Final Report

Project Title: ***Exposure Response Relationships in Hand-Arm Vibration***

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List of Terms and Abbreviations

HAVIC - Hand-Arm Vibration International Consortium
Segmental Nerve Conduction
Cold Challenge Plethysmography, Vibrometry
HAVS – hand-arm vibration syndrome
HAV – hand-arm vibration
Data Logging
Thermography
SNCV – sensory nerve conduction velocity

Abstract

The Hand-Arm Vibration International Consortium (HAVIC) is a collaboration of investigators from Europe and North America studying health effects from hand arm vibration (HAV). The consortium was funded by the National Institute for Occupational Health (NIOSH) to perform multi-cohort prospective studies to examine human responses to HAV exposure from 2000-20006. There were two new North American cohorts (dental hygienists and dental hygiene students), two existing cohorts (Finnish forest workers, and Swedish truck cab assemblers), and a previously studied population (US shipyard workers). Study instruments included surveys, quantitative medical tests (segmental nerve conduction, cold challenge plethysmography, vibrometry), physical examination, and work simulation and data logging to assess exposure. Exposure assessment was based on working day data logging of vibration and contact force. Sensors and belt-mounted portable computers were developed especially for this project. New methods were developed for performing specialized nerve conduction in the field and for measuring exposure through data logging.

Study Aims

- Characterization of the exposure response relationship for hand-arm vibration through a study design, incorporating multiple cohorts, some having existing historical data,
- Selection of cohorts to include different types of vibration: oscillatory (forest workers) impact (truck cab workers), high frequency (dental hygienists) and mixed (shipyard workers),
- Inclusion of two inception cohorts: dental hygiene students and Swedish truck cab workers,
- Inclusion of multiple cohorts from very different occupations to insure a range of exposures and responses.
- Selection of battery of “best tests” (cold challenge plethysmography, multi-frequency tactometry, segmental sensory nerve conduction velocity [SNCV]) applied across groups to quantify responses to exposure.
- Exposure characterization through daylong data logging at the individual level.

The HAVIC consortium developed and applied exposure and health assessment instruments across cohorts. Previous studies were available for both the Finnish-Suomussalmi forest workers and the Swedish truck cab workers, the latter constituting an inception cohort. Thus observations on the exposure response relationships could be extended beyond the relatively short duration of the study. Each cohort presented strengths and weaknesses. The North American shipyard cohort had been previously characterized and was known to have significant disease. A cohort of dental hygienists and students exposed to high frequency ultrasonic vibration had dramatic and interesting findings, but their exposures and presentation were very different from the industrial workers. The Suomussalmi cohort was reassembled only for this study; it was first assembled in 1972 and its survivors were in their last years of employment. The Swedish inception cohort had declined from 148 to 56 members over 13 years. Attrition was due career mobility decisions rather than to disease or lay-off. In fact, 100% of retained workers agreed to physical follow-up. This has important implications for the viability of future long-term cohort studies in a young inception group. In addition, our results had made it clear that the <3 year inter-test period, which was defined by the study funding period was too short to rationalize retesting, since a minimum of 5 years appeared to be required in order to assess meaningful change. Fortunately, early test data was suitable for inclusion.

Highlights/Significant Findings

Initial segmental SNCV on shipyard workers corresponded with the earlier observations of Sakikibara et al. That is, vibration exposed workers appeared to have slowed velocities in the digital segments, when compared to controls. As noted, results from this baseline study also suggested a possible etiologic relationship between warming method and SNCV results in vibration exposed subjects. The elimination of the temperature effect on nerve conduction velocity suggests another perspective for understanding the etiology of the hand-arm vibration syndrome.

The usefulness of the data logging method was confirmed in this study. Results were significantly different from other estimates, suggesting the importance of the technique and the unreliability of exposure matrix construction. Results on Swedish and Finnish workers also demonstrated a profile of exposures where disease incidence and progression appeared to be controlled or eliminated.

Because of flux in personnel, job content, and technology, the feasibility of future cohort studies like this must be questioned. The Suomussalmi cohort – a defined and isolated population with a single available employment – has been invaluable, but its recreation is very problematic.

With further analysis, the current data promises to identify a probable “safe” exposure-response level.

Translation of Findings

The effect of warming methods on SNCV, which was particularly dramatic in vibration-exposed workers, has already been communicated in public forums and has relevance to the interpretation of nerve conduction tests, particularly in this group.

The demonstration of a robust segmental nerve conduction test in the field has been reported in the literature and the technique can be replicated through this demonstration of method.

The fact that data logging produces uniformly different results than either surveys or observational matrices has been communicated in the open literature and has been submitted to ACGIH and the European Union.

The low level of disease in truck cab workers and the low level of new disease in forestry workers helps define a safe exposure range in the setting of appropriate ergonomics. This has been communicated in the open literature and to standard setting bodies.

Outcomes/Relevance/Impact

As noted above, an important outcome is evidence for a high level of neurologic abnormality in dental hygienists. This has been communicated in the open literature and at least one international research group is considering studies in this area. A major American stand setting group is currently reviewing this data and planning to incorporate precautions on dental exposures in its next review document.

The data suggests minimal disease in the setting of low vibratory exposures (anti-vibration tools) and optimized workplace design (good ergonomics). There appears to be interaction which supports the conclusion that vibratory control and elimination of HAVS is feasible at exposures identified in these studies, providing there is sufficient workplace design.

Scientific Report

Exposure Assessment and Data Logging

Vibration exposure measurements were made on a diverse sample of subjects that adequately represented the exposed workforce population within each cohort. Workers at each site were instrumented with a microcomputer-based Vibration Exposure Monitoring (VEM) system developed at the Biodynamics Laboratory of UCHC, which is about the size of a police walkie-talkie, to record user-specific tool-operating times, vibrations, and grip forces throughout all, or a representative part, of their workday. More specifically, data logging methods involved the direct monitoring of work cycles, involving tool operation time and calculated measures of tool vibration, namely the root-mean-square (RMS), root-mean-quad (RMQ), and root-mean-oct (RMO), and grip forces. Ultimately, the measurements made with the exposure monitor only provide estimates, given the nature of the root-mean and averaged calculations, for the time histories of accelerations entering the hands and for the grip forces exerted throughout the workday. These estimates were used to assist in the subsequent construction of vibration exposure metrics for the development of exposure-response relationships.

At the core of the custom-made exposure monitoring system is a low-power Motorola 68332 microprocessor with a PIC 16C64 coprocessor, which functions as a tunable system clock from 160 kHz to 16 MHz, and 256 kilobytes of flash EEPROM memory for program storage and one megabyte of resident RAM memory for data storage. This unit is manufactured specifically as a battery-powered data logger (Tattletale, Model 8v2, Onset Computer, Onset, MA) and draws less than 250 microamps in low-power mode and 150 milliamps under the most strenuous conditions. It has the capability of hosting and executing complex protocols to control, collect, and process the sampled data from up to 8 analog channels using 12-bit sampling at a single-channel maximum of 100 kHz. It weighs approximately one ounce and is resistant to shock and vibration and can operate over a -40^{O} to 65^{O} C temperature range. Because this technology was originally designed for simple applications of remote monitoring using low-resolution signals from sensors such as thermometers, barometers, humidistats, and speedometers sampled at very low frequencies, it had to be adapted for use as a high-frequency, eight-hour, VEM system by efficiently managing the data storage limitations.

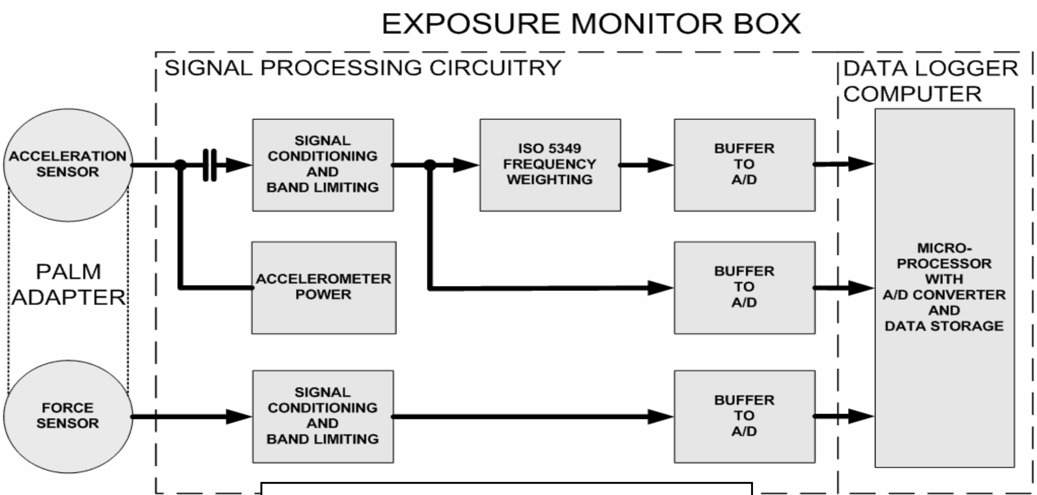


Figure 1. Block diagram of data logger

Under the current design, the data logger system is set to collect samples from three analog channels at 3 kHz per channel, involving broadband (frequency "unweighted") acceleration, frequency-weighted acceleration, and grip force. A custom-designed and constructed electronic circuit board is directly interfaced with the data logger system, as depicted in the flow chart of the VEM system, to pre-process the signals originating from the accelerometer (Model 352C22, PCB Piezotronics, Depew, NY) and the force sensor (Model 400, Interlink Electronics, Camarillo, CA), which were mounted in a palm adapter and secured to the subject's palm. Operational amplifiers are used as anti-aliasing and noise rejection bandpass filters with 4 and 1250 Hz as the frequency cutoffs for both sensor signals. The entire VEM system, including the ICP-type accelerometer in the palm adapter, is powered using three 9 V batteries and provides a clean +/- 5 V power supply to all components using power regulation circuitry that is also contained on the signal processing board

As was previously mentioned, the VEM system involved sampling the output of two sensors, a uniaxial accelerometer and a force sensitive resistor (FSR), which were mounted on the palm using a custom designed housing constructed entirely out of aluminum. The housing is sheathed in flexible rubber and is secured to the palm using elastic straps. The palm mounting system, or palm adapter, is not secured tightly to the palmar aspect of the hand, but is allowed to shift and roll slightly by design in order to provide a small margin of movement during its use to greatly reduce the potential for sensor cable, or strap breakage. The activation axis of each sensor is parallel as the force sensor and accelerometer are placed atop one another within the rubber sheathing and aluminum housing. The palm adapter is situated on the palmar surface so that the overall activation axis (i.e. both sensor activation axes taken as one) is perpendicular to the palmar surface even when it is 'sandwiched' between the tool handle and the hand. Its performance was validated by laboratory studies involving an electro-dynamic shaker outfitted with an instrumented handle.

Table 1. Sample Summary of Data Logging Results

	SHIPYARD (n = 52)		TRUCK CAB (n = 38)		FORESTRY (n = 8)	
	mean (sd)	min - max	mean (sd)	min - max	mean (sd)	min - max
Data Logger Operating Time	243.20 (99.40)	17 - 414	222.9 (64.20)	85 - 312	206.37 (7.54)	193 - 215
Weighted Accel^n – RMS	4.96 (7.27)	0.66 - 35.95	2.92 (2.05)	1.06 - 10.2	2.42 (0.88)	1.64 - 4.29
Weighted Accel^n – RMQ	14.66 (12.29)	2.88 - 63.32	11.85 (5.52)	6.06 - 29.41	7.8 (2.34)	5.97 - 12.72
Weighted Accel^n – RMO	33.06 (16.79)	9.31 - 89.81	29.4 (7.41)	21.35 - 53.85	24.81 (5.66)	21.59 - 38.64

Operating Time = minutes RMS= m/s^2, RMQ = m/s^4, RMO = m/s^8

Full shift data logging was performed on the shipyard, truck cab assembly, and forestry workers. The results pertinent to the present proposal are summarized in Table 1 above. There is a clear progression in vibratory exposure from forestry workers to shipyard workers that mirrors the relationship in symptoms. The weighted RMS discounts frequencies >125 Hz, the range that would be most reduced by AV gloves, uniformly worn by all Finnish workers. The RMO and RMQ are more reflective of impacts and higher frequencies. Although not shown in this table, equivalent metrics have also been formed without a frequency weighting (i.e., frequency unweighted RMS, RMQ and RMO). The relative differences in the RMS, RMQ and RMO ratios are being interpreted in terms of the observed symptoms and results of objective tests, in order to establish which metric better reflects the health effects. The results of this analysis will be used to determine the metrics to be included in the revised VEM system to be constructed.

Results from individual workers demonstrate another feature of the differentiation between vibration exposure at the hand and time of tool operations. There is a very poor correspondence between the daily minutes of vibratory exposure and vibratory energy recorded at the palm. Since the same tools were used to obtain the results in Figure 2, the variability is almost certainly a function of individual differences in coupling of the hand to the tool and handle-glove-hand and transmissibility. There is an important implication for an intervention study based around transmissibility through AV materials, namely any pre to post-intervention comparison of vibratory exposure requires a daylong exposure measurement for each subject. The combining of acceleration data logging with monitoring of handgrip and push-pull forces offers a practical solution to the problem of exposure measurement, and will be undertaken with apparatus developed in this proposal.

Figure 2. Correspondence between exposure duration and magnitude for individual workers

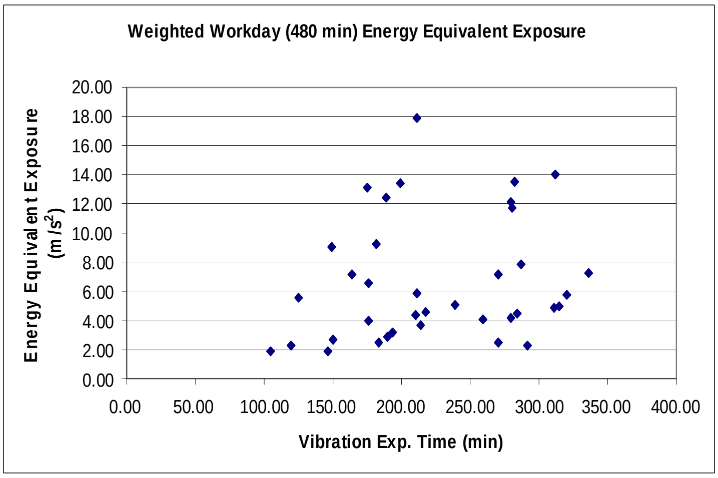
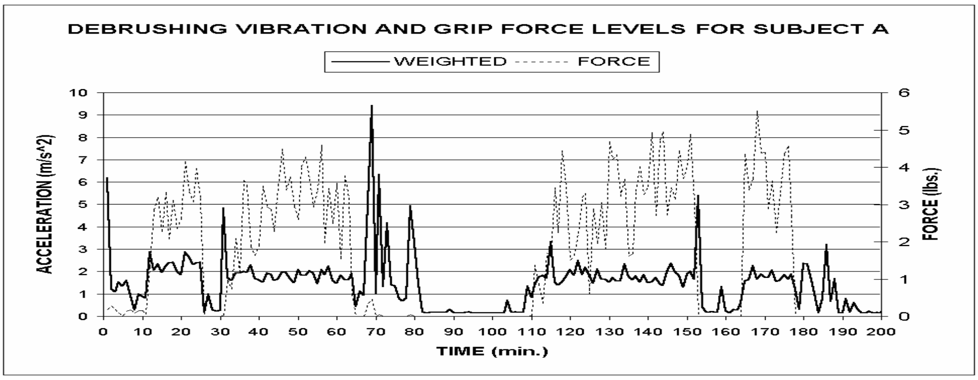
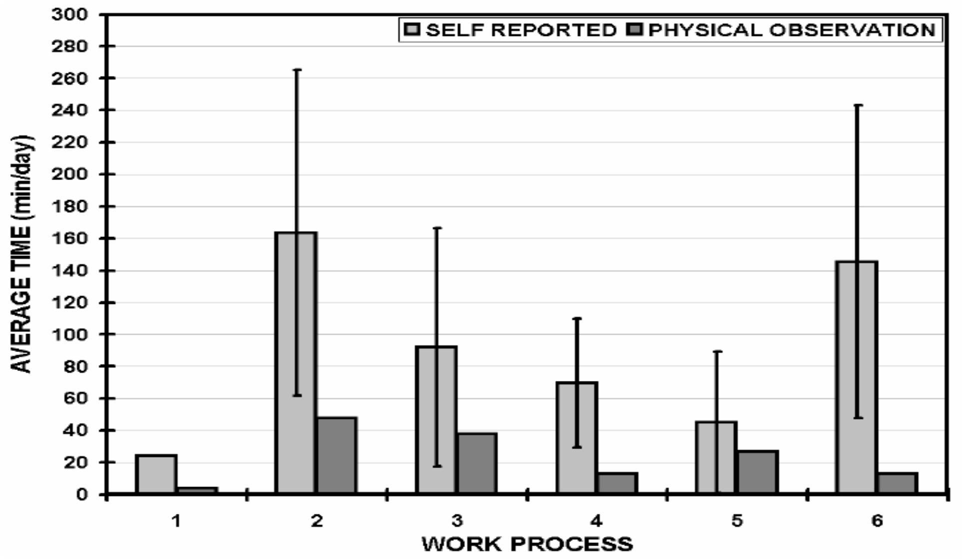


Figure 3. Comparing Vibration and Force Levels



The data logger record shown above in Figure 3 displays the frequency-weighted acceleration and contact force during 200 minutes of brush cutting by a single subject. The inconsistent relationship between contact force and energy absorption is represented. Implications are significant, since force estimates must be more precise than descriptive observation will allow. The problems posed by extrapolating exposure from an anamnestically derived matrix is further demonstrated in Figure 4, which compares same-day diary self-report of daily tool use with an estimate from a skilled observer. The poor association between direct observation and self-description coupled with the relative independence of exposure time and absorbed energy measurements undercuts the putative value of extrapolated exposure measurements which either substitute time for physical exposure or which rely on mixed measures of exposure time and type.

Figure 4. Correspondence between self-report and observed exposure time for workers by department



This laboratory's experience with data logging provides several insights.

1. Full-day multi-channel recording is feasible and reliable; however, significant piloting and laboratory validation is required to correct for system and artifactual noise.
2. Assessing contact force poses a very modest challenge compared with studying vibration, since the sampling frequency needed (<5 Hz) is 1000 times slower.
3. Patterns of work and movement are highly individualized, requiring that exposure be assessed at the individual level.

The practicality of exposure measurement from daylong monitoring was proven to be both feasible and replicable. While this satisfies a key study aim, it also renders problematic exposure metrics that rely on an extrapolation matrix or which mix modalities of exposure. The practical effect is that methods used to assess vibratory exposure traditionally must be called into question, but the feasibility of direct measurement can be offered as a robust replacement.

Review of Cohorts and Findings

As noted, European and United States industrial cohorts came with accumulated health and exposure databases, which were incorporated to telescope beyond the limits of a 5-year study. In the case of shipyard workers, there was survey and tool exposure data from 1988, although detailed subject testing was only available within the lifetime of the study, from 2001 to 2005. Tables 2 and 3. summarize the cohorts.

Cohort	*U.S. Shipyard Workers*	*Swedish Truck Cab Workers*	*Swedish Controls*	*Finnish Forest Workers*	*Experienced Dental Hygienists*	*Student Dental Hygienists*
Projected	220-230	148	90	80	80	80
Actual	217	56	34	61	94	66

Table 2. Cohort Summary

Table 3. Study Intervals for HAVIC Cohorts

Design	Duration	Populations	Time Line
Longitudinal, historical data inclusion, variable re-test intervals	2000-2006	• 217 US shipyard worker	→ baseline 2001→F/U 2004
		• 56 Swedish automotive workers	→ baseline 2002 -- 1990- 2002 comparison
		• 34 Swedish automotive controls	→ baseline 2002 -- 1990- 2002 comparison
		• 61 Finnish forestry worker	→ survey 2003 -- 1990-1995 comparison
		• 94 US dental hygienists	→ baseline 2001→F/U 2004
		• 56 US dental hygiene students	→ baseline 2001→F/U 2004

Table 4 demonstrates the considerable variation in cohort-specific directly measured exposure and the different patterns of disease presentation. The American shipyard workforce had high exposures, high levels of neuropathic findings, and high levels of carpal tunnel syndrome (CTS) diagnoses. The Finnish forest workers had lower levels of exposure, a low prevalence of CTS, but a relatively high level of paresthesias. The truck cab workers in Sweden had lower exposures and reduced evidence of disease.

Table 4. Baseline characteristics of HAVIC cohorts and data logged vibratory exposure

Cohort	**Baseline Test Year**	**Subject Tested**	**+ Hand Paresthesia**	**CTS Cases Physician Dxed Dominant Hand**	**Data Logged Subjects**	**Operating Time (min) mean (SD)**	**Weighted Accel^n – RMS mean (SD)**
Shipyard Workers	2001	217	146 (69%)	74 (35%)	53	243.20 (99.40)	4.96 (7.27)
Dental Hygienists	2002	94	42 (45%)	14 (15%)	--	--	--
Forestry Workers	2003	61	17(29%)	3 (6%)	8	206.37 (7.54)	2.42 (0.88)
Truck Cab Workers	2002	54	7 (12%)	2 (4%)	37	222.90 (64.20	2.92 (2.05)
Controls	2002	36	4 (11%)	0 (0%)	NA	NA	NA

--Dental Hygienists vibratory exposure was determined in simulation only and data is not comparable.

These data on truck cab workers and on forest workers substantiated that there was an exposure range and patterns that did not appear to lead to symptomatic disease.
The Finnish forest workers had cumulative health data on a cohort (n=52) that had been studied from 1976. For 18 of these subjects, there was detailed tactometry testing in 1990, 1995, and 2003. The following tables demonstrate that despite sensorineural symptoms being relatively high, they had not progressed over several years of observation in what was an aged cohort.

Table 5. Resurvey of Forestry Cohort (n=52)

Test Year	Vibration White Finger	Neurosensory Symptoms
1995	4 (8%)	21(40%)
2003	4 (8%)	17(33%

A hierarchy of chronic health effects was observed, with the effects for shipyard workers > truck cab workers > forestry workers. However, the Finnish cohort had no apparent progression of symptoms or abnormal tactometry. Of even greater significance, there was no progression in VPT among 18 subjects retested from 1990-2003. Improvement or deterioration in tactile acuity in individual hands was estimated from measurements of mechanoreceptor-specific VPTs conducted using the tactometer, and compared with symptoms determined by questionnaire and objective tests. Statistically significant positive threshold shifts (i.e., reductions in acuity) were found in one hand at induction (2.8%), and in five hands five years' later (13.9%) ($p < 0.0025$). Statistically significant positive changes in threshold over an initial five-year period (reductions in acuity) were recorded in a majority of the hands ($p < 0.005$), even though many workers remained symptom free. However, the introduction of a new generation of AV tools and gloves and a change in work practices after 1995 appeared to produce a significant effect. Despite being 8 years older, there was no progression of VPT in any of the 18 retested subjects in 2003. A fuller report on these findings is included in the bibliography.

Neurologic Effects of Hand Arm Vibration

A robust methodology and field technique for performing SNCV, divided into wrist, palmar and digital components, was developed and applied to all four consortium cohorts (see bibliography). As we had explained in earlier reports, we unexpectedly found a segment specific temperature/velocity relationship, not previously described in the peer-reviewed literature. This is presented below for the dental and shipyard cohorts. Results are shown for the median nerve in Table 6a: an identical pattern was observed for the ulnar nerve. The cross-palmar and cross-digit segments for the shipyard workers and experienced dental hygienists showed a significant velocity/temperature relationship, which was not observed across the wrist. The problems of segmental variation in the skin temperature-velocity association inspires a menu of explanations, including distal slowing due to myelin tapering, skin temperature flux due to variations in cutaneous blood flow, and discontinuity between near nerve and surface temperatures.

Table 6a. Change in Velocity per Segment Compared with Temperature Change (Hands Combined)

	Shipyard workers n=334		Dental hygienists n=181	
Nerve Segment	**ΔV/ Δ C(SD)**	***Prob > F****	**ΔV/ Δ C(SD)**	***Prob > F****
Median Nerve				
Proximal – distal digit	1.67 (0.38)	<0.0001	3.17 (0.47)	<0.0001
Palm – proximal digit	1.11 (0.38)	0.0041	2.83 (0.44)	<0.0001
Wrist – palm	0.22 (0.29)	0.4411	1.02 (0.42)	0.0155
Wrist – distal digit	0.58 (0.25)	0.0204	1.77 (0.34)	<0.0001
Wrist – proximal digit	0.54 (0.25)	0.0281	1.63 (0.38)	<0.0001

ΔV/ Δ C= velocity/ C^0 and SD Prob > F is Compared to slope Δ velocity/ Δ 1^0 C = 0*

These considerations were addressed in two ways. The first was an adoption of warming protocol relying on sub-maximal exercise on a bicycle ergometer (12 minutes ramped at 50-100 watts), followed by whole body warming in a controlled environment. This approach of exercise-based whole body warming had produced stable and prolonged surface temperatures in laboratory environments. In the second adaptation, infrared digital thermography (ISI Snapshot v. 2.1/Plymouth, MN) was utilized to record skin temperatures as volume averages of the inter-electrode segments, in order to provide an average surface temperature over the expected peripheral nerve course.

The results are presented below in Table 6b. The dramatic relationship between nerve conduction velocity and temperature in the palm and finger segments was eliminated by exercise warming in the median nerve and reduced in the ulnar nerve. These effects were particularly pronounced in the symptomatic shipyard cohort, implying a possible link between SNCV and vascular profusion.

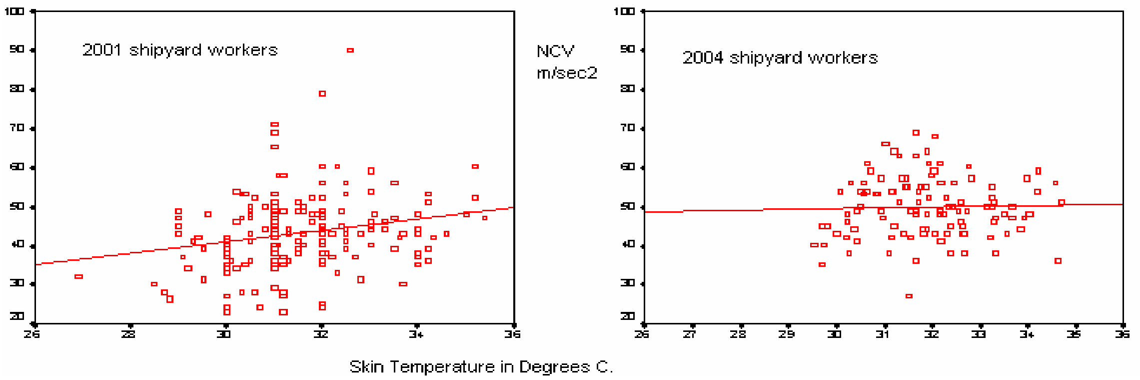
Table 6b. Segmental Nerve Conduction Velocity and Temperature Relationship [1]
Compared to slope Δ velocity/ Δ 1^0 C = 0

	2001[2]		2004[3]	
Nerve Segment	**Δ velocity/ Δ 1^0 C ± SD**	***p-Value***[5]	**Δ velocity/ Δ 1^0 C ± SD**	***p-Value***[5]
Median Nerve				
Proximal digit - distal digit	2.00 (0.43)	***<0.0001***	-0.01(0.44)	0.9760
Palm - proximal digit	1.17 (0.43)	***0.0077***	-0.01(0.45)	0.9746
Wrist - palm	-0.38 (0.35)	0.2870	0.53(0.43)	0.2149
Wrist - distal digit	0.33 (0.31)	0.2908	0.29(0.33)	0.3803
Wrist - proximal digit	0.36 (0.30)	0.2284	0.32(0.35)	0.3595
Ulnar Nerve				
Proximal digit - distal digit	2.09 (0.53)	***0.0001***	0.92(0.42)	***0.0298***
Palm - proximal digit	1.61 (0.64)	***0.0127***	0.40(0.45)	0.3749
Wrist - palm	0.52 (0.36)	***0.1468***	0.97(0.35)	***0.0060***
Wrist - distal digit	1.21 (0.25)	***<0.0001***	0.77(0.25)	***0.0020***
Wrist - proximal digit	0.70 (0.29)	***0.0166***	0.76(0.28)	***0.0068***

1. *Combined left and right hands n = 220*
2. *Point temperature at digit base*
   Surface Temperature (^{O}C)
   - *Median Nerve: mean (sd) = 31.59 (1.49), range = 27.30 – 35.20*
   - *Ulnar Nerve: mean (sd) = 31.55 (1.47), range = 27.30 – 35.20*
3. *Point temperature at digit base*
   Surface Temperature (^{O}C)
   - *Median Nerve: mean (sd) = 33.50 (1.18), range = 28.48 – 39.70*
   - *Ulnar Nerve: mean (sd) = 33.38 (1.32), range = 28.67 – 36.73*
4. *p-Value for difference between sample and slope=0.*
5. *p-Value for difference between slope for 2004 compared with 2001*

The following figure compares 2001 (externally warmed) and 2004 (exercise warmed) subjects. The temperature velocity relationship has disappeared even though the skin surface temperatures are the same. This change in protocol obviated longitudinal comparison of SNCVs for shipyard workers and dental hygienists, but the international study team was convinced that longitudinal measurements, without this level of standardization, would generate results that would be less meaningful than recordings using the exercise protocol. The concern was generic for all field SNCV and specific for cohorts with possible vascular disease.

Figure 5. R Median Nerve Digital Segment



Patterns of Vascular Disease: Vibration White Finger

Vascular disease is the hallmark vibration related disorder, although vascular testing suitable for fieldwork is considerably cruder than the other test modalities. The following table represents an incomplete profile of data that has been analyzed to date. The difference in shipyard workers between Class I disorder (Finger Systolic Blood Pressure[FSBP%]= 0 and Class II (FSBP%=30-70), reflects technician differences in ability to recognize an initiating pulse wave on four abnormal patients in the initial study. In reality, Class I and Class II are both abnormal, and when combined they are effectively identical. In an analysis of historical data from the shipyard workforce, performed as part of this study, we have shown that exposure cessation produces FSBP% improvement over 5 years from Class I-II status to normality, but no improvement or worsening was noted over the 30 month interval of this study. The truck cab workers present an interesting finding. The studies were all technically excellent. It is clear that there were mild abnormalities in 12% of the workforce and 0% of controls. There was no evidence of total arterial closure – FSBP%=0-30 in either group.

Table 7. Finger Systolic Blood Pressure Percent (FSBP%)

	0-30	***31-70***	***>70***	***Total***
	N /(%)	N /(%)	N /(%)	N /(%)
Shipyard Workers	30 (14.4%)	24 (11.5%)	154 (74.0%)	208 (100%)
Shipyard Workers –follow-up	11 (9.6%)	18 (15.8%)	85 (74.6%)	114 (100%)
Student hygienists	7 (10.9%)	5 (7.8%)	52 (81.3%)	64 (100%)
Experienced hygienists	8 (8.8%)	10 (11.0%)	73 (80.2%)	91 (100%)
Swedish truck cab workers	0 (0.0%)	6 (12.0%)	44 (88.0%)	50 (100%)
Swedish reference	0 (0.0%)	0 (0.0%)	33 (100%)	33 (100%)
Finnish forestry workers	2 (3.4%)	7 (12.1%)	49 (84.5)	58 (100%)

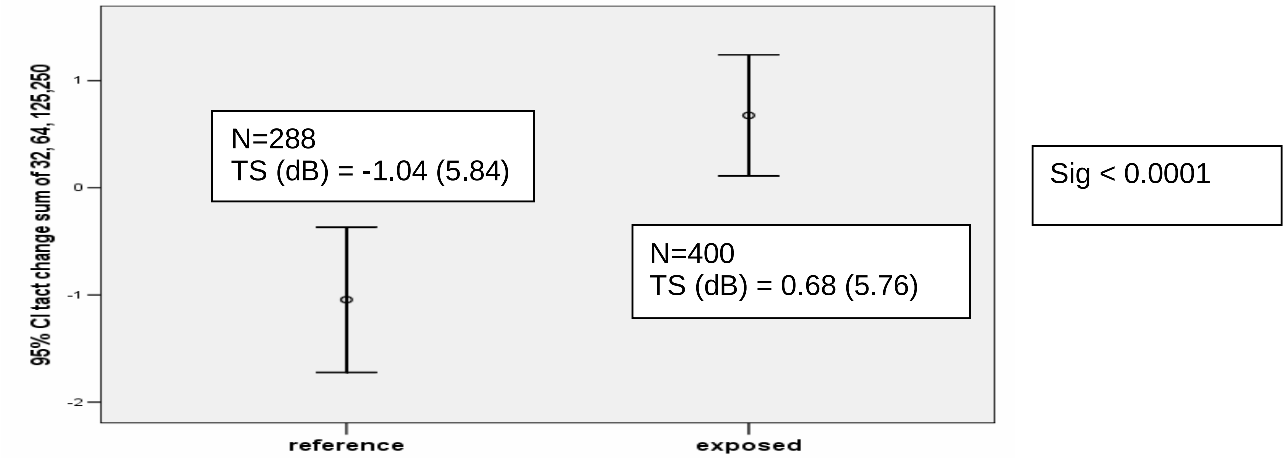
There was little correspondence between abnormal tests and symptoms. There was only one overlap between the seven workers with abnormal plethsymography and the 11 workers with cold related symptoms. While these findings are probably too subtle to use as a disease marker at the individual level, it suggests a mild effect at low levels of exposure. As seen below, differences between exposed and referents were insignificant.

Table 8. Vascular Symptom Patterns in Truck Cab Workers and Controls

Symptom: past 12 months, fingers turn white or painful?	Exposed n/(%)	Reference n/(%)	Total n/(%)
No	43 (79.6%)	32 (88.9%)	75 (83.3%)
Painful in cold, but do not turn white	8 (14.8%)	3 (8.3%)	11 (12.2%)
Turned white or lost color, with or without pain	3 (5.6%)	1 (2.8%)	4 (4.4%)
Total	54	36	90

Vibrometric Thresholds and Vibratory Exposure

Figure 6. Tactometry on Swedish Truck Cab Workers 1997-2002



In the shipyard workforce there was no significant difference between tactometry measurements in 2001 and 2004. Among Finnish forestry workers, followed from 1990, there had been stability and actual improvement with greater AV protection. Figure 6. compares decibel shifts (dB) for Swedish truck cab workers and controls measured at a 5-year interval. FAII response profiles are combined for four digits on each participant. These results appear to confirm a small but significant dB shift over 5 years without significant tool or process change, which was not recognizable over 30 months in the shipyard workforce. As noted, however, the population remained minimally symptomatic. Six percent of the reference group met case criteria for carpal tunnel syndrome, compared to 4% of production workers; 13% of referents had recurrent hand paresthesias in the preceding year, compared to 15% of production workers. These are insignificant differences that suggest, along with the plethsymography data, that quantitatively defined abnormalities are asymptomatic (or pre-symptomatic) in the exposed workforce. Up to this point, the relationship ship between vibratory exposures at the individual level and VPT change remains to be clarified, but there does appear to be a "zero" VPT change/ 5 y at ~ 3.0 m/s^2 for unweighted RMS. Postural and activity related covariates have not been particularly predictive of neurosensory effects. The Swedish truck cab plant is internationally acclaimed for its excellent ergonomics. Shoulder abduction does appear to be related to symptomatic numbness and tingling, but there are no clear relationships between PATH analyses (Posture, Activity, Tool and Hand use) and VPT. Results are for unweighted RMS; additional analyses must precede more emphatic conclusions. The inter-test interval for shipyard workers was 30 months. There was no change in VPT for the 4 Hz and 32 Hz mechanoreceptors (signs are reversed to resemble an audiogram). At 125 Hz (FAII), function declined for workers with highest weekly exposures ($\geq$ 15h). Because of multiple tool use and irregular exposure patterns, estimation of a vibration threshold requires additional exposure reconstruction, but it appears to parallel the Swedish results.

Publications

Morse TF, Michalak-Turcotte C, Atwood-Sanders M, Warren N, Peterson D, Bruneau H, Cherniack M: [2003] A Pilot Study of Hand and Arm Musculoskeletal Disorders in Dental Hygiene Students. Journal of Dental Education Vol.77 Issue III:173-179.

Cherniack M, Brammer AJ, Meyer J, Morse TF, Peterson D, Warren N, Fu RW: [2003] Skin Temperature Recovery from Cold Provocation in Workers Exposed to Vibration: A Longitudinal Study. OEM December Vol. 60(12):962-968.

Cherniack M, Gemne G, Lawson I, Nasu Y, Nilsson T: [2004] The clinical management of suspected cases of hand-arm vibration syndrome. 9th Conference on Hand-Arm Vibration, Nancy France, May 5-8, 2001. INRS, pp 130-146.

Cherniack M, Brammer AJ, Lundstrom R, Meyer J, Morse TF, Neely G, Nilsson T, Peterson D, Toppila E, Warren N, Fu RW, Bruneau H: [2004] Segmental Nerve Conduction Velocity in Vibration Exposed Shipyard Workers. International Archives of Occupational and Environmental Health 77(3):159-176.

Cherniack M, Morse TF, Brammer AJ, Lundstrom R, Meyer J, Nilsson T, Peterson D, Toppila E, Warren N, Fu RW, Bruneau H, Croteau M: [2004] Vibration Exposure, Workplace Modification, and Disease in a Shipyard: a 13-year Revisit. American Journal of Industrial Medicine 45:500-512.

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Morse T, Bruneau H, Michalak-Turcotte C, Sanders M, Warren N, Dussetschleger J, Diva U, Croteau M, Cherniack M: [2007] Musculoskeletal Disorders of the Neck and Shoulder in Dental Hygienists and Dental Hygiene Students. Journal of Dental Hygiene 81(1):10. Epub 2007 Jan 1.

Cherniack M, Brammer AJ, Lundstrom R, Meyer JD, Morse T, Neely G, Nilsson T, Peterson D, Toppila E, Warren N: [2007] The Hand-Arm Vibration International Consortium (HAVIC): Prospective Studies on the Relationship between Power Tool Exposure and Health Effects. Journal of Occupational and Environmental Medicine 49(3):289-30.

Cherniack M, Brammer AJ, Lundstrom R, Morse T, Neely G, Nilsson T, Peterson D, Toppila E, Warren N, Diva U, Croteau M, Dussetschleger J: [2008] The Effect of Different Warming Methods on Sensory Nerve Conduction Velocity in Shipyard Workers Occupationally Exposed to Hand-Arm Vibration. International Archives of Occupational and Environmental Health. Epub 2008 Jan 15.

Cherniack M, Brammer AJ, Lundstrom R, Morse T, Neely G, Nilsson T, Peterson D, Toppila E, Warren N, Diva U, Croteau M, Dussetschleger J: [2007] Syndromes from Segmental Vibration and Nerve Entrapment: Observations on Case Definitions for Carpal Tunnel Syndrome. International Archives of Occupational and Environmental Health. Epub 2007 Oct 2.

Peterson D, Brammer AJ, Cherniack MG: [2007] Exposure Monitoring System for Day-Long Vibration and Grip Force Measurements. International Journal of Industrial Ergonomics, accepted for publication.

Inclusion Enrollment Report Table

This report format should NOT be used for data collection from study participants.

Study Title: Exposure Response Relationship in Hand Arm Vibration

Total Enrollment: 528 **Protocol Number:** 03-115
Grant Number: 1 U01 OH07312

PART A. TOTAL ENROLLMENT REPORT: Number of Subjects Enrolled to Date (Cumulative) by Ethnicity and Race				
	Sex/Gender			
Ethnic Category	**Females**	**Males**	**Unknown or Not Reported**	**Total**
Hispanic or Latino	6	3		9 **
Not Hispanic or Latino	165	349		514
Unknown (Individuals not reporting ethnicity)	0	5		5
Ethnic Category: Total of All Subjects*	171	357		528 *
Racial Categories				
American Indian/Alaska Native	0	2		2
Asian	2	1		3
Native Hawaiian or Other Pacific Islander	0	0		0
Black or African American	4	11		15
White	162	337		499
More than one race	0	0		0
Unknown or not reported	3	6		9
Racial Categories: Total of All Subjects*	171	357		528 *

PART B. HISPANIC ENROLLMENT REPORT: Number of Hispanics or Latinos Enrolled to Date (Cumulative)				
Racial Categories	**Females**	**Males**	**Unknown or Not Reported**	**Total**
American Indian or Alaska Native	0	0		0
Asian	0	0		0
Native Hawaiian or Other Pacific Islander	0	0		0
Black or African American	0	0		0
White	3	3		6
More Than One Race	1	0		1
Unknown or not reported	2	0		2
Racial Categories: Total of Hispanics or Latinos**	6	3		9 **

* These totals must agree.
** These totals must agree.