Noise-induced Hearing Loss in Construction Workers Being Assessed for Hand-arm Vibration Syndrome

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ABSTRACT

Background: Construction workers are at risk of noise-induced hearing loss (NIHL) but often have no periodic audiometric testing.

Methods: The participants were construction workers assessed for Hand-Arm Vibration Syndrome (HAVS) at the Occupational Health Clinic, St. Michael's Hospital, Toronto, Ontario. Audiometry was offered and 169 of the 191 workers assessed for HAVS agreed to have the audiometric test. The objective was to examine the prevalence of hearing loss in these 169 workers and to determine the effect on hearing of duration of work in construction (as a proxy for noise exposure) and the severity of vibration white finger (VWF) which previous studies have suggested is a marker for increased individual susceptibility for NIHL. VWF was measured by the Stockholm vascular scale.

Results: All participants were men, median age of 57 (range: 28-75), median number of years worked in construction of 35 (range: 4-52). All of the Spearman rank correlations between years worked in construction and the hearing levels at each audiometric frequency were statistically significant ($p < 0.001$). Overall, 31 (18.3%) participants had hearing loss at or above the level at which a workers' compensation pension would be granted in Ontario and the prevalence of this auditory outcome had a statistically significant increase as years worked in construction increased. Multivariate linear regression indicated that VWF also had a statistically significant effect on hearing loss for all audiometric frequencies combined after controlling for years worked in construction.

Conclusion: Improved prevention of hearing loss in construction workers is needed.

Key words: Hearing; noise; construction; vibration; VWF

La traduction du résumé se trouve à la fin de l'article.

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Many workers are exposed to high noise levels and may develop noise-induced hearing loss (NIHL).^{1,2} Tak et al.³ estimated that, after the manufacturing sector, the construction sector had the greatest number of workers occupationally exposed to noise in the US. Construction workers in Canada are similarly exposed to high noise levels⁴ and at risk of NIHL.^{5,6} In construction work, the use of hand-held vibrating tools is an important source of noise exposure.⁴

Exposure to hand-arm vibration may result in Hand-Arm Vibration Syndrome (HAVS) which is comprised of vascular, neurological and musculoskeletal components.^{7,8} The main vascular component consists of cold-induced blanching of the fingers, a form of secondary Raynaud's phenomenon which is often referred to as Vibration White Finger (VWF).⁹ Several studies have found that in workers exposed to both noise and hand-arm vibration, those workers with VWF have greater hearing loss than workers without VWF, after controlling for noise exposure.¹⁰⁻¹⁵ However a well-designed study by Pyykko et al.¹⁶ found that the permanent hearing loss in workers exposed to noise and vibration did not exceed the permanent hearing loss from exposure to noise only. Therefore it appears that VWF might be a marker for increased individual susceptibility to noise-induced hearing loss without the vibration conferring increased risk of hearing loss from noise exposure.^{17,18}

The Occupational Health Clinic at St. Michael's Hospital in Toronto, Ontario has a comprehensive program to assess workers

for HAVS. Most of the construction workers assessed for HAVS have not had audiometry at work and therefore the clinic offers audiometry to these workers as a means of case finding for NIHL. This study was carried out to assess the extent of NIHL in these construction workers and to examine possible predictors, in particular the duration of work in construction and the severity of VWF.

METHODS

A total of 191 construction workers were assessed for HAVS between January 1, 2006 and December 31, 2007. All had been exposed to noise from their vibrating tools such as grinders, drills and impact tools. Twenty-two workers decided not to have the audiometric test that was offered and therefore the study group with new audiometric data comprised 169 subjects.

The data abstracted from these workers' medical charts in 2008-9 included the age at assessment, years worked in construction, job title, audiometric test results and the HAVS Stockholm vascular

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scale results in each hand. This scale is based on the frequency and severity of cold-induced blanching in the fingers and ranges from 0 to 4 with stage 0 indicating no blanching and stage 4 the most severe abnormalities.¹⁹ Audiometry had been carried out using a calibrated Tracor Instruments RA 410S micro-automated audiometer in a soundproof booth with measurement of hearing levels at 0.5, 1, 2, 3, 4, 6 and 8 kHz in each ear. The Workplace Safety and Insurance Board (WSIB) in Ontario uses a presbycusis-corrected average hearing level in the speech range (0.5 to 3 kHz) of 26.25 dB as the threshold for granting a pension for NIHL²⁰ which is based on the American Medical Association Guides to the Evaluation of Permanent Impairment.²¹ The presbycusis correction is (age in years - 60) × 0.5 for those over age 60 which is deducted from the average hearing level in the speech range to obtain the presbycusis-corrected average hearing level. Therefore this level of hearing loss was used in our study as the basis for identifying clinically significant hearing loss.

Statistical analyses were performed using SAS Version 9.2 (SAS Institute, Cary, NC). The continuous variables age, years worked in construction and many of the hearing levels at the specific audiometric frequencies were not normally distributed and therefore, in the bivariate analysis, Spearman rank correlations were used. The relationship between the number (%) of workers with a presbycusis-corrected hearing level ≥26.25 dB averaged over the speech range and years worked in construction in the categories <25, 25-40, >40 years was evaluated using the Cochran-Mantel-Haenszel test and treating the data as ordinal. To examine the effect of the HAVS Stockholm vascular scale on hearing loss, after controlling for years worked in construction, we first conducted multivariate (more than one dependent variable) linear regression with the hearing levels at all of the audiometric frequencies (0.5 to 8 kHz) as dependent variables and the HAVS Stockholm vascular scale and years worked in construction as independent variables. Follow-up univariate (single dependent variable) linear regressions were then conducted to examine whether hearing loss at each audiometric frequency was associated with the HAVS Stockholm vascular scale after controlling for years worked in construction. All of these regressions were carried out for each ear using the Stockholm vascular scale variable from the same side. Age could not be included in these models because it was highly correlated with years worked in construction. All p-values were two-tailed with p<0.05 being statistically significant.

The study was approved by the Research Ethics Board of St. Michael's Hospital, a teaching hospital affiliated with the University of Toronto.

RESULTS

All 169 workers in this study were men, median age of 57 (range: 28-75) and median years worked in construction of 35 (range: 4-52). One hundred and thirty-eight (81.7%) of the workers were pipefitters with the others working in similar trades. Of the 169 workers, 22 could not provide an accurate history of the frequency and distribution of finger blanching to allow the Stockholm vascular classification to be done. Of the 147 subjects who could be classified, the number (%) of subjects in the Stockholm scale stages is indicated in Table 1.

The audiometric hearing levels at each frequency in each ear are provided in Table 2. The highest mean hearing levels were obtained

Table 1. Number (%) of Subjects in the Stockholm Vascular Scale Stages

Hand	Stockholm Vascular Scale Stage*				
	0	1	2	3	4
Right	28 (19.0%)	14 (9.5%)	51 (34.7%)	54 (36.7%)	0 (0%)
Left	28 (19.0%)	17 (11.6%)	48 (32.7%)	54 (36.7%)	0 (0%)

* The Stockholm scale stages as described by Gemne et al.¹⁹ are as follows:
 Stage 0: No attacks of finger blanching
 Stage 1: Occasional attacks affecting only the tips of one or more fingers
 Stage 2: Occasional attacks affecting distal and middle (rarely also proximal) phalanges of one or more fingers
 Stage 3: Frequent attacks affecting all phalanges of most fingers
 Stage 4: As in Stage 3, with trophic skin changes in the fingertips

Table 2. Audiometric Hearing Levels and Spearman Correlations with Years Worked in Construction

Ear	Frequency (kHz)	Hearing Level		Correlation† (95% CI)
		Mean (SD)*	Median (Range)	
Right	0.5	18.4 (13.7)	15 (-10, 80)	0.16 (0.01-0.30) ‡
	1	17.1 (13.9)	15 (0, 75)	0.24 (0.09-0.38)
	2	17.6 (16.2)	15 (-10, 90)	0.36 (0.22-0.48)
	3	27.4 (20.9)	25 (-5, 90)	0.43 (0.29-0.54)
	4	36.8 (21.5)	35 (-5, 90)	0.42 (0.28-0.53)
	6	40.9 (20.6)	40 (5, 90)	0.47 (0.34-0.58)
Left	8	35.5 (23.3)	30 (-5, 90)	0.42 (0.28-0.53)
	0.5	19.4 (15.1)	15 (0, 70)	0.22 (0.07-0.36)
	1	17.5 (15.6)	15 (-5, 80)	0.25 (0.10-0.38)
	2	20.1 (16.7)	20 (-5, 80)	0.34 (0.19-0.46)
	3	32.1 (20.8)	30 (-5, 90)	0.48 (0.35-0.59)
	4	40.4 (21.0)	40 (0, 90)	0.50 (0.37-0.60)
	6	43.7 (21.7)	40 (5, 90)	0.48 (0.36-0.59)
	8	37.8 (23.8)	35 (-10, 90)	0.45 (0.32-0.57)

* SD=Standard deviation.

† Spearman correlation between audiometric hearing level and years worked in construction.

‡ p<0.001 for all correlations.

at 6 kHz in each ear and the highest median value of 40 dB was obtained at 4 kHz in the left ear and 6 kHz bilaterally. As indicated in Table 2, years worked in construction had statistically significant correlations (p<0.001) with the hearing levels at every audiometric frequency in each ear. The highest correlations were obtained at the audiometric frequencies of 6 kHz (r=0.47) for the right ear and 4 kHz (r=0.50) for the left ear.

The number (%) of subjects with a presbycusis-corrected average hearing level in the speech range ≥26.25 dB was 35 (20.7%) in the right ear, 48 (28.4%) in the left ear and 31 (18.3%) in both ears. As indicated in Table 3, there was a statistically significant increase (p<0.001) in the percentage of workers with this level of impairment for each ear and for both ears combined as the number of years in construction increased.

The results from the multivariate linear regression (Table 4) indicated that, after controlling for years worked in construction and hence noise exposure, the Stockholm vascular scale had a statistically significant effect on the audiometric hearing levels at all of the audiometric frequencies (0.5 to 8 kHz) for both the right side (F (7,138)=3.20, p=0.004) and the left side (F (7,138)=3.11, p=0.005). However, follow-up univariate linear regression analysis indicated that, after controlling for years worked in construction, the effect of the Stockholm vascular scale on the hearing level at each of the specific audiometric frequencies did not reach statistical significance except for 0.5 Hz on the left side.

DISCUSSION

In our study, there were statistically significant correlations between the hearing levels at each audiometric frequency and years worked

Table 3. The Number (Percentage) of Workers with a Presbycusis-corrected Average Hearing Level in the Speech Range ≥ 26.25 dB According to Years Worked in Construction

Ear	Mean HL*	Years Worked in Construction			p-value†
		≥ 26.25	<25	25-40	
Right	Yes	1 (3.7%)	13 (14.1%)	21 (42.0%)	<0.001
	No	26 (96.3%)	79 (85.9%)	29 (58.0%)	
Left	Yes	3 (11.1%)	19 (20.6%)	26 (52.0%)	<0.001
	No	24 (88.9%)	73 (78.9%)	24 (48.0%)	
Both	Yes	1 (3.7%)	11 (12.0%)	19 (38.0%)	<0.001
	No	26 (96.3%)	81 (88.09%)	31 (62.00%)	

* Mean HL=hearing level averaged over the speech range (0.5-3 kHz) after subtracting a presbycusis correction for subjects aged over 60 years as follows: [(age in years - 60) $\times$ 0.5].

† The p-value was obtained from the Cochran-Mantel-Haenszel test treating the data as ordinal (i.e., indicative of trend).

Table 4. Linear Regression Analysis of Audiometric Hearing Levels

Ear	Audiometric Frequency	Predictor	Estimate (SE)	F-value	p-value
Right	Overall	Years in construction *		6.81	<0.001
		Stockholm vascular scale†		3.20	0.004
	0.5	Years in construction	0.37(0.12)		0.003
		Stockholm vascular scale	1.08(1.07)		0.31
	1	Years in construction	0.47(0.12)		<0.001
		Stockholm vascular scale	0.80(1.07)		0.46
	2	Years in construction	0.58(0.14)		<0.001
		Stockholm vascular scale	2.03(0.19)		0.09
	3	Years in construction	1.03(0.17)		<0.001
		Stockholm vascular scale	1.18(1.47)		0.42
Left	Overall	Years in construction *		9.83	<0.001
		Stockholm vascular scale		3.11	0.005
	0.5	Years in construction	0.49(0.13)		<0.001
		Stockholm vascular scale	2.32(1.14)		0.04
	1	Years in construction	0.55(0.13)		<0.001
		Stockholm vascular scale	1.12(1.17)		0.34
	2	Years in construction	0.72(0.14)		<0.001
		Stockholm vascular scale	0.58(1.20)		0.63
	3	Years in construction	1.16(0.16)		<0.001
		Stockholm vascular scale	0.17(1.38)		0.90
	4	Years in construction	1.27(0.16)		<0.001
		Stockholm vascular scale	1.97(1.37)		0.15
	6	Years in construction	1.11(0.16)		<0.001
		Stockholm vascular scale	0.50(1.44)		0.73
	8	Years in construction	1.11(0.19)		<0.001
		Stockholm vascular scale	1.68(1.62)		0.30

* Years worked in construction is a continuous variable. The estimates indicate the effect of a single year worked in construction.

† Stockholm scale is treated as a continuous variable. The estimates indicate the effect of one stage of the Stockholm scale.

in construction. The correlations were highest at 4 and 6 kHz and tapered off at 8 kHz, which is a typical pattern for NIHL.¹ Therefore the number of years worked in construction was probably a good metric for cumulative noise exposure in our study group. However, because of the high correlation between years worked in construction and age, it is likely that age also contributed to the hearing loss in some of the workers in our study.

This study found a high prevalence of clinically significant hearing loss in construction workers being assessed for HAVS. Thirty-one (18.3%) subjects had a presbycusis-corrected average hearing level in the speech frequencies of ≥ 26.25 dB in both ears, which is the level at which a pension would be granted for NIHL by the

WSIB in Ontario. The proportion of subjects with this level of hearing loss increased as the number of years worked in construction increased, with the trend being statistically significant.

Other studies have found an increased risk of hearing loss in construction workers. Tak and Calvert²² recently reported that the construction sector had the largest number of workers of any industrial sector in the US with hearing difficulty attributable to employment. The estimated prevalence (SE) of hearing difficulty in workers in the construction industry was 15.1% (0.5%) and the prevalence ratio (95% CI) in comparison to workers assumed not to be exposed to noise was 1.43 (1.31-1.57). Arndt et al. found a prevalence ratio of hearing loss of 1.5 (1.29-1.82) for construction workers in Germany in comparison to non-exposed controls.²³ Workers in Canada likely face similar risks of NIHL. Sinclair and Hafliðson carried out a noise survey of workers in 27 construction projects and contractors' facilities in Ontario and found that the average noise exposure was 98.8 dB(A) with 91.3% of the samples exceeding 85 dB(A).⁴

Our study also found a statistically significant multivariate effect of the HAVS Stockholm vascular scale on the hearing levels at the audiometric frequencies 0.5 to 8 kHz after controlling for years worked in construction. However, the effect of HAVS on hearing appeared to be small because we could only identify a single audiometric frequency of the 14 specific frequencies tested that had a statistically significant association with the Stockholm vascular scale. Other studies have reported an association between VWF and hearing loss with the assumed mechanism being an increased susceptibility to generalized vasospasm, including vasospasm in the cochlea, in workers who develop HAVS.¹⁰⁻¹⁵ Interestingly, primary Raynaud's phenomenon unrelated to vibration exposure also has been found to be associated with increased susceptibility to NIHL.¹⁰

Zhu et al. reported greater temporary threshold shift in hearing from acute noise and hand-arm vibration exposure in comparison to just noise exposure in a small group of healthy subjects.²⁴ However, permanent hearing loss is the most important auditory outcome and this does not appear to be increased from combined noise and hand-arm vibration exposure in comparison to just noise exposure.¹⁶ Our study included only workers exposed to hand-arm vibration and therefore could not further address this question.

Despite the fact that the hazardous auditory effects of noise have been known for many years, our study has indicated that construction workers continue to develop NIHL. An increased focus on prevention is needed for workers in this sector and should involve input from workers and employers and focus on all levels of prevention.²⁵ This would be aided by legislation restricting noise exposure, but in Ontario, the legislation which limits noise exposure to 85 dB(A) for an eight-hour daily exposure does not apply to con-

struction workers and there is no requirement for these workers to have routine audiometry. The situation is similar in the US in that the OSHA standard for noise exposure for construction workers is less rigorous than the standard for general industrial workers.^{3,26} In addition, construction workers often move from one job site to another to carry out serial construction projects and this pattern of work is not conducive to having employers provide comprehensive surveillance as well as other program elements to prevent hearing loss.^{3,26} It also creates difficulty for monitoring of programs by government inspectors. Construction contractors, workers, unions, health and safety associations and Ministries of Labour in Canada need to consider improved methods for prevention of NIHL in construction workers.

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RÉSUMÉ

Contexte : Les travailleurs du bâtiment courent un risque de perte d'audition due au bruit (PADB), mais souvent ne se soumettent pas à des examens audiométriques périodiques.

Méthode : Les participants étaient des travailleurs du bâtiment évalués pour le syndrome vibratoire main-bras (SVMB) à la clinique de santé au travail de l'hôpital St. Michael de Toronto, en Ontario. Nous leur avons proposé un examen audiométrique, et 169 des 191 travailleurs évalués pour le SVMB ont accepté. Notre objectif était de déterminer la prévalence de la perte auditive chez ces 169 travailleurs, l'effet sur l'ouïe de la durée du travail dans l'industrie du bâtiment (variable substitutive à l'exposition au bruit) et la gravité du syndrome du doigt mort (SDM), lequel, selon des études antérieures, pourrait être un indicateur de susceptibilité individuelle accrue pour la PADB. Nous avons mesuré le SDM selon l'échelle de Stockholm pour les symptômes vasculaires.

Résultats : Tous les participants étaient des hommes d'âge médian de 57 ans (intervalle : 28-75) ayant travaillé 35 ans (nombre médian) dans l'industrie du bâtiment (intervalle : 4-52). Toutes les corrélations des rangs de Spearman entre les années de travail dans le bâtiment et le niveau d'ouïe à chaque fréquence audiométrique étaient significatives ($p < 0,001$). Dans l'ensemble, 31 participants (18,3 %) avaient une perte auditive supérieure ou égale au niveau auquel l'Ontario accorde une rente accident du travail, et la prévalence de cette perte auditive augmentait de façon significative avec les années de travail dans le bâtiment. Une régression linéaire multivariée a aussi montré un effet significatif du SDM sur la perte auditive pour toutes les fréquences audiométriques combinées, en tenant compte des années de travail dans le bâtiment.

Conclusion : Il faut améliorer la prévention de la perte auditive chez les travailleurs du bâtiment.

Mots clés : ouïe; bruit; construction; vibration; syndrome du doigt mort