Ergonomics

ISSN: 0014-0139 (Print) 1366-5847 (Online) Journal homepage: https://www.tandfonline.com/loi/terg20

Digital vibration threshold testing and ergonomic stressors in automobile manufacturing workers: a cross-sectional assessment

JE Gold , L Punnett , M Cherniack & DH Wegman

To cite this article: JE Gold , L Punnett , M Cherniack & DH Wegman (2005) Digital vibration threshold testing and ergonomic stressors in automobile manufacturing workers: a cross-sectional assessment, Ergonomics, 48:1, 66-77, DOI: 10.1080/00140130412331311408

To link to this article: https://doi.org/10.1080/00140130412331311408

Published online: 09 Nov 2010.

Ergonomics, Vol. 48, No. 1, January 2005, 66 – 77

Digital vibration threshold testing and ergonomic stressors in automobile manufacturing workers: a cross-sectional assessment

J. E. GOLD†*, L. PUNNETT†, M. CHERNIACK‡ and D. H. WEGMAN†

†Department of Work Environment, 1 University Ave., University of Massachusetts Lowell, Lowell, MA 01854, USA
‡University of Connecticut Health Center, Dowling North, 263 Farmington Ave., Farmington, CT 06030, USA

Upper extremity musculoskeletal disorders (UEMSDs) comprise a large proportion of work-related illnesses in the USA. Physical risk factors including manual force and segmental vibration have been associated with UEMSDs. Reduced sensitivity to vibration in the fingertips (a function of nerve integrity) has been found in those exposed to segmental vibration, to hand force, and in office workers. The objective of this study was to determine whether an association exists between digital vibration thresholds (VTs) and exposure to ergonomic stressors in automobile manufacturing. Interviews and physical examinations were conducted in a cross-sectional survey of workers (n = 1174). In multivariable robust regression modelling, associations with workers' estimates of ergonomic stressors stratified on tool use were determined. VTs were separately associated with hand force, vibration as felt through the floor (whole body vibration), and with an index of multiple exposures in both tool users and non-tool users. Additional associations with contact stress and awkward upper extremity postures were found in tool users. Segmental vibration was not associated with VTs. Further epidemiologic and laboratory studies are needed to confirm the associations found. The association with self-reported whole body vibration exposure suggests a possible sympathetic nervous system effect, which remains to be explored.

Keywords: Vibrotactile thresholds; Whole body vibration; Occupational exposures; Work-related musculoskeletal disorders

*Corresponding author. Email: Judith_Gold@uml.edu

Ergonomics
ISSN 0014-0139 print/ISSN 1366-5847 online © 2005 Taylor & Francis Ltd
http://www.tandf.co.uk/journals
DOI: 10.1080/00140130412331311408

1. Introduction

Upper extremity musculoskeletal disorders (UEMSDs) such as carpal tunnel syndrome (CTS), tendinitis, and other soft tissue diseases are highly detrimental in terms of both human suffering and costs to society. The Bureau of Labor Statistics (1999) reported that disorders associated with repeated trauma made up 65% of the 392 000 total workplace illnesses reported in 1998. Epidemiologic evidence links UEMSDs with exposure to physical risk factors such as manual force and segmental vibration (Bernard 1997, National Academy of Sciences 1998, 2001).

Reduction in sensitivity to vibration, or elevation of the vibration threshold (VT) at 120 Hz (the vibration frequency evaluated in this study), is thought to reflect impairment in the Pacinian corpuscle, a cutaneous mechanoreceptive nerve ending (Lundström *et al.* 1992). The association of elevated digital vibration thresholds (VTs) with exposure to vibrating hand tools is well established (Cherniack *et al.* 1990, Virokannas 1992). In fact, a dose-response relationship between duration of exposure to power tools and VTs has been ascertained in both railway workers and lumberjacks (Virokannas 1995).

However, vibrotactile impairment has also been found in those not exposed to segmental vibration. For instance, Flodmark and Lundborg (1997) found decreased vibration sensitivity in workers performing heavy manual work without vibration exposure, compared with population norms. Also, increased vibration thresholds have been found at 120 Hz in office workers (Greening and Lynn 1998) and at 125, 250 and 500 Hz in medical transcriptionists (Doezie *et al.* 1997). These findings imply a possible effect on vibration sensitivity of repetitive manual activity or static postural loading.

We had the opportunity to examine VTs in a population with mixed ergonomic exposures in an existent data set, collected from a cohort of automobile manufacturing workers (Punnett 1998). Few of the cohort subjects were exposed to vibrating hand tools at the time of the study.

The objective of this study was to examine whether an association exists between digital vibration thresholds and exposures to ergonomic stressors. It was hypothesized that VTs would be associated with each worker's self-reported exposure to segmental vibration, to grip force, and to an exposure index formed from the sum of worker's estimations of ergonomic stressors (Punnett 1998).

2. Subjects and methods

2.1. *Study cohort*

The study population consisted of a cohort of Detroit automobile manufacturing workers in one engine and one stamping plant (Punnett 1998). After exclusions of non-production workers, and of those with questionable data quality (including quality of vibration threshold testing), the study population consisted of 1174 workers. All subjects gave their informed consent to their study participation. The study protocol was approved by the Institutional Review Board of the University of Massachusetts Lowell and by the joint company-union health and safety programme.

2.2. *Physical examination and vibrometry*

Vibration threshold testing in the second and fifth digits was included in a physical examination (PE) administered to the study subjects to determine the presence of muscle/

tendon, joint and nerve problems in the upper extremity. Vibration sensitivity was measured using the method of limits with the 120 Hz Vibratron II vibrometer (Physitemp, Clifton, NJ). A forearm support held the subject's hand in place, permitting only minimal movement while maintaining uniform pressure on the instrument.

Using a procedure detailed by Werner *et al.* (1994), the first threshold measured and the highest and the lowest of five test values were discarded. The average of the remaining two values determined the vibration threshold for each of the second and fifth digits on each hand. The 'vibration units' obtained from the instrument were converted into microns of displacement (as recommended by Gerr and Letz (1993)) after measuring the vibrometer amplitude at a range of vibration units by means of a calibrated accelerometer (the equation used was amplitude (μm displacement) = 0.65 (vibration units)^2.) These values were then converted into decibels (dB) relative to 10^{-6} ms^2, using the following formula: acceleration (dB) = 20 log $((4\pi^2(120)^2 * \mu\text{m displacement} * 10^{-6})/10^{-6})$.

2.3. *Exposure assessment*

2.3.1. Psychophysical exposure assessment: A psychophysical questionnaire was used to assess ergonomic stressors. Using a Borg CR-10 scale (Borg 1990), workers rated their exposures to the following stressors: repetition, grip force, awkward neck/shoulder, arm, and wrist/hand postures, whole body effort, contact stress, machine pace, segmental and whole body vibration factors. For example, the question regarding whole body vibration read 'On a scale of 0 to 10, how would you rate the amount of vibration that you feel through the floor while you are working?'.

The questionnaire and the PE were administered during the working day; the VT exam was given approximately one-half hour after the subject had last performed his/her job duties.

2.3.2. Exposure index: As was done previously (Punnett 1998, Punnett *et al.* 2004), an exposure index based on workers' psychophysical assessment of exposures was constructed. To form this index, eight individual items on the exposure questionnaire (work pace, grip force, neck/shoulder posture, arm posture, wrist/hand posture, tool handle contact stress, segmental vibration, and whole body vibration) were transformed from the original Borg scale into a 4-point (0–3) scale. An additional question regarding machine pacing was scored 1 for yes, and 0 for no. The final score (possible values 0–25) was constructed using the sum of these re-scored items (see Punnett (1998) for additional details). The association of (here denoted as Exposure Index A) VTs with the same exposure index was evaluated.

A variation on this exposure index was developed for these analyses. This index did not include workers' reported exposures to either contact stress or segmental vibration (here denoted as Exposure Index B) since only tool users were asked questions about these items. Elimination of these items allowed comparison of the exposure index when stratifying on tool use. The possible range of exposure scores for Exposure Index B was 0–19.

2.4. *Statistical analysis*

Despite the transform into dBs, the VT measurements were not normally distributed. Hence, they were analysed with non-parametric statistics. Data are presented as median (25th percentile–75th percentile). The Wilcoxon rank-sum test was used in binary comparisons of group medians, while trends were assessed with the Wilcoxon rank-sum test extension (Cuzick 1985). SAS 6.12 (SAS Institute Inc., Cary, NC) and Stata 5.0 and 6.0 (Stata Corporation, College Station, TX) were used in statistical analyses.

Median vibration threshold was compared between subgroups defined by a number of occupational and non-occupational covariates. These included raw scores of individual items from the exposure questionnaire as well as the two exposure indices as described above. Potential confounders for an association of exposure with VT comprised age, gender, height, wrist injury (any and localized by side), any upper extremity injury, systemic disease, alcoholism, and smoking.

In multivariable modelling, robust regression (Huber 1981) was used to downweigh the influence of outliers. Models were constructed for the dataset as a whole and for the cohort stratified on tool use status. Based on the prior univariate analyses, all models included age and gender. The modelling approach focused on ergonomic stressors and on identifying potential confounders and effect modifiers. The covariate inclusion criterion was $p <= 0.05$. Potential confounders were kept in the model when their exclusion resulted in a change of 15% or greater in the main effects. Effect modifiers, including those of age or gender with exposure effect, were retained with a *p*-value of 0.05 or less.

3. Results

The cohort median VT for both second digits was 123 (interquartile range: 118 – 127) dB, while the cohort median VT for both fifth digits was 122 (interquartile range: 118 – 127) dB. Left and right second digit VTs were highly correlated (Spearman rank correlation coefficient [SRCC] = 0.99, $p < 0.0001$), as were the corresponding fifth digits (SRCC = 0.98, $p < 0.0001$). Since the right second and fifth digit VTs were also highly correlated (SRCC = 0.78, $p < 0.0001$), subsequent analyses focused on the second right digit.

Exposure Index A was associated with vibration threshold in the second right hand digit and showed a positive trend over the index quartiles (table 1). VT showed a similar trend with Index B. Tool use status (No/Yes indicator) showed no association with VTs in any digit.

The second right digit VT was higher in women, increased with age and decreased with height (table 1). Since previous studies have found no effect of height on VTs in the upper extremity and height was confounded by gender in this study, it was decided to retain gender but not height for regression modelling. Systemic disease, cigarette smoking status and self-reported history of alcoholism were not associated with VTs.

In univariate robust regression, Exposure Indices A and B were associated with VTs (table 2). Four ergonomic stressors (awkward arm posture, WBV, hand force, and contact stress) were also individually associated with the second right digit VT. Of the potential confounders, only age and gender were of statistical significance in univariate robust regression modelling.

In age- and gender-adjusted robust regression multivariable models, VT was associated with each exposure index (table 3). Since associations were found with the composite exposure indices, index components were examined to determine which individual stressors (if any) lead to the association. Hand force, floor vibration and awkward arm posture were fit as individual exposure effects in three additional models. No association with segmental vibration was found, nor was any association found with any of the other remaining components of Exposure Index A. No effect modification terms of exposure by age or gender were statistically significant in any of the models.

Table 1. Median vibration threshold (dB) in the second right digit and ergonomic stressors in automotive stamping plant and engine plant workers, Detroit MI, USA, 1993

Variable	*n*	%	Median	Q1	Q3
Exposure Index A*					
0–6	115	11	122.0	117.2	127.3
7–12	348	33	123.0	118.4	126.9
13–18	459	44	123.0	118.4	126.6
19–24	127	12	124.7	120.1	128.3
Exposure Index B (excludes contact stress and segmental vibration) *					
0–5	87	8	122.5	117.8	126.9
6–10	258	25	123.0	118.4	127.3
11–15	505	48	122.5	118.4	126.9
16–19	196	19	124.7	120.1	128.0
Hand Tool Use					
Yes	448	38	122.5	118.4	127.3
No	716	62	123.3	118.4	127.3
Gender∧					
male	973	83	122.5	117.8	126.6
female	203	17	125.0	120.1	129.4
Age (years)*					
20–39	213	18	121.1	115.9	124.7
40–49	540	46	123.0	118.4	126.6
> = 50	410	35	124.7	119.5	129.2
Height (inches) *					
< 65	139	12	124.7	119.5	128.9
65–68	359	31	123.4	119.0	127.3
69–72	521	45	122.5	117.8	126.9
> = 73	143	12	123.0	117.2	126.2
Alcoholism					
No	1105	95	123.0	118.4	127.3
Yes	57	5	122.0	118.4	127.3
Disease					
No	931	80	123.0	117.8	126.9
Yes	231	20	123.0	119.0	128.0
Cigarette Smoking					
Never	369	32	123.0	118.4	127.6
Former	265	23	122.5	117.8	126.6
Current	529	45	123.4	118.4	127.3

∧Wilcoxon rank test, $p < = 0.05$.
*non-parametric test for trend $p < = 0.05$.
Q1: 25th percentile, Q3: 75th percentile.

Among tool users, age- and gender-adjusted models could be fit separately with each of Exposure Index B, or seven individual exposure ratings. A model with both contact stress and awkward neck postures showed separate effects and little confounding (model T9, table 4). No other models with multiple ergonomic stressors could be constructed. A variant of Exposure Index B, excluding WBV, was associated with VT (model T2, table 4).

Neither the awkward posture items nor Exposure Index B were associated with VT in non-tool users. No posture or physical effort effects were found in this sub-group. As in tool users, age- and gender-adjusted effects were found for hand force and floor vibration. The effects of age and gender were smaller in tool users than non-tool users.

Table 2. Univariate robust regression models of second right digit vibration threshold (dB) on ergonomic stressors, demographics, and medical history (n = 1174)

Covariate	Model coefficient	95% Confidence interval
Sum of ergonomic exposures		
Exposure Index A * (0–25 scale)	0.7	(0.2–1.2)
Exposure Index B * (0–19 scale)	0.6	(0.1–1.2)
Individual ergonomic stressors (all 0–10 scale)		
Pace	0.02	(−0.2–0.2)
Awkward neck posture	0.1	(−0.1–0.2)
Awkward arm posture *	0.1	(0.01–0.3)
Awkward wrist posture	0.004	(−0.1–0.1)
Whole body vibration *	0.4	(0.3–0.5)
Hand force *	0.2	(0.03–0.3)
Physical effort	0.05	(−0.1–0.2)
Segmental vibration	−0.1	(−0.3–0.2)
Contact stress *	0.3	(0.1–0.5)
Potential confounders		
Age * (years)	0.2	(0.2–0.3)
Gender * (0 = male, 1 = female)	2.8	(1.7–3.9)
Systemic disease (no/yes)	0.8	(−0.3–1.8)
Upper ext. injury (no/yes)	−0.04	(−0.9–0.8)
Right wrist injury (no/yes)	0.2	(−0.8–1.3)
Cigarette smoking status (3 = never, 2 = former, 1 = current)	0.1	(−0.4–0.5)
Alcoholism (no/yes)	−0.5	(−2.4–1.4)

(* $p <= 0.05$.
Segmental vibration and contact stress applicable for tool users only.
See text for definitions of Exposure Indices.

Table 3. Multivariate robust regression models of second right digit vibration threshold (dB) and ergonomic stressors, adjusted for age and gender (n = 1174)

Model number	Ergonomic stressor **	Model coefficient	95% CI
A1	Exposure Index A	0.8 *	(0.3–1.3)
A2	Exposure Index B	0.9 *	(0.4–1.3)
A3	Hand force	0.3 *	(0.1–0.4)
A4	Floor vibration (WBV)	0.5 *	(0.3–0.6)
A5	Arm posture	0.1 *	(0.01–0.3)
A6	Neck posture	0.1	(− 0.1–0.2)
A7	Wrist posture	0.04	(− 0.1–0.2)
A8	Physical effort	0.02	(− 0.1–0.2)

*: p-value $\leqslant 0.05$.
**: Exposure Index A: 0–25 scale, Exposure Index B: 0–19 scale (see text for description), all other exposures: 0–10 scale.
Age (years) coefficient = 0.2 (95%CI: 0.2–0.3) in all models.
Gender (0:M, 1:F) coefficient ranged from 2.5–2.8 in models (typical 95%CI: 1.4–3.6).

There was no confounding by alcoholism, systemic disease, smoking status, or previous wrist or upper extremity injury in any of the models (entire cohort, tool users or non-tool users) and no effect modification by any of these variables. No association was found between segmental vibration exposure and VTs in any of the models. Nonetheless, the

Table 4. Multivariable robust regression models of second right digit vibration thresholds (dB) and ergonomic stressors in tool users, adjusted for age and gender ($n = 452$)

Model number	Ergonomic stressor **	Model coefficient	95% CI	Ergonomic stressor	Model coeff.	95% CI
T1	Exposure Index B	1.4 *	(0.6 – 2.2)			
T2	Exposure Index B (w. no WBV)	1.3 *	(0.3 – 2.3)			
T3	hand force	0.3 *	(0.04 – 0.5)			
T4	WBV	0.5 *	(0.3 – 0.7)			
T5	arm posture	0.2 *	(0.03 – 0.4)			
T6	neck posture	0.3 *	(0.1 – 0.5)			
T7	wrist posture	0.2 *	(0.04 – 0.4)			
T8	contact stress	0.2 *	(0.1 – 0.4)			
T9	contact stress	0.2 *	(0.001 – 0.4)	neck posture	0.2 *	(0.0 – 0.4)
T10	physical effort	0.3 *	(0.02 – 0.5)			
T11	segmental vibration	0.03	(− 0.2 – 0.2)			

*: p-value $\leqslant 0.05$.
Segmental vibration and contact stress were evaluated only in tool users.
**: Exposure Index B: 0 – 19 scale (see text for description), Exposure Index B (with no WBV): 0 – 16 scale, all other exposures 0 – 10 scale.
Age (years) coefficient = 0.2 or 0.3 (95%CI: 0.2 – 0.3) in all models.
Gender (0:M, 1:F) coefficient ranged from 2.9 – 3.7 in models (typical 95%CI: 1.9 – 5.4).

prevalence of hand/arm numbness was greater among tool users who reported any non-zero intensity of vibration through the hand (31%) than those reporting no such feeling of vibration through the hand (21%) (χ^2 test, $p \leqslant 0.01$).

4. Discussion

Consistent with previous literature (Gerr *et al.* 1990, Wiles *et al.* 1991, Gerr and Letz 1993, Bartlett *et al.* 1998, Skov *et al.* 1998), vibration thresholds among these autoworkers increased with age. Although a large percentage of the variance in vibration thresholds was due to age in the present study, we found an additional effect of occupational exposure in these subjects.

Interestingly, females in this cohort showed a higher VT than males, even after adjusting for age and exposure. Several authors have found no effect of gender on VTs, with (Bartlett *et al.* 1998) or without (Wiles *et al.* 1991) height adjustment. There was no association with cigarette smoking status, as expected (Wiles *et al.* 1991), or with past treatment for alcoholism.

An association between segmental vibration exposure and VTs (Cherniack *et al.* 1990, Virokannas 1992, 1995) is fairly widely accepted. Thus, it is puzzling why no such association with workers' self-rated intensity of exposure was seen in this study. Since the prevalence of hand/arm numbness was significantly greater among tool users reporting any segmental vibration exposure than tool users reporting no such exposure, the segmental vibration exposure rating appears to have some validity. On the other hand, although 22% ($n = 268$) of workers gave a rating above zero for vibration felt through the tool handle, only 3% ($n = 38$) of workers were observed by the investigators to be using power tools. There may have been substantial misclassification in this exposure rating. Alternatively, some workers may have felt vibration through the hand from other sources while using a tool; it may not have been the tool itself that was producing this sensation of vibration. Hence, the exposure may have been of insufficient magnitude to increase the VT.

It is also possible that one reason we found no difference in VT between those with and without segmental vibration exposure is that workers presently unexposed had been in the past. In a longitudinal study of workers with vibration white finger, Ogasawara *et al.* (1997) found that VTs did not improve through time (5–6 years after initial assessment). It is possible that many workers had been exposed to vibrating hand tools in previous years (prior to plant re-tooling). Further investigation would be necessary to determine whether present exposures influence VTs beyond the effects of previous exposure to segmental vibration. Unfortunately, we do not have detailed exposure histories of these workers.

The association between elevation of digital VT and intensity of vibration felt through the floor has not been previously reported and we are not certain how to interpret it. In structural equation models of data from this cohort, Punnett and van der Beek (2000) found that self-reported exposure to WBV was significantly associated with hand/wrist disorders. These findings may reflect a true association or could be an artifact of the exposure assessment (see below).

It is possible that WBV may have an effect specifically on the nerve fibres involved in digital vibration sensation. Centralized sympathetic nervous system effects of vibration exposure have been postulated. After digital vibration exposure, reduced blood flow has been measured in the corresponding contralateral finger (Griffin and Bovenzi 2002). It is noted that some patients with HAVS experience paraesthesias and coldness in the feet (Sakakibara *et al.* 1988). Sakakibara *et al.* (1990) found a decrease in blood flow in the right toe when vibration was applied to the left hand in normal subjects. However, the reverse experiment was not performed. Decreased sensory conduction velocities in the medial plantar nerve in those with vibration syndrome vs. control subjects have been detected (Hirata *et al.* 1995). Whether these findings are relevant to ours remains to be further explored, but they suggest a possible mechanism for the association that we observed.

In any case, none of the cited studies likely replicated the actual exposure conditions of this workplace. The stamping plant in particular is a unique environment. The press room contains approximately 25 presses ranging from one to several stories in height. The presses produce metal parts at a mean rate of 53 parts/min. Upon entering this section of the plant, it is immediately apparent to the most casual observer that the noise level is extremely high and the floor of this room is constantly vibrating. The floor is most probably vibrating at a range of low frequencies, although a frequency spectrum of this vibration has not been measured.

However, it is also possible that WBV is a surrogate for the true exposure causing the effect. For instance, the ambient noise level in the areas with the strongest floor vibrations may be greater than in other areas of the plant. Workers are required to wear earplugs, but noise may still be transmitted through conductive vibration. Although noise is regarded as a general stressor, the effect of long-term noise exposure on VTs is unknown. Also, vibration may be perceived as transmitted through the floor even though actual transmission may be at least partially through workers' hands as they handle tools to manipulate objects through the presses or come in contact with the presses themselves.

The age- and gender- adjusted association between the exposure index, which reflects the sum of workers' self-reported exposures (excluding segmental and whole body vibration factors), and elevated VTs suggests that ergonomic stressors in addition to those of vibration affect the VT.

Hand force was associated with VTs in both tool users and non-tool users. Flodmark and Lundborg (1997) found a similar relationship in those performing heavy manual work but without segmental vibration exposure.

The specific association between awkward postures and elevated VT has not been reported in the literature. These posture ratings may reflect not only angle of excursion, but also an integration of force/load factors (Punnett and van der Beek 2000). Although forest workers, railroad repair workers and others with vibration exposure likely perform their jobs with frequent non-neutral postures, studies assessing the effect of segmental vibration exposure on VTs (Cherniack *et al.* 1990, Virokannas 1992) have not reported or adjusted for the effects of awkward postures.

Elevated vibration thresholds have been found in those performing highly repetitive manual tasks, such as medical transcriptionists (Doezie *et al.* 1997) and office workers (Greening and Lynn 1998). However, the repetition rating was not found to be associated with VTs in this cohort. Repetitiveness and work pace may not vary enough in the autoworkers' jobs to explain any variability in health effects (Punnett and van der Beek 2000). Alternatively, it may not be 'repetition' alone that has resulted in the elevated VT in computer operators. Repetitive work in VDT users is part of a constellation of postures and forces (i.e., static neck and shoulders with mobile fingers). This mix of exposures is very different from that represented by the work pace rating analysed here.

4.1. *Study limitations and strengths*

There are several limitations in the present study. First, it must be noted that the Vibratron II does not conform to ISO standard 13091-1 (1998)—which post-dated this study—with regard to probe size and contact force. Thus, the VT values may not be comparable with those in studies using instruments other than the Vibratron II. However, the VTs are internally comparable, so this should not affect the associations reported here.

The validity of any quantitative sensory test depends on the cooperation of those under evaluation (Zaslansky and Yarnitsky 1998). We did not assess validity in this population, but the protocol was designed to exclude subjects with unusually high variability of responses. Several authors have found high test-retest reliability of vibration threshold testing (Gerr *et al.* 1990, Rosecrance *et al.* 1994).

The study was cross-sectional and, therefore, we cannot determine whether elevated VTs followed or preceded the exposure to ergonomic stressors. The cohort consisted of a middle-aged population (mean age = 46.3) who had been in the workforce for many years (mean seniority = 21.5 years). As noted above, those with low exposure to vibration or other stressors currently may have had high exposures in the past. It is also possible that workers who had experienced the most severe UEMSDs (and possibly those with the highest VTs) had transferred to less exposed jobs or even had left the workforce prior to cohort enrollment, resulting in a healthy worker selection effect. If so, the magnitudes of the associations seen here may be underestimated.

A separate concern is the potential for information bias in the exposure variables. The literature is inconclusive with regard to how self-ratings of exposures to ergonomic stressors are influenced by MSD morbidity (Viikari-Juntura *et al.* 1996, Wiktorin *et al.* 1993). In separate analyses of this data set (Park 2000, Park and Punnett 2000) found higher correlations with observed non-neutral postures among workers with pain. Yet, these self-reported exposure ratings in non-cases have been shown to have predictive value for new MSD signs and symptoms 1 year later (Punnett *et al.* 2004). The effect of worker MSD morbidity on the validity of self-reported exposure variables in this dataset is unknown.

The chief strength of the study was the large population (n = 1174) who were exposed to a wide variety of ergonomic stressors. The resulting statistical power enabled adequate control for confounding as well as stratification on tool use. Since the VT coefficients as estimated in univariate models differed little from those in multivariable models when adjusted for age and gender, confounding is not a likely explanation for the results.

4.2. *Conclusions*

Second digit VTs were associated with the sum of workers' ratings of ergonomic exposures. Segmental vibration was not associated with second digit VTs in this cohort, whereas hand force was associated in tool users and non-tool users alike. In tool users, both contact stress and awkward postures at various upper extremity sites were correlated with VTs. In both tool and non-tool users, right second digit VTs were associated with vibration felt through the floor, possibly indicating a sympathetic nervous system effect.

The results of the present study indicate that awkward postures, contact stress, and hand force factors may be associated with VTs. As these exposures are self-reported, further epidemiologic studies are needed to clarify these associations.

Measurements should be done to characterize the frequency spectrum of the floor vibration at the automobile manufacturing plants. A laboratory experiment analogous to the study by Sakakibara *et al.* (1990) where vibration is applied to the foot and VTs measured in the fingers would examine any potential sympathetic nervous system effect due to vibration through the floor.

Acknowledgements

This research was supported by a contract from the United Auto Workers Chrysler (now Daimler-Chrysler) National Joint Committee (NJC) on Health and Safety. Twila Eshelman and Trudy Johnson Hall conducted the physical examinations and interviews. We thank Dr. Rebecca Moreland, the UAW-Chrysler National Training Center staff, plant managers, safety directors, UAW ergonomics trainers and health and safety committee members for their valuable assistance. Rebecca Gore provided assistance with statistical analyses.

References

Bartlett, G., Stewart, J. D., Tamblyn, L. and Abrahomowicz, M., 1998, Normal distributions of thermal and vibration sensory thresholds. *Muscle and Nerve*, **21,** 367–374.

Bernard, B. P., 1997, *Musculoskeletal disorders and workplace factors: A critical review of epidemiologic evidence for work-related musculoskeletal disorders of the neck, upper extremity, and low back* (Cincinnati, OH: National Institute of Occupational Safety and Health).

Borg, G., 1990, Psychophysical scaling with applications in physical work and the perception of exertion. *Scandinavian Journal of Work Environment Health,* **16 (suppl 1),** 55–58.

Bureau of Labor Statistics, 1999, Workplace Illnesses and Injuries in 1998, USDL 99–358 (Washington, D.C.: U.S. Department of Labor).

Cherniack, M. G., Letz, R., Gerr, F., Brammer, A. and Pace, P., 1990, Detailed clinical assessment of neurological function in symptomatic shipyard workers. *British Journal of Industrial Medicine*, **47,** 566–572.

Cuzick, J., 1985, A Wilcoxon-type test for trend. *Statistics in Medicine*, **4,** 566–572.

Doezie, A. M., Freehill, A. K., Novak, C. B., Dale, A. M. and Mackinnon, S. E., 1997, Evaluation of cutaneous vibration thresholds in medical transcriptionists. *The Journal of Hand Surgery*, **22A,** 867 – 872.

Flodmark, B. T. and Lundborg, G., 1997, Vibrotactile sense and hand symptoms in blue-collar workers in a manufacturing industry. *Occupational and Environmental Medicine*, **54,** 880 – 887.

Gerr, F., Hershman, D. and Letz, R., 1990, Vibrotactile threshold measurement for detecting neurotoxicity: reliability and determination of age and height-standardized normative values. *Archives of Environmental Health*, **45,** 148 – 154.

Gerr, F. and Letz, R., 1993, Vibrotactile threshold testing in occupational health: a review of current issues and limitations. *Environmental Research*, **60,** 145 – 159.

Greening, J. and Lynn, B., 1998, Vibration sense in the upper limb in patients with repetitive strain injury and a group of at-risk office workers. *International Archives of Occupational and Environmental Health*, **71,** 29 – 34.

Griffin, M. J. and Bovenzi, M., 2002, The diagnosis of disorders caused by hand-transmitted vibration: Southampton Workshop 2000. *International Archives of Occupational and Environmental Health*, **75,** 1 – 5.

Hirata, M., Sakakibara, H., Yamada, S.-Y., Hashiguchi, T., Toibana, N. and Koshiyama, H., 1995, Nerve conduction velocities in the lower extremities among patients with vibration syndrome. *Central European Journal of Public Health,* **3(suppl),** 78 – 80.

ISO/CD 13091-1, 1998, *Second Committee Draft. Mechanical vibration - Vibrotactile perception threshold for the assessment of nerve dysfunction: Part 1 – Method of measurement at the fingertips.*

Lundström, R., Strömberg, T. and Lundborg, G., 1992, Vibrotactile perception threshold measurements for diagnosis of sensory neuropathy: Description of a reference population. *International Archives of Occupational and Environmental Health*, **64,** 201 – 207.

National Academy of Sciences, Panel on Musculoskeletal Disorders and the Workplace, Commission on Behavioral and Social Sciences and Education, National Research Council, 2001, *Musculoskeletal Disorders and the Workplace: Low Back and Upper Extremities*. Series (Washington, D.C.: National Academy Press).

National Academy of Sciences, Steering Committee for the Workshop on Work-Related Musculoskeletal Injuries, The Research Base Committee on Human Factors, National Research Council, 1998, *Work-Related Musculoskeletal Disorders: A Review of the Evidence*. Series (Washington, D.C.: National Academy Press).

Ogasawara, C., Sakakibara, H., Kondo, T., Miyao, M., Yamada, S.-Y. and Toyoshima, H., 1997, Longitudinal study on factors related to the course of vibration-induced white finger. *International Archives of Occupational and Environmental Health*, **69,** 180 – 184.

Park, J.-S., 2000, Ergonomic Exposure Assessment and Musculoskeletal Disorders in Automobile Manufacturing, in Department of Work Environment. Unpublished doctoral thesis (University of Massachusetts, Lowell, MA).

Park, J.-S. and Punnett, L., 2000, *Factors influencing psychophysical ratings of postural stresses by automotive manufacturing workers*. In *Human Factors and Ergonomics Society/International Ergonomics Association* (San Diego, CA).

Punnett, L., 1998, Ergonomic stressors and upper extremity disorders in vehicle manufacturing: cross sectional exposure-response trends. *Occupational and Environmental Medicine*, **55,** 414 – 420.

Punnett, L. and van der Beek, A.J., 2000, A comparison of approaches to modeling the relationship between ergonomic exposures and upper extremity disorders. *American Journal of Industrial Medicine*, **37,** 645 – 655.

Punnett, L., Gold, J. E., Katz, J. N. and Gore, R., 2004, Ergonomic stressors and upper extremity disorders in automotive manufacturing: a one-year follow-up study. *Occupational and Environmental Medicine*, **61,** 668 – 674.

Rosecrance, J. C., Cook, T. M., Goode, J. D. and Shroder, M. J., 1994, Vibration sensibility testing in the workplace: day-to-day reliability. *Journal of Occupational Medicine*, **36,** 1032 – 1037.

Sakakibara, H., Akamatsu, Y., Miyao, M., Kondo, T., Furuta, M., Yamada, S.-Y., Harada, N., Miyake, S. and Hosokawa, M., 1988, Correlation between vibration-induced white finger and symptoms of upper and lower extremities in vibration syndrome. *International Archives of Occupational and Environmental Health*, **60,** 285 – 289.

Sakakibara, H., Iwase, S., Mano, T., Watanabe, T., Kobayashi, F., Furuta, M., Kondo, T., Miyao, M. and Yamada, S.-Y., 1990, Skin sympathetic activity in the tibial nerve triggered by vibration applied to the hand. *Occupational and Environmental Health*, **62,** 455 – 458.

Skov, T., Steenland, K. and Deddens, J., 1998, Effect of age and height on vibrotactile threshold among 1,663 U.S. workers. *American Journal of Industrial Medicine*, **34,** 438 – 444.

Viikari-Juntura, E., Rauas, S., Martikaninen, R., Kuosma, E., Riihimäki, H. and Takala, E., 1996, Validity of self-reported physical work load in epidemiologic studies on musculoskeletal disorders. *Scandinavian Journal of Work Environment Health*, **22,** 251 – 259.

Virokannas, H., 1992, Vibration perception thresholds and workers exposed to vibration. *International Archives of Occupational and Environmental Health*, **64,** 377 – 382.

Virokannas, H., 1995, Dose-response relation between exposure to two types of hand-arm vibration and sensorineural perception of vibration. *Occupational and Environmental Medicine*, **52,** 332 – 336.

Werner, R. A., Franzblau, A. and Johnston, E., 1994, Quantitative vibrometry and electrophysiological assessment in screening for carpal tunnel syndrome among industrial workers: a comparison. *Archives of Physical Medicine and Rehabilitation*, **75,** 1228 – 1232.

Wiktorin, C., Karlqvist, L., Winkel, J. and The S.M.S. Group, 1993, Validity of self-reported exposures to work postures and manual materials handling. *Scandinavian Journal of Work Environment Health*, **19,** 208 – 214.

Wiles, P. G., Pearce, S. M., Rice, P. J. S. and Mitchell, J. M. O., 1991, Vibration perception threshold: influence of age, height, sex, and smoking, and calculation of accurate centile values. *Diabetic Medicine*, **8,** 157 – 161.

Zaslansky, R. and Yarnitsky, D., 1998, Clinical applications of quantitative sensory testing (QST). *Journal of Neurological Sciences*, **8,** 215 – 238.