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Associations between anthropometric factors and peripheral neuropathy defined by vibrotactile perception threshold among industrial vibrating tool operators in Japan

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Abstract: Objectives: The effect of anthropometric factors on the fingertip vibrotactile perception threshold (VPT) of industrial vibrating tool operators (IVTOs) is not well known. The purpose of this study was to investigate the associations between anthropometric factors and fingertip VPT. **Methods:** We included for analysis two groups of IVTOs: Group 1, predominantly forestry workers (*n*=325); and Group 2, public servants (*n*=68). These IVTOs regularly received medical examinations to evaluate hand-arm vibration syndrome. In the examination, measurements of their fingertip VPTs were taken before and after cold-water immersion (10 minutes at 10°C for Group 1 and 5 minutes at 12°C for Group 2). Their body height and weight were measured to calculate the body mass index (BMI). The presence of peripheral neuropathy (PN) was defined as a VPT ≥17.5 dB at 10 minutes after finishing immersion. **Results:** In the univariate analysis, weight and BMI were associated with a decreased risk of PN in both Groups 1 and 2. The negative association between BMI and PN remained in the multivariate analysis consistently, but weight reached marginal significance only in the multivariate analysis without BMI in both the groups. Age was positively associated with PN consistently in Group 1 but not in Group 2. Years exposed to vibration showed positive association with PN only in the univariate analysis of Group 1. **Conclusions:** Among IVTOs, factors reflecting body heat production, such as weight and BMI, were associated with a decreased risk of VPT-defined PN, regardless of the task engaged.
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Introduction

Prolonged exposure to hand-arm vibration is a cause of hand-arm vibration syndrome (HAVS). This disorder is characterized by circulatory disturbances, neurological disorders, and bone-and-joint (musculoskeletal) changes in upper extremities[1]. In cases of HAVS, the severity of peripheral neuropathy (PN) is evaluated by measuring vibrotactile perception thresholds (VPTs) at the fingertips[2,3]. However, to evaluate HAVS neuropathy with VPTs, it is necessary first to rule out conditions such as (1) traumas (burning, frostbite, and other causes), (2) Raynaud's phenomenon of nonvibratory causes, (3) thoracic outlet syndrome, (4) neuropathy/angiopathy caused by poisoning and related agents, (5) angiopathy caused by pulseless disease, diabetes, Buerger's disease and related disorders, (6) collagen vascular diseases (e.g., rheumatoid arthritis, systemic sclerosis, etc.), (7) gout, and (8) certain other chronic arthritides (e.g., tuberculosis-induced, etc.)[4].

Some recent studies have shown associations between selected anthropometric factors and PN. In a study by Skov et al. using vibrometry data gathered from workers in the United States who were exposed to organic solvents, older age and taller body were positively associated with higher VPT. Specifically, the foot's VPT was positively associated with body height, but the hand's VPT was not. The greater effects of age and height on toe threshold, rather than finger threshold, is consistent with the hypothesis that the length of the nerve increases susceptibility to PN[5]. The regrowth of injured axons is apparently as slow as 1 mm per day[6], and it takes a longer time for longer nerve fibers to recover if they get injured. Chuang et al. did not find a significantly positive association between body height and VPT in a population exposed to lead[7]. This negative finding was probably because the study subjects were shorter, on average, than those in the study by Skov et al.[5]. As for body weight, the associations of body weight and body mass index (BMI) with VPT were either negative[5] or not evaluated[7].

The prevalence of overweight or obesity (BMI ≥25.0 kg/m^2) is increasing, especially among males in Japan[8,9]. Overweight or obesity itself is a risk factor for some chronic diseases such as hypertension, diabetes, and dyslipidemia[10,11]. It is also reported that PN is observed among obese patients with or without diabetes[12,13]. In other words, larger body size may be associated with an increased risk of PN.

On the other hand, the surface-area-to-volume ratio (SA:V) of the human body is lower in those with a larger body volume (the square-cube law). In other words, those with a larger body size will have a lower SA:V; they radiate less body heat per unit of mass and stay warmer in cold climates. Bergmann's rule[14] attests to this mechanism, which indicates that species of larger size are found in colder environments, and species of smaller size are found in warmer environments. Higher body height, body weight, and BMI indicate larger body sizes that will stay warmer in cold environments. On the basis of this perspective, we hypothesize that large body size may be negatively (i.e., protectively) associated with VPTs. In other words, larger body size may be associated with a decreased risk of PN.

Thus, although some papers have reported the association between anthropometric factors and HAVS, as well as evidence to support the association between these factors and somatic disorders related to HAVS, only a limited number of studies have been conducted to evaluate the associations between anthropometric factors and VPT. In Japan, health examinations are provided for industrial vibrating tool operators (IVTOs) to evaluate HAVS, but to the best of our knowledge, the associations between anthropometric factors and VPT among IVTOs remain unclear. If anthropometric factors are proven to be associated with HAVS-related PN, such information may be useful for preventing it, for example, by excluding high-risk populations from this type of physically hard work, or for advising IVTOs to gain or lose weight to a certain level that would minimize the risk of HAVS-related PN. This study examines the associations between anthropometric factors and VPTs among IVTOs.

Subjects and Methods

Study subjects

For this analysis, we recruited study participants from two groups of workers: Group 1, workers predominantly engaged in forestry, who were exposed to hand-arm vibration through hand-held vibrating tools, mainly chain saws (n=336, all males); and Group 2, public servants engaged in road or farm maintenance, who were exposed to hand-arm vibration through handheld vibrating tools, mainly bush clearers (n=92, 91 males and 1 female). These workers received medical examinations to evaluate HAVS. The examinations were conducted annually as a part of occupational health management, pursuant to a circular from the Ministry of Health, Labour and Welfare (formerly the Ministry of Labour), Government of Japan[15]. We have been providing annual medical examinations for the abovementioned workers. We included both Groups 1 and 2 in the study to evaluate whether anthropometric factors affect PN regardless of the task performed.

Medical examinations that included the assessment of VPTs were performed from November to December 2013 for Group 1 and from January to February 2012 for Group 2.

A total of 331 workers in Group 1 (98.5%) and 92 workers in Group 2 (100%) gave written consent to have their data from the medical examinations included in this study. This study was approved by the Institutional Review Board of Wakayama Medical University.

Procedure

Workers were asked to complete a self-administered questionnaire about their conditions, including years engaged in operating industrial vibrating tools, days per year operating such tools, hours per day operating them, lifestyle factors (smoking, alcohol consumption, etc.), medical history (including occupational traumas), HAVS-related symptoms (tingling, numbness, dysesthesia, pain, white finger, etc.), and other symptoms and complaints. Total operating time (TOT) (hours) was defined as daily operating time (hours/day)×number of days exposed to vibration (days/year)×years exposed to vibration (years).

Medical examinations were conducted in a quiet room, with the temperature set at 20-23°C. Workers were asked to abstain from smoking and drinking beverages with caffeine and alcohol for at least two hours beforehand.

After acclimatization to the room temperature for at least 30 minutes, VPTs at 125 Hz were measured in four fingertips (except thumbs) of both hands in Group 1 and in all five fingertips (thumbs included) of both hands in Group 2. VPTs were measured in a sitting position with a vibrometer [AU-02, Rion Co., Ltd., Tokyo, Japan (reference value: 0 dB=308 mm/s^2)]. During measurement, the

Table 1. Vibrotactile perception thresholds before and cold-water immersion among public servants.

	Vibrotactile perception threshold (dB)			
Test condition of cold-water immersion	Before immersion	0 min after immersion	5 min after immersion	10 min after immersion
10˚C, 10-min method (year 2010, *n*=87)	1.36 (4.77)	16.18 (8.24)	8.85 (8.40)	6.44 (8.30)
12˚C, 5-min method (year 2012, *n*=86)	–0.17 (5.30)	11.66 (7.06)	8.92 (7.85)	7.33 (7.52)
p^a	0.047	0.000	0.953	0.462
p^b	—	0.001	0.345	0.098

Figures indicate the average (standard deviation) of vibrotactile perception thresholds unless otherwise specified.
[a]The unpaired *t*-test was conducted between the year 2010 and year 2012 data.
[b]Analysis of covariance was conducted between the year 2010 and year 2012 data, controlling for the vibrotactile perception threshold before immersion.

ascending threshold was observed; vibration began at a low level (-10.0 dB in general) and then gradually intensified at an interval of 2.5 dB until the worker perceived it, which was taken as the VPT.

Afterwards, the workers were given a cold-water immersion test. After staying in a sitting position, they immersed their dominant hand or the hand with HAVS-related symptoms (tingling, numbness, dysesthesia, pain, white finger, etc.), if any, in cold water to the wrist for a designated time period (10 minutes at 10°C[16,17]) for Group 1 and 5 minutes at 12°C[18]) for Group 2).

The 10°C, 10-min method is a conventional test condition for evaluating HAVS in Japan. The 12°C, 5-min method is less invasive than the 10°C, 10-min method and can be conducted easily among IVTOs with exposure to a smaller amount of vibration.

Body height was measured with a stadiometer, with shoes removed. As for subjects whose body height was unavailable, their self-reported values were adopted instead. Self-reported height is known to be generally reliable[19]). Greater worker height served not only as factor representing body size but also as a proxy indicator for longer peripheral nerve fiber lengths. Body weight was measured in both groups with light clothing and also with shoes removed. Body mass index (BMI) (kg/m^2) was calculated as body weight in kilograms divided by the square of the height in meters.

After finishing the cold-water immersion test, the subjects received physical and neurological examinations from a physician.

Statistical analysis

After excluding (a) female workers (*n*=1 in Group 2), (b) workers who reported a history of diabetes (*n*=1 in Group 1, and *n*=5 in Group 2), (c) workers who did not participate in the cold-water immersion test (*n*=2 in Group 1), and (d) workers with some missing data for age, body height, body weight, BMI, or years exposed to vibrating tools (*n*=3 in Group 1, and *n*=18 in Group 2), male workers with complete data (*n*=325 in Group 1 and *n*=68 in Group 2) were used for the statistical analyses.

For both Group 1 (10°C, 10-min method) and Group 2 (12°C, 5-min method), PN was defined as a VPT ≥17.5 dB at 10 minutes after finishing the cold-water immersion[20]). We reviewed public servants' medical records and found that the VPT at 10 minutes after finishing immersion was virtually the same between Group 2 public servants in January to February 2012 (12°C, 5-min method) and public servants of the same population who received a cold-water immersion test (10°C, 10-min method) in January to February 2010, while the VPT before immersion was significantly different [Table 1]. Therefore, we adopted the same cutoff value for the VPT at 10 minutes after immersion in both the groups. (Unfortunately, anthropometry was not conducted among the public servants in 2010, and so we could not compare anthropometric data for them with those of Group 1 workers in 2013.)

The characteristics of IVTOs were compared between Group 1 and Group 2. Continuous variables (age, body height, body weight, BMI, years, days and hours exposed to vibrating tools, and TOT) were compared with Mann-Whitney's *U*-test. Categorical variables (prevalence of PN) were compared with the chi-square test.

The odds ratio (OR) for PN, along with its 95% confidence interval (CI), was calculated as an outcome variable of each explanatory variable using a logistic regression model. In the univariate analysis, we evaluated independent exposure variables such as age, body height, body weight, BMI, years exposed to industrial vibrating tools, days per year exposed to industrial vibrating tools, hours per day exposed to industrial vibrating tools, and TOT. The study subjects of each group were divided into quartiles according to each variable. In Group 2, due to the small number of subjects with PN, we merged more than one classes into a single class in some analyses.

In the multivariate analysis, we included all variables with $p<0.10$ in the univariate analysis as well as body weight and BMI in Group 1. In Group 2, due to the small number of study subjects, we included variables with $p<0.10$ in the univariate analysis as well as variables in-

Table 2. Characteristics of industrial vibrating tool operators.

	Group 1 (*n*=325)	Group 2 (*n*=68)	p^{f}
Age (years)	47.8 (11.9)	49.8 (7.3)	0.106
Body height (cm)	169.6 (6.3)	168.4 (6.7)	0.179
Body weight (kg)	68.8 (11.1)	70.7 (11.3)	0.162
Body mass index (kg/m^2)	23.9 (3.3)	24.9 (3.7)	0.024
Years exposed to vibrating tools (years)	15.6 (11.3)	19.5 (8.9)	0.000
Days exposed to vibrating tools (days/year)	168.6 (58.7)[b]	40.2 (30.3)[e]	0.000
Hours exposed to vibrating tools (hours/day)	4.8 (1.5)[c]	3.5 (1.1)[e]	0.000
Total operating time (hours)	12512.0 (11308.7)[d]	2609.1 (2468.8)[e]	0.000
Peripheral neuropathy (% of subjects)[a]	79 (24.3)	9 (13.2)	0.046[g]

Figures indicate average (standard deviation) values unless otherwise specified. [a]Peripheral neuropathy was defined as a vibrotactile perception threshold ≥17.5 dB at 10 minutes after finishing cold-water immersion (10 minutes at 10°C for Group 1, and 5 minutes at 12°C for Group 2). [b]*n*=307. [c]*n*=305. [d]*n*=300. [e]*n*=65. [f]Mann-Whitney's *U*-test was conducted unless otherwise specified. [g]The chi-square test was conducted.

cluded in the multivariate model of Group 1. Then we performed additional analyses, removing body weight or BMI in a mutually exclusive manner, in order to control potential multicollinearity between BMI and body weight[21].

All comparisons were two-tailed. A value of $p<0.05$ was considered significant, and a value of $0.05 \le p<0.10$ was considered marginally significant. All analyses were conducted using the SAS 9.3 software (SAS Institute, Inc., Cary, NC, USA).

Results

Table 2 shows the characteristics of the IVTOs. There was no significant difference in age, body height, and body weight between Groups 1 and 2. Their body statures were also similar to those of the average of Japanese male in the fifth decade of life in 2012 (height, 170.9 cm; weight, 70.5 kg)[22]. Workers in Group 2 had higher BMIs. Workers in Group 1 had a lower number of years exposed to vibration but a higher number of days and hours exposed to vibrating tools as well as a larger TOT. The prevalence of PN was 24.3% (79/325) in Group 1 and 13.2% (9/68) in Group 2.

Tables 3 shows the ORs for PN in Group 1. In the univariate analysis, higher body weight (OR 0.39, 95% CI 0.17-0.85 in quartile 4 (Q4) *versus* quartile 1 (Q1); trend p=0.021) and BMI (OR 0.37, 95% CI 0.17-0.80 in Q4 *versus* Q1; trend p=0.009) were significantly negatively associated with PN, whereas older age (OR 4.98, 95% CI 2.18-11.3 in Q4 *versus* Q1; trend p=0.000) and higher number of years exposed to vibration (OR 2.78, 95% CI 1.35-5.75 in Q4 *versus* Q1; trend p=0.008) were positively associated with PN. Operating days, operating hours, and TOT did not show any significant association with PN. In the multivariate analysis, age and BMI remained significant, while the statistically significant association between body weight and operating years and PN disappeared. Removal of BMI from the model resulted in a negative association between body weight and PN with marginally statistical significance. Removal of body weight from the model instead did not cause BMI to lose its negative association with PN.

Likewise, Table 4 shows the ORs for PN in Group 2. In the univariate analysis, higher body weight (OR 0.10, 95% CI 0.01-0.97 in quartiles 3 and 4 *versus* Q1; trend p=0.034) and BMI (OR 0.06, 95% CI 0.006-0.53 in quartiles 3 and 4 *versus* Q1; trend p=0.007) were significantly associated with a decreased risk of PN, just like in Group 1. Age did not show no positive association with PN (OR 2.05, 95% CI 0.41-10.2 in Q4 *versus* Q1; trend p=0.307). Higher numbers of years, days and hours exposed to vibrating tools as well as TOT were associated with higher ORs but were not significantly associated with PN, unlike in Group 1.

In the multivariate analysis, the negative (protective) association found between BMI and PN remained, whereas the negative association between body weight and PN was no longer significant. Furthermore, by removing body weight or BMI in a mutually exclusive manner, BMI still decreased the risk of PN, while the PN-preventing effect of body weight reemerged but did not reach significance. The risk of PN among workers exposed to vibration for 25 years or longer was seven times as high as for those with vibration exposure for less than 15 years, although it was not significant.

Discussion

In this study, both body weight and BMI were associated with a decreased risk of PN. In the multivariate model, BMI remained significantly protective, while

Table 3. Odds ratios and 95% confidence intervals for peripheral neuropathy in Group 1 (n=325).

		PN positive/ Total (%)	*Univariate analysis*			*Mutivariate analysis*								
						Full model			*Full model minus BMI*			*Full model minus weight*		
			OR	(95% CI)	p	OR	(95% CI)	p	OR	(95% CI)	p	OR	(95% CI)	p
Age (years)	21-38	9/79 (11.4)	1.00	(Ref.)		1.00	(Ref.)		1.00	(Ref.)		1.00	(Ref.)	
	39-47	15/87 (17.2)	1.62	(0.67-3.94)	0.288	1.85	(0.72-4.74)	0.202	1.69	(0.67-4.26)	0.262	1.77	(0.70-4.50)	0.232
	48-57	23/77 (29.9)	3.31	(2.18-7.74)	0.006	3.78	(1.45-9.81)	0.006	3.29	(1.30-8.33)	0.012	3.52	(1.38-9.02)	0.009
	58-75	32/82 (39.0)	4.98	(1.82-11.3)	0.000	4.90	(1.77-13.6)	0.002	4.03	(1.49-10.9)	0.006	4.54	(1.67-12.3)	0.003
			Trend	p=0.000		Trend	p=0.001		Trend	p=0.003		Trend	p=0.001	
Height (cm)	152.0-165.8	23/81 (28.4)	1.00	(Ref.)										
	165.9-169.9	15/66 (22.7)	0.74	(0.35-1.57)	0.436									
	170.0-173.8	26/97 (26.8)	0.92	(0.48-1.79)	0.813									
	173.9-185.0	15/81 (18.5)	0.57	(0.27-1.20)	0.141									
			Trend	p=0.235										
Weight (kg)	47.6-61.1	24/82 (29.3)	1.00	(Ref.)		1.00	(Ref.)		1.00	(Ref.)				
	61.2-67.5	23/80 (28.8)	0.98	(0.50-1.92)	0.942	1.74	(0.76-3.99)	0.190	1.10	(0.54-2.24)	0.795			
	67.6-74.3	21/83 (25.3)	0.82	(0.41-1.63)	0.568	1.87	(0.70-5.00)	0.212	0.85	(0.42-1.75)	0.665			
	74.4-112.6	11/80 (13.8)	0.39	(0.17-0.85)	0.019	1.42	(0.42-4.86)	0.575	0.45	(0.20-1.02)	0.055			
			Trend	p=0.021		Trend	p=0.523		Trend	p=0.052				
BMI (kg/m^2)	17.5-21.6	26/81 (32.1)	1.00	(Ref.)		1.00	(Ref.)					1.00	(Ref.)	
	21.7-23.5	21/76 (27.6)	0.81	(0.41-1.60)	0.542	0.63	(0.28-1.45)	0.281				0.83	(0.40-1.72)	0.618
	23.6-25.3	20/87 (23.0)	0.63	(0.32-1.25)	0.187	0.37	(0.14-0.99)	0.048				0.54	(0.26-1.11)	0.091
	25.4-35.1	12/81 (14.8)	0.37	(0.17-0.80)	0.011	0.23	(0.07-0.77)	0.017				0.32	(0.14-0.71)	0.005
			Trend	p=0.009		Trend	p=0.013					Trend	p=0.003	
Years exposed to vibration (years)	0.4-8.9	15/79 (19.0)	1.00	(Ref.)		1.00	(Ref.)		1.00	(Ref.)		1.00	(Ref.)	
	9.0-10.9	16/77 (20.8)	1.12	(0.51-2.46)	0.779	0.90	(0.38-2.10)	0.799	0.90	(0.39-2.10)	0.810	0.92	(0.39-2.16)	0.852
	11.0-21.9	18/93 (19.4)	1.02	(0.48-2.19)	0.951	0.72	(0.31-1.66)	0.434	0.73	(0.32-1.68)	0.463	0.74	(0.32-1.69)	0.470
	22.0-60.0	30/76 (39.5)	2.78	(1.35-5.75)	0.006	1.33	(0.53-3.32)	0.538	1.24	(0.50-3.05)	0.644	1.33	(0.54-3.31)	0.537
			Trend	p=0.008		Trend	p=0.705		Trend	p=0.799		Trend	p=0.704	
Days exposed to vibration (days/ year) (n=307)	3.0-149.9	15/70 (21.4)	1.00	(Ref.)										
	150.0-189.9	20/85 (23.5)	1.13	(0.53-2.41)	0.756									
	190.0-219.9	22/103 (21.4)	1.00	(0.48-2.09)	0.991									
	220.0-300.0	15/49 (30.6)	1.62	(0.70-3.72)	0.258									
			Trend	p=0.403										

body weight failed to reach statistical significance. These preventive effects were stronger in Group 2 than in Group 1. On the other hand, age was positively associated with an increased risk of PN, but this was only consistently ob-

Table 3. Odds ratios and 95% confidence intervals for peripheral neuropathy in Group 1 (n=325). (continued)

		PN positive/ Total (%)	*Univariate analysis*			*Mutivariate analysis*								
						Full model			*Full model minus BMI*			*Full model minus weight*		
			OR	(95% CI)	p	OR	(95% CI)	p	OR	(95% CI)	p	OR	(95% CI)	p
Hours exposed to vibration (hours/day) (n=305)	0.1-3.9	15/62 (24.2)	1.00	(Ref.)										
	4.0-5.4	28/120 (23.3)	0.95	(0.47-1.96)	0.897									
	5.5-6.4	20/95 (21.1)	0.84	(0.39-1.79)	0.644									
	6.5-8.0	7/28 (25.0)	1.04	(0.37-2.94)	0.934									
			Trend	p=0.828										
TOT (hours) (n=300)	30-4999	15/75 (20.0)	1.00	(Ref.)										
	5000-9499	18/74 (24.3)	1.29	(0.59-2.79)	0.526									
	9500-14999	11/71 (15.5)	0.73	(0.31-1.73)	0.478									
	15000-54000	25/80 (31.3)	1.82	(0.87-3.80)	0.112									
			Trend	p=0.221										

PN, peripheral neuropathy; OR, odds ratio; CI, confidence interval; BMI, body mass index; TOT, total operating time. Full model: adjusted for all variables with p<0.10 in the univariate analysis (age, weight, BMI, and years exposed to vibration).

served in Group 1. Years exposed to vibration showed a risk-increasing effect on PN in the univariate analysis of Group 1 only.

The negative (preventive) association between body weight and BMI and PN is consistent with the hypothesis that higher body heat production per unit of mass accelerates the recovery of hand warmth and VPT. Given the greater preventive effects of body weight and BMI in Group 2, these anthropometric factors might be more effective among populations with lower exposure to vibration.

Our findings showed the association between body weight/BMI and PN in a population of Japan. From our findings, people with greater body weight/BMI such as Western people[23] will obtain greater benefit than Japanese people. However, these findings should not encourage IVTOs to gain weight simply to prevent HAVS-related PN. Overweight itself is associated with some chronic diseases, such as hypertension, dyslipidemia, and diabetes[10,11]. Therefore, a combination of interventions such as dietary modifications and physical exercise has been advocated to help control obesity, lose weight, and limit progressive decline in lean tissues with age[10,11]. By contrast, a recent review shows that up to 30% of obese patients are metabolically healthy; they have insulin sensitivity similar to healthy lean individuals, lower liver fat content and carotid artery intima/media thicknesses than the majority of metabolically "unhealthy" obese patients[24]. The effects of obesity, metabolism, and lean tissues on VPTs should be investigated in the future.

The positive association between older age and PN may reflect aging and/or chronic exposure to vibration. This positive association was detected only in Group 1. This may be due to the greater range of age among Group 1 subjects (21-75 years) than among Group 2 subjects (33-73 years). Years exposed to vibration showed statistical significance only in the univariate analysis of Group 1 with the greater range of age. This finding reflects the confounding effect of age on operating years. Therefore, some other variables should be also considered. Total operating time, which indicates occupational vibration exposure more directly than operating years, showed no association with PN, unlike operating years in the univariate analysis of Group 1. If a higher number of years or TOT indicates a greater amount of vibration exposure, these factors may not appropriately represent the vibration dose in this study; various kinds of recall bias may be involved here (see the first limitation shown below).

In a study by Skov et al.[5], a J-shaped increase in finger VPT was demonstrated with age; there was no increase up to age 35, and a linear increase was seen thereafter. For finger VPT, the subject's height was not an important predictor. The data were sparser for the toe threshold, but they suggested a linear increase with both age and height. The researchers concluded that the greater effect of age and height on toe threshold, rather than finger threshold, was consistent with the hypothesis that the length of a

Table 4. Odds ratios and 95% confidence intervals for peripheral neuropathy in Group 2 (n=68).

		PN positive/ Total (%)	*Univariate analysis*			*Mutivariate analysis*								
						Full model			*Full model minus BMI*			*Full model minus weight*		
			OR	(95% CI)	p	OR	(95% CI)	p	OR	(95% CI)	p	OR	(95% CI)	p
Age (years)	33-46	3/19 (15.8)	1.00	(Ref.)		1.00	(Ref.)		1.00	(Ref.)		1.00	(Ref.)	
	47-49	0/16 (0.0)	0.18	(0.02-1.85)	0.149	0.59	(0.11-3.22)	0.546	0.14	(0.01-1.91)	0.139	0.15	(0.009-2.38)	0.178
	50-53	1/15 (6.7)												
	54-73	5/18 (27.8)	2.05	(0.41-10.2)	0.381				1.55	(0.16-14.8)	0.705	5.18	(0.45-60.1)	0.189
			Trend	p=0.307					Trend	p=0.489		Trend	p=0.147	
Height (cm)	144.2-164.9	1/16 (6.3)	1.00	(Ref.)										
	165.0-168.3	2/18 (11.1)	1.88	(0.15-22.9)	0.622									
	168.4-172.2	4/19 (21.1)	4.00	(0.40-40.1)	0.239									
	172.3-186.0	2/15 (13.3)	2.31	(0.19-28.5)	0.514									
			Trend	p=0.386										
Weight (kg)	50.1-61.0	4/17 (23.5)	1.00	(Ref.)		1.00	(Ref.)		1.00	(Ref.)				
	61.1-69.9	4/17 (23.5)	1.00	(0.21-4.88)	1.000	5.10	(0.38-67.6)	0.217	1.65	(0.20-13.7)	0.645			
	70.0-77.5	1/17 (5.9)	0.10	(0.01-0.97)	0.047				0.10	(0.009-1.06)	0.056			
	77.6-109.9	0/17 (0.0)												
			Trend	p=0.034					Trend	p=0.051				
BMI (kg/m²)	19.5-22.1	6/17 (35.3)	1.00	(Ref.)		1.00	(Ref.)					1.00	(Ref.)	
	22.2-25.0	2/18 (11.1)	0.23	(0.04-1.35)	0.104	0.03	(0.002-0.39)	0.008				0.08	(0.008-0.81)	0.032
	25.1-27.3	1/17 (5.9)	0.06	(0.006-0.53)	0.012							0.02	(0.002-0.34)	0.006
	27.4-40.2	0/16 (0.0)												
			Trend	p=0.007								Trend	p=0.005	
Years exposed to vibration (years)	1.0-14.9	1/16 (6.3)	1.00	(Ref.)		1.00	(Ref.)		1.00	(Ref.)		1.00	(Ref.)	
	15.0-20.9	5/17 (29.4)	2.88	(0.31-27.1)	0.354	7.07	(0.47-107)	0.158	3.62	(0.27-48.1)	0.330	7.49	(0.42-134)	0.171
	21.0-24.9	0/14 (0.0)												
	25.0-38.0	3/21 (14.3)	2.50	(0.24-26.6)	0.448				1.25	(0.08-20.2)	0.877	3.38	(0.14-80.2)	0.452
			Trend	p=0.516					Trend	p=0.942		Trend	p=0.486	
Days exposed to vibration (days/ year) (n=65)	5.0-17.9	1/16 (6.3)	1.00	(Ref.)										
	18.0-34.9	5/20 (25.0)	2.78	(0.30-26.0)	0.371									
	35.0-59.9	0/12 (8.3)												
	60.0-120.0	3/17 (17.7)	3.21	(0.30-34.6)	0.336									
			Trend	p=0.353										

nerve increases susceptibility to PN. On the other hand, a study by Chuang et al.[7] showed that body height did not correlate with the VPT of hands or feet. The average (standard deviation) of body height among study subjects

Table 4. Odds ratios and 95% confidence intervals for peripheral neuropathy in Group 2 (*n*=68). (continued)

		PN positive/ Total (%)	*Univariate analysis*			*Mutivariate analysis* *Full model*			*Full model minus BMI*			*Full model minus weight*		
			OR	(95% CI)	*p*	OR	(95% CI)	*p*	OR	(95% CI)	*p*	OR	(95% CI)	*p*
Hours exposed to vibration (hours/ day) (*n*=65)	2.0-2.9	1/16 (6.3)	1.00	(Ref.)										
	3.0-3.9	1/16 (6.3)	1.00	(0.06-17.5)	1.000									
	4.0-4.9	4/19 (21.1)	4.00	(0.40-40.1)	0.239									
	5.0	3/14 (21.4)	4.09	(0.37-44.8)	0.249									
			Trend	*p*=0.130										
TOT (hours) (*n*=65)	30-874	2/16 (12.5)	1.00	(Ref.)										
	875-1919	0/16 (0.0)	1.00	(0.16-6.14)	1.000									
	1920-3399	4/16 (25.0)												
	3400-10560	3/17 (17.7)	1.50	(0.22-10.4)	0.681									
			Trend	*p*=0.665										

PN, peripheral neuropathy; OR, odds ratio; CI, confidence interval; BMI, body mass index; TOT, total operating time. Full model: adjusted for all variables with $p<0.10$ in the univariate analysis (age, weight, BMI, and years exposed to vibration).
In some analyses, more than one class was merged into a single class due to the small number of subjects with peripheral neuropathy.

in Skov's study was 170.1 (9.1) cm, which was similar to our population's body height, while it was 158.7 (8.4) cm among Chuang's study subjects. We did not measure toe VPTs or show a significant effect of body height in our population, neither as a factor representing body size nor as a proxy indicator for peripheral nerve fiber lengths. The abovementioned studies might support our findings. However, as for body weight and BMI, unlike Skov's study, where these factors did not show consistent associations with VPT, we showed their preventive effects on HAVS-related PN, which will provide some information for the prevention of PN caused by occupational exposure.

Some limitations of this study should be mentioned.

Firstly, information on workers' exposure to vibration was collected only by self-report using a self-administered questionnaire in a cross-sectional manner. Hours per day and days per year exposed to vibrating tools fluctuated, as workers' task types changed during their careers, and workers may not correctly remember information about their vibration exposures (recall bias). However, if failure to recall the history of exposure to vibration correctly occurs to all IVTOs equally, this will be non-differential misclassification of exposure, resulting in the underestimation of the effect of exposure to vibration on VPT.

Secondly, as we evaluated vibration dose, we did not take into consideration factors such as different types of tools operated, nor did we have available their acceleration values. We previously reported the dose-response relationship between hand-transmitted vibration and HAVS in a tropical environment[25], concluding that lifetime vibration dose and cumulative exposure index, which were indices calculated from both time exposed to vibration and acceleration values of vibrating tools, were more useful than total operating time (TOT), which was an index calculated from time exposed to vibration only. The current study was based on annual regular health examinations for HAVS, in which acceleration values of vibrating tools were not measured. To evaluate exposure to vibration more accurately, some special settings would be required to measure acceleration values in the workplace.

Thirdly, diabetes was evaluated based only on self-reporting by workers, and more objective measures such as fasting plasma glucose or glycosylated hemoglobin (HbA1c) were not available. Further studies utilizing blood samples in evaluation of the effect of diabetes on PN are desirable.

Fourthly, workers' body compositions (e.g., lean body weight) were not considered in this investigation. Besides, due to the nature of cross-sectional studies, longitudinal changes in anthropometric factors were not included in the analysis. These factors should also be studied in the future, possibly in a cohort study.

Some advantages in this study should also be mentioned. Firstly, as far as we know, this study is the first to show the protective effects of higher body weight and

BMI against PN among IVTOs. Secondly, this study was based on a population representing one of the largest active study fields of HAVS in Japan. Findings from our study may help decrease HAVS by considering anthropometric factors of workers and identifying workers at high risk of HAVS.

Conclusion

Among IVTOs, factors reflecting body heat production, such as body weight and BMI, were associated with a decreased risk of PN defined by the VPT, regardless of the task performed.

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