of zero and standard deviations of one before being used in the FASTCLUS procedure. The cluster analysis was used to determine how many clusters could be found utilizing the vascular test results alone, and the sensorineural test results alone in each hand. To be included in a cluster each subject was required to have a complete set of vascular or sensory test results. For this reason the subject totals varied slightly between hands and clusters. As part of the cluster analysis, a discriminant analysis was done to confirm the results of the cluster analysis. The discriminant analysis calculated weighted sums of the results of the diagnostic tests which could be used to determine the cluster to which a subject should be assigned.

RESULTS

The agreement between the history and diagnostic Stockholm staging in this group of subjects, as reported elsewhere[1] was low. For the vascular component, agreement was 35% and the history staging was more severe than the diagnostic staging in 39%. For the sensorineural component, the corresponding percentages were 37% and 17% respectively.

The results of the cluster analysis show that the subjects could be classified, utilizing the vascular tests, into four clusters with the right hand data and three with the left. Using the sensory tests, four clusters were obtained with both hands. Tables 1(a) and 1(b) compare the vascular clusters with the Stockholm history (SH) and Stockholm diagnostic (SD) vascular staging in the separate hands. The results for the hands combined reveal a strong correlation with the SD ($p=4 \times 10^{-11}$) but not with the SH stages ($p=0.3$). Tables 2(a) and 2(b) compare the sensory clusters with the SH and SD sensorineural staging. Similarly, there is a strong correlation between the sensory clusters and the SD ($p=3 \times 10^{-14}$), and unlike the vascular clusters there is a correlation with the SH stages ($p=9 \times 10^{-8}$). The totals in Tables 1 and 2 differ because the analysis was restricted, as mentioned earlier, to those subjects having complete sensory or vascular test results.

Tables 3(a) and (b) compare the vascular and sensory clusters for the right and left hands. A correlation between these two categories could not be found for the right hand ($p=0.4$) or both hands combined ($p=0.2$), although a weak correlation may be present in the left hand ($p=0.04$). It must be appreciated that the subjects in the vascular cluster 1 differ from the subjects in the sensory cluster 1, and this applies to the other clusters as well. For example, although 68 men in vascular clusters 2 and 4 suffered severe vascular effects (Table 3(a)) only 14 of the 68, the men in sensory clusters 3 and 4, suffered severe sensory effects.

Table 4 compares the temperature changes in degrees centigrade at 3 minutes following immersion in the cold water bath, for the middle finger in both hands by vascular cluster. Since the right hand has a cluster at 14°C which does not have a corresponding cluster in the left hand, it appears that in this series of cases the left hand has suffered more vascular impairment than the right. As can be seen from the Table, for each cluster the remaining mean temperature changes in the right and left hands compare well.

In general, the data analysis shows that the mean sensory test values of the sensory clusters of the right and left hands correspond. Table 5 compares the vibrometer means for low (8 to 125 Hz) and high (250 and 500 Hz) frequency groupings. In both the low and high frequency groups, the mean vibrometer thresholds in the left and right hands are very similar for the men who are mildly, severely and very severely affected. In the moderately affected men, the mean vibrometer scores for both the low and high frequency groups appear to be lower for the left hand. It also appears that the low frequency vibrometer thresholds for the left hand define four distinct degrees of sensory impairment. In the high frequency group in the left hand and in both

Table 1(a). Comparison of vascular clusters with Stockholm History and Diagnostic Vascular Stagings — right hand.

Severity (Vascular cluster)	Stockholm history vascular staging					Total
	0 (0)	Mild (1)	Moderate (2)	Severe (3)	Very severe (4)	
Mild (1)	0	5	3	4	5	17
Moderate (3)	0	5	2	1	2	10
Severe (2)	0	16	7	15	10	48
Very severe (4)	0	9	5	14	6	34
Total	0	35	17	34	23	109

Chi-square for test of no association between vascular clusters and Stockholm history vascular staging is 5.2 on 9 degrees of freedom, P=0.8.

Severity (Vascular cluster)	Stockholm diagnostic vascular staging					Total
	0 (0)	Mild (1)	Moderate (2)	Severe (3)	Very severe (4)	
Mild (1)	0	1	14	2	0	17
Moderate (3)	0	6	4	0	0	10
Severe (2)	0	8	34	4	2	48
Very severe (4)	0	0	10	15	9	34
Total	0	15	62	21	11	109

Chi-square for test of no association between vascular clusters and Stockholm history vascular staging is 59.6 on 9 degrees of freedom, $P=2\times10^{-9}$.

frequency groups in the right hand, there are only 3 distinct sensory impairment groups.

Tables 6(a) and 6(b) compare the current perception test thresholds for the median and ulnar nerves at 2000, 250 and 5 Hz. It should be noted, as stated earlier, that this test was not included in the analysis for the cluster group separation. When the clusters are ranked by the mean total score for each nerve, they have the same severity ranking order as the sensory

Table 1(b). Comparison of vascular clusters with Stockholm History and Diagnostic Vascular Stagings — left hand.

Severity (Vascular cluster)	Stockholm history vascular staging					Total
	(0)	Mild (1)	Moderate (2)	Severe (3)	Very severe (4)	
Moderate (1)	0	8	3	3	2	16
Severe (2)	0	19	7	12	13	51
Very severe (3)	0	13	6	16	8	43
Total	0	40	16	31	23	110

Chi-square for test of no association between vascular clusters and Stockholm history vascular staging is 4.8 on 6 degrees of freedom, P=0.6.

Severity (Vascular cluster)	Stockholm diagnostic vascular staging					Total
	(0)	Mild (1)	Moderate (2)	Severe (3)	Very severe (4)	
Moderate (1)	0	7	9	0	0	16
Severe (2)	0	5	36	7	3	51
Very severe (3)	0	2	17	16	8	43
Total	0	14	62	23	11	110

Chi-square for test of no association between vascular clusters and Stockholm history vascular staging is 34.1 on 6 degrees of freedom, $P=6\times10^{-6}$.

clusters derived from the other sensory tests. At the higher frequencies the mean severity scores correspond to the severity of sensory impairment with both the median and ulnar nerves. But at the low frequency (5 Hz) the mean severity scores appear to be weakly related to the sensory clusters.

Table 7 compares the cluster groupings at 250 Hz thresholds for the vibrometer and current perception tests. The vibrometer thresholds for the median nerve appear to correlate well with the current perception scores. This is less so with the ulnar nerve.

Table 8 compares the clusters by nerve conduction latencies. This test clearly identifies as a distinct group the most severely affected subjects, i.e. a cluster 4.

Table 2(a). Comparison of sensory clusters with Stockholm History and Diagnostic Sensorineural Stagings — right hand.

Severity (Sensory cluster)	Stockholm history sensorineural staging					Total
	(0)	Mild (1)	Moderate (2)	Severe (3)	Very severe (X)	
Mild (2)	0	6	15	13	4	38
Moderate (1)	0	2	16	40	10	68
Severe (3)	0	0	3	11	4	18
Very severe (4)	0	0	3	5	6	14
Total	0	8	37	69	24	138

Chi-square for test of no association between sensory clusters and Stockholm history sensorineural staging is 23.5 on 9 degrees of freedom, P=0.005.

Severity (Sensory cluster)	Stockholm diagnostic sensorineural staging					Total
	(0)	Mild (1)	Moderate (2)	Severe (3)	Very severe (X)	
Mild (2)	0	6	6	17	9	38
Moderate (1)	0	3	7	29	29	68
Severe (3)	0	0	0	5	13	18
Very severe (4)	0	0	0	1	13	14
Total	0	9	13	52	64	138

Chi-square for test of no association between sensory clusters and Stockholm history sensorineural staging is 30.7 on 9 degrees of freedom, P=0.0003.

Table 9 compares the clusters by grip strength, and the clusters correspond in order of severity with all the sensory tests, except nerve conduction latency.

DISCUSSION

The evaluation of HAV exposed subjects and their grading according to the Stockholm

Table 2(b). Comparison of sensory clusters with Stockholm History and Diagnostic Sensorineural Staging — left hand.

Severity (Sensory cluster)	Stockholm history sensorineural staging					Total
	(0)	Mild (1)	Moderate (2)	Severe (3)	Very severe (X)	
Mild (1)	0	8	15	16	2	41
Moderate (4)	0	0	5	11	8	24
Severe (3)	0	2	12	30	6	50
Very severe (2)	0	0	1	9	4	14
Total	0	10	33	66	20	129

Chi-square for test of no association between sensory clusters and Stockholm history sensorineural staging is 28.7 on 9 degrees of freedom, $P=7\times10^{-4}$.

Severity (Sensory cluster)	Stockholm diagnostic sensorineural staging					Total
	(0)	Mild (1)	Moderate (2)	Severe (3)	Very severe (X)	
Mild (1)	0	6	6	24	5	41
Moderate (4)	0	0	0	1	23	24
Severe (3)	0	0	5	24	21	50
Very severe (2)	0	0	0	4	10	14
Total	0	6	11	53	59	129

Chi-square for test of no association between sensory clusters and Stockholm history sensorineural staging is 64.5 on 9 degrees of freedom, $P=2\times10^{-10}$.

Workshop stages[21,22] is a well established protocol now for most HAVS assessment studies. The patient's history is not sufficient to stage severity since, as shown from this analysis, subjects tend to exaggerate their symptoms. Furthermore the assignment of an individual to a Stockholm diagnostic stage can be influenced by the personal judgement of the physician so an assessment method more objectively linked to the diagnostic test results is required. This is especially so when worker's compensation and litigation are an issue. To determine the degree of sensory and

Table 3(a). Comparison of vascular and sensory clusters — right hand.

Severity (Vascular cluster)	Vascular Severity (Clusters)				Total
	Mild (1)	Moderate (3)	Severe (2)	Very severe (4)	
Mild (2)	4	1	17	5	27
Moderate (1)	8	3	17	15	43
Severe (3)	2	2	3	5	12
Very severe (4)	1	1	2	4	8
Total	15	7	39	29	90

Chi-square for test of no association between sensory and vascular clusters is 9.2 on 9 degrees of freedom, P=0.4.

Table 3(b). Comparison of vascular and sensory clusters — left hand.

Severity (Vascular cluster)	Vascular Severity (Clusters)			Total
	Moderate (1)	Severe (2)	Very severe (3)	
Mild (1)	6	14	14	34
Moderate (4)	0	4	6	10
Severe (3)	1	22	10	33
Very severe (2)	3	3	3	9
Total	10	43	33	86

Chi-square for test of no association between sensory and vascular cluster is 13.4 on 6 degrees of freedom, P=0.04.

vascular impairment it is preferable to reference the results of tests. The mean values of tests in the vascular and sensory clusters could be used for this purpose. The cluster analysis, as used in this study, permits the objective separation of individuals based upon their individual and collective diagnostic test results.

The results from the analysis clearly indicate that significantly different categories (clusters) of

Table 4. Comparison of vascular clusters by mean temperature change in degrees centigrade at 3 minutes following immersion — middle fingers.

Hand	Vascular Clusters			
	Mild	Moderate	Severe	Very severe
Right	14°C	12°C	6°C	3°C
Left	—	11°C	7°C	4°C

Table 5. Comparison of sensory clusters by mean of thresholds at low frequencies (8 to 125 Hz) and at high frequencies (250 and 500 Hz).

Hand & frequency	Sensory Clusters			
	Mild (R2/L1)	Moderate (R1/L4)	Severe (R4/L3)	Very severe (R3/L2)
Right Low	111.1	129.0	131.0	141.6
Left Low	111.8	117.5	131.1	141.4
Right High	122.4	149.0	153.6	155.6
Left High	124.8	140.7	152.4	155.4

Key: R = right hand
L = left hand
1 to 4 = cluster

subjects suffering from HAVS exist. When separated into two groups, vascular and sensory, four cluster groups differing in rank order emerged with each group of tests. The mean values of the diagnostic tests in the vascular test and sensory test clusters differed between the two groupings, as did the order of severity.[23] For example, in the sensory group clusters, the temperature changes of the middle finger three minutes after removal from the cold water bath were similar ($p=0.8$), while for the vascular group clusters they were markedly different ($p<10^{-5}$).[23] This confirms that although there is an association between the vascular and sensorineural components of HAVS, the two components appear to both occur and progress independently of each other.

Another result from the analysis is that, within the vascular and sensory group clusters, the order of severity of the clusters differed between the different tests. The ranking order in the depth sense, two-point, current perception, vibrometer and grip strength tests was found to be comparable (Tables 5, 6, 7 and 9) in order of increasing severity in the respective hands i.e. clusters 2,1+4,3 right hand, and 1,4,3,2 left hand. Thus this group of tests would seem to be evaluating impairment and severity on the same basis. If the sensory cluster analysis had been limited to these tests, the number of clusters would have been no more than three. However

Table 6(a). Median nerve — comparison of sensory clusters by mean current perception hypoesthesia severity score.

Frequency	Sensory Clusters				p values
	Mild (R2/L4)	Moderate (R1/L1)	Severe (R4/L3)	Very severe (R3/L2)	(R/L)
2000 Hz	1.07/0.72	1.50/0.54	1.35/1.39	1.86/2.27	$0.4/8\times10^{-4}$
250 Hz	0.41/0.72	1.80/0.92	1.31/1.56	2.21/1.91	$5\times10^{-4}/0.06$
5 Hz	0.96/1.28	0.50/1.58	1.25/1.42	1.86/2.00	0.3/0.6
Totals	2.44/2.72	3.80/3.04	3.91/4.37	5.93/6.18	$7\times10^{-3}/0.02$

Key: R = right hand
L = left hand
1 to 4 = cluster

Table 6(b). Ulnar nerve — comparison of sensory clusters by mean current perception hypoesthesia severity score.

Frequency	Sensory Clusters				p values
	Mild (R2/L1)	Moderate (R1/L4)	Severe (R4/L3)	Very severe (R3/L2)	(R/L)
2000 Hz	0.26/0.29	0.82/0.67	0.80/1.07	1.57/2.18	$9\times10^{-3}/2\times10^{-4}$
250 Hz	0.59/0.63	1.12/0.89	1.50/1.59	2.07/1.91	0.02/0.03
5 Hz	1.11/1.33	1.22/1.11	1.30/1.73	2.00/1.91	0.2/0.4
Totals	1.96/2.25	3.16/2.67	3.60/4.39	5.64/6.00	$2\times10^{-3}/0.01$

Key: R = right hand
L = left hand
1 to 4 = cluster

when the sensory nerve conduction (latency) test (Table 8) is incorporated, a more severe cluster 4 emerges. This test strongly influences the ranking order of subjects in the right hand when all the sensory tests are included. The ranking order now becomes 2,1,3,4 in the right hand, while in the left the ranking order remains the same. The inclusion of nerve conduction tests in the cluster analysis clearly shows that the tests designed to evaluate the function of myelinated nerve fibres add a new dimension to the sensorineural grading, thus indicating the need for a forth sensory category.

It is usual when evaluating the merits of clinical tests to consider sensitivity and specificity. The usual gold standard is the presence or absence of disease. In respect to HAVS there are

Table 7. Comparison of sensory clusters at 250 Hz — current perception and vibrometer.

Vibrometer dB 250 Hz	Sensory Clusters				p values
	Mild (R2/L1)	Moderate (R1/L4)	Severe (R4/L3)	Very severe (R3/L2)	
Median N.	117/118	146/134	151/151	155/154	$<10^{-5}/<10^{-5}$

Current Perception score 250 Hz	Sensory Clusters				p values
	Mild (R2/L4)	Moderate (R1/L1)	Severe (R4/L3)	Very severe (R3/L2)	
Median N.	0.41/0.72	1.25/0.91	1.50/1.56	1.86/2.27	$5\times10^{-4}/0.06$

Current Perception score 250 Hz	Sensory Clusters				p values
	Mild (R2/L1)	Moderate (R1/L4)	Severe (R4/L3)	Very severe (R3/L2)	
Ulnar N.	0.59/0.63	1.12/0.89	1.50/1.59	2.07/1.91	0.02/0.03

Key: R = right hand
L = left hand
1 to 4 = cluster

grades of severity which are identified by the different tests. Hence the sensitivity and specificity of a specific test will depend on the severity grade e.g. plethysmography is highly sensitive and specific for early vascular impairment,[1] whereas Digimatic systolic pressure and nerve conduction tests are highly sensitive and specific only in the severe stages. These issues will be considered in a further paper.

CONCLUSION

1. By the use of cluster analysis, four vascular and four sensorineural categories of impairment can be recognised in patients suffering from HAVS.

2. There is an association between the Stockholm diagnostic stages and the clusters found in this survey for both vascular and sensory effects. The vascular stages and clusters correspond well, and it appears that the Stockholm vascular classification Stages 1, 2, 3, and 4 equate to the diagnostic vascular clusters 1, 3, 2, 4 (Tables 1(a) and (b)). Although it is more difficult to equate four sensory clusters and three sensorineural Stockholm stages (Tables 2(a) and (b)), there is

Table 8. Comparison of sensory clusters by nerve conduction latencies.

Motor Latency m. secs	Sensory Clusters				p values
	Mild (R2/L1)	Moderate (R1/L3)	Severe (R3/L2)	Very severe (R4/L4)	
Median N.	3.5/3.3	3.7/3.6	3.7/3.7	5.3/4.2	$<10^{-5}/<10^{-5}$

Motor Latency m. secs	Sensory Clusters				p values
	Mild (R2/L1)	Moderate (R1/L3)	Severe (R3/L2)	Very severe (R4/L4)	
Ulnar N.	2.6/2.47	2.6/2.49	2.6/2.52	3.0/2.83	$6\times10^{-4}/3\times10^{-5}$

Sensory Latency m. secs	Sensory Clusters				p values
	Mild (R2/L1)	Moderate (R1/L3)	Severe (R3/L2)	Very severe (R4/L4)	
Median N.	3.1/2.99	3.2/3.12	3.2/3.15	4.1/3.77	$<10^{-5}/<10^{-5}$

Key: R = right hand
L = left hand
1 to 4 = cluster

Table 9. Comparison of sensory clusters by grip strength.

Grip Strength	Sensory Clusters				p values
	Mild (R2/L1)	Moderate (R1/L4)	Severe (R4/L3)	Very severe (R3/L2)	
Kg.	48.1/47.95	44.9/46.98	42.1/42.32	32.3/22.32	$5\times10^{-4}/<10^{-5}$

an association between them. It appears that the Stockholm sensorineural classification Stages 1, 2, 3 equate to clusters formed from all the sensory tests evaluating the sensitivity of the nerve endings and the distal digital branches of the median and ulnar nerves.

3. When the myelinated nerve fibres are affected as detected by abnormal Tinel's, Phalen's, and nerve conduction tests, an additional cluster group emerges (Table 8). The subjects with

abnormal nerve conduction test results constitute a distinct group with further sensorineural impairment. A Stage 4 SN (noted as X in Table 2(a) and (b)) is suggested, requiring a revision of the Stockholm sensorineural classification.

4. The outcome of the analysis of this survey confirms that multiple tests are required to determine the severity of HAVS. The data obtained in this survey shows that both vascular and sensory changes occur in subjects with HAVS. Each component may occur and progress independently.

REFERENCES

1) Pelmear, P.L., Wong, L. and Dembek, B.: Laboratory tests for the evaluation of Hand-arm Vibration Syndrome. In *Proceedings 6th International Conference on Hand-Arm Vibration,* edited by Dupuis, H., Christ, E., Sandover, D.J., Taylor, W. and Okada, A., pp.817–827 (1993), Hauptverband der gewerblichen Berufsgenossenschaften, Sankt Augustin, Germany.

2) Pelmear, P.L. and Taylor, W.: Hand-arm Vibration Syndrome — Clinical evaluation. *J. Occup. Med.*, 33(11), 1144–1149 (1991).

3) Pelmear, P.L. and Taylor, W.: Clinical evaluation. In *Hand-Arm Vibration: A Comprehensive Guide,* edited by Pelmear, P.L., Taylor, W. and Wasserman, D.E., pp.77–91 (1992), Van Nostrand Reinhold, New York.

4) McGeoch, K.L., Taylor, W. and Gilmour, W.H.: The use of objective tests as an aid to the assessment of Hand-arm Vibration Syndrome by the Stockholm classification. In *Proceedings 6th International Conference on Hand-Arm Vibration,* edited by Dupuis, H., Christ, E., Sandover, D.J., Taylor, W. and Okada, A., pp.783–792 (1993), Hauptverband der gewerblichen Berufsgenossenschaften, Sankt Augustin, Germany.

5) Adson, A.W.: Surgical treatment for symptoms produced by cervical ribs and the scalenus anticus muscle. *Surg. Gynecol. Obstet.*, 85, 687–700 (1947).

6) Ashbell, T.S., Kutz, J.E. and Kleinert, H.E.: The digital Allen test. *Plast. Reconstr. Surg.*, 39, 311–312 (1967).

7) Carlson, W.S., Samueloff, S., Taylor, W. and Wasserman, D.E.: Instrumentation for measurement of sensory loss in the fingertips. *J. Occup. Med.*, 21(4), 260–264 (1979).

8) Lundborg, G., Lie-Stenström, A., Sollerman, C., Ströberg, T. and Pyykkö I.: Digital vibrogram: A new diagnostic tool for sensory testing in compression neuropathy. *J. Hand Surgery,* 11A(5), 693–699 (1986).

9) Dyck, P.J., Curtis, D.J., Bushek, W. and Offord, K.: Description of Minnesota thermal dices and normal values of thermal discrimination in man. *Neurology,* 24(4), 325–330 (1974).

10) Ekenvall, L., Nilsson, B.Y. and Gustavsson, P.: Temperature and vibration thresholds in vibration syndrome. *Br. J. Ind. Med.*, 43, 825–829 (1986).

11) Katims, J.J., Naviasky, E.H., Rendell, M.S., Ng, L.K.Y. and Bleecker, M.L.: New screening device for assessment of peripheral neuropathy. *J. Occup. Med.*, 28(12), 1219–1221 (1986).

12) Araki, S., Yokoyama, K., Aono, H. and Murata, K.: Determination of the distribution of nerve conduction velocities in chain saw operators. *Br. J. Ind. Med.*, 45, 341–344 (1988).velocities in chain saw operators. *Br. J. Ind. Med.*, 45, 341–344 (1988).

13) Nielsen, S.L. and Lassen, N.A.: Measurement of digital blood pressure after local cooling. *J. Appl. Physiol.*, 43, 907–910 (1977).

14) Bovenzi, M.: Finger systolic pressure during local cooling in normal subjects aged 20 to 60 years: reference values for the assessment of digital vasospasm in Raynaud's phenomenon of occupational origin. *Int. Arch. Occup. Environ. Health,* 61, 179–181 (1988).

15) Pelmear, P.L., Roos, J., Leong, D. and Wong, L.: Cold provocation test results from a 1985 survey of hard rock miners in Ontario. *Scand. J. Work Health,* 13, 343–347 (1987).

16) Mossman, S.S. and Blau, J.N.: Tinel's sign and carpal tunnel syndrome. *BMJ.*, 294, 680 (1987).

17) Heller, L., Ring, H., Costeff, H. and Solzi, P.: Evaluation of Tinel's and Phalen's signs in diagnosis of carpal tunnel syndrome. *Ear Neurol.*, 25, 40–42 (1986).

18) Lundborg, G., Sollerman, C., Stromberg, T., Pyykkö I. and Rosen, B.: A new principle for assessing vibrotactile sense in vibration-induced neuropathy. *Scand. J. Work Environ. Health,* 13, 375–379 (1987).

19) Katims, J.J., Naviasky, E.H., Rendell, M.S., Ng, L.K.Y. and Bleecker, M.L.: Constant current sine wave transcutaneous nerve stimulation for the evaluation of peripheral neuropathy. *Arch. Phy. Med. Rehab.*, 68, 210–213 (1987).

20) Katims, J.J., Rouvelas, P., Sadler, B.T. and Weseley, S.A.: Current perception threshold. Reproducibility and comparison with nerve conduction in evaluation of carpal tunnel syndrome. *Trans. Amer. Soc. Art. Int. Org.*, 35, 180–284 (1989).
21) Gemne, G., Pyykkö I., Taylor, W. and Pelmear, P.L.: The Stockholm Workshop scale for the classification of cold-induced Raynaud's phenomenon in the hand-arm syndrome (revision of the Taylor-Pelmear scale). *Scand. J. Work Environ. Health*, 13, 275–278 (1987).
22) Brammer, A.J., Taylor, W. and Lundborg, G.: Sensorineural stages of the hand-arm vibration syndrome. *Scand. J. Work Environ. Health*, 13, 279–283 (1987).
23) Pelmear, P.L., Kusiak, R. and Dembek, B.: Cluster analysis of laboratory tests used for the evaluation of hand-arm vibration syndrome. *J. Low Freq. Noise Vib.*, 12(3), 98–109 (1993).