

# VIBRATION DOSE, DISTURBANCE STAGE, AND EXAMINATION RESULTS AND SUBJECTIVE SYMPTOMS IN VIBRATION SYNDROME

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## ABSTRACT

The 1973 national survey of 461 chainsaw operators in private forests was reexamined with respect to vibration exposure dose and the Stockholm Workshop Scale (CIRP and SN stages). Vibration dose (VD) was calculated by the formula " $a_{hw(eq,4h)} \times D$  (days)  $\times Y$  (years)". Vibration dose index (VDI) was calculated according to the level of VD. Subjects were divided into five VDI, four CIRP stage, and four SN stage groups. Examination results and prevalence of subjective symptoms were compared between VDI-1 and other VDI groups, CIRP-0 and other CIRP groups, and SN-0 and other SN groups. VD had higher values in CIRP-2 and 3, and SN-2 and 3 than CIRP-0 and SN-0, respectively. The most severe CIRP-3 and SN-3 appeared at higher rate in VDI-4 and 5 groups than in VDI-1 group. VDI had a correlation with mean value of prevalence of CIRP, vibrotactile perception, mean SN stage and fingertip pinch strength. A correlation was observed between skin temperature and CIRP stage, and between vibrotactile perception and SN stage. Decrease of muscle strength and difficulty in fine finger movement were associated with severe sensorineural disturbance.

Key Words: Vibration exposure dose, Disturbance stage, Exposure dose dependency, Stage dependency, Vibration syndrome

## INTRODUCTION

Studies on the correlations between hand-arm transmitted vibration exposure dose and exposure effects are aimed towards the establishment of preventive guidelines for vibration exposure and diagnostic methods for vibration syndrome. In Japan, many pilot surveys started in the late 1960s in the national forests, e.g., a local survey for physiological evaluation of vibration exposure effects (1967 to 1968)<sup>1)</sup> and a national epidemiological survey for evaluation of long-term vibration exposure effects (1968 to 1969).<sup>1)</sup> These surveys were the foundations for establishing exposure time regulations by the Forest Agency and Ministry of Labor. Local surveys for diagnostics were performed among workers in many national forests (1965 to 1968).<sup>2)</sup>

Based on the results of these pilot surveys, national surveys for diagnostics in seven private forests nationwide were performed in 1972 and 1973 (1973 Survey).<sup>3)</sup> These surveys were well designed in detail and the results were repeatedly analyzed from various viewpoints. Japanese diagnostics for vibration syndrome was established on the basis of these surveys by the Ministry of Labor.<sup>4,5)</sup>

Since the 1980s, studies on the evaluation of vibration exposure and its effects, and on the diagnostics of vibration syndrome, have been conducted around the world. These prompted us to reexamine the results of earlier surveys in Japan. In this paper we reexamined the results of the 1973 survey with reference to 4-hour equivalent vibration exposure dose (ISO: 1986),<sup>5)</sup> the

Stockholm workshop scale for cold-induced Raynaud's phenomenon (CIRP) (Gemne et al.: 1987),<sup>6)</sup> and sensorineural disturbances (SN) (Brammer et al., 1987).<sup>3)</sup>

## METHODS

### *Subjects*

The subjects were 461 chain saw operators without other diseases (248 with CIRP onset after beginning of vibration exposure and 213 without CIRP) in private forests. Their ages ranged from 30 to 59, and duration of saw operation ranged from 1 to 18 years.

### *Vibration exposure dose*

Vibration exposure doses (VD) were estimated using the following formula:

$$VD = a_{hw(eq.4h)} \times D \times Y$$

where

$a_{hw(eq.4h)}$  : 4-hour 'energy-equivalent' frequency-weighted acceleration (m/s<sup>2</sup> rms/day) (according to ISO 5349, 1986)

D : days of exposure to vibration (days/year)

Y : years of exposure to vibration (years)

Vibration exposure dose indexes were evaluated as follows:

VDI 1:  $< 5 \times 10^3$  m/s<sup>2</sup>,      VDI 2:  $\geq 5 \times 10^3$  m/s<sup>2</sup>,      VDI 3:  $\geq 10 \times 10^3$  m/s<sup>2</sup>,  
VDI 4:  $\geq 15 \times 10^3$  m/s<sup>2</sup>,      VDI 5:  $\geq 20 \times 10^3$  m/s<sup>2</sup>

Among Japanese private forest workers, the initial year for chain saw use ranged from 1955 to 1972. In this period, the acceleration level of chain saws decreased gradually about every five years after 1965. Vibration exposure dose was calculated every five years. Numbers of individual vibration exposure days in a year differed greatly among private forest workers, and ranged from about 50 to 300 days.

### *Physical examinations*

Physical examination items were as follows:

vascular system: skin temperature, nail press test before and after 5°C cold water immersion test at 20 to 23°C room temperature

sensorineural system: vibrotactile perception threshold before and after 5°C cold water immersion test at 20 to 23°C room temperature

musculoskeletal system: grip strength, fingertip pinch strength and tapping ability.

### *Subjective symptoms*

Subjective symptoms were elicited by medical interview. The specific items are as follows:

vascular system: hypersensitivity to cold

sensorineural system: numbness in hands

musculoskeletal system: morning finger stiffness, difficulty in fine finger movement and difficulty of elbow joint movement.

### *Staging*

The frequency in attacks of CIRP, number of white fingers and severity of numbness of hands in conjunction of results of vibrotactile perception testing were evaluated according to the Stockholm Workshop Scales for the Classification of Cold-Induced Raynaud's Phenomenon

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(CIRP) (Gemne et al.: 1987)<sup>6)</sup> and for the Sensorineural Stages (SN) (Brammer et al.: 1987).<sup>7)</sup> Stages were scored for analysis according to the severity of symptoms; stage 0="0", stage 1="1", stage 2="2" and stage 3="3". Prevalences of symptoms were evaluated in each stage group.

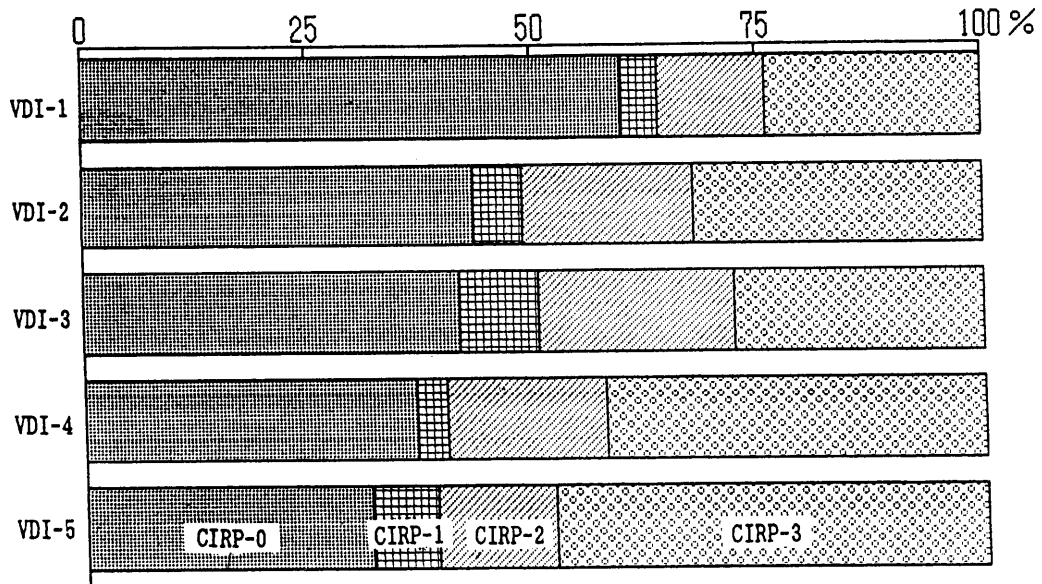
## RESULTS

The ratios of the four CIRP and SN stage groups in each VDI groups are shown in Table 1 and 2. Ratios of four CIRP and SN stage groups in each VDI group were statistically tested between VDI-1 and other VDI groups, respectively. The vibration exposure dose, age, examination results and symptom prevalence in each VDI, CIRP and SN stages are shown in Table 3, 4

Table 1. Vibration Exposure Dose Index (VDI) and CIRP Stage

	CIRP-0	CIRP-1	CIRP-2	CIRP-3	Total
VDI-1	91 (60.3)	6 (4.0)	18 (11.9)	36 (23.8)	151 (100.0)
VDI-2	48 (43.6)	6 (5.5)	21 (19.1)	35 (31.8)	110 (100.0)
VDI-3	29 (42.1)	6 (8.7)	15 (21.7)	19 (27.5)	69 (100.0)
VDI-4	23 (39.1)	2 (3.2)	11 (17.8)	26 (41.9)	62 (100.0)
VDI-5	22 (31.9)	5 (7.2)	9 (13.0)	33 (47.9)	69 (100.0)
Total	213 (46.2)	25 (5.4)	74 (16.1)	149 (32.3)	461 (100.0)

$\chi^2$  28.9 (Freedom=12)  $p=0.004$



$\chi^2$  28.9 (freedom=12)  $p=0.004$

Fig. 1. Ratio of CIRP stages (0-3) in each group of vibration exposure dose index (VDI)

and 5. Difference in those items were statistically tested between VDI-1 and other VDI groups, CIRP-0 and other CIRP groups, and SN-0 and other SN groups, respectively. Significant differences are indicated by \* ( $P < 0.05$ ) or \*\* ( $P < 0.01$ ).

*Relations between VDI and disturbance stages (CIRP and SN)*

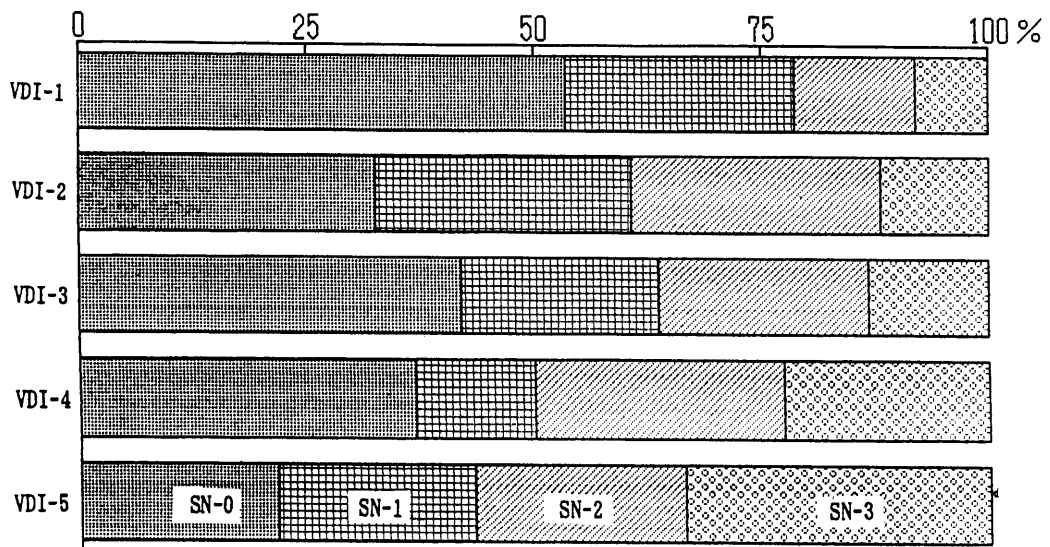
As seen in Table 1 and Fig. 1, increase of VDI was accompanied by the development of CIRP stage (Chi-square test,  $p=4 \times 10^{-3}$ ). The difference with VDI-1 is weak in VDI-2 ( $p=0.0631$ ), clear in VDI-3 ( $p=0.0432$ ) and VDI-4 ( $p=0.0147$ ), and strong in VDI-5 ( $p=0.0007$ ).

As shown in Table 2 and Fig. 2, increase of VDI was accompanied by the development of SN stages (Chi-square test,  $p=2 \times 10^{-6}$ ). The difference with VDI-1 was clear in VDI-2 ( $p=0.0029$ ), unclear in VDI-3 ( $p=0.13$ ), and strong in VDI-4 ( $p=0.0004$ ) and VDI-5 ( $p=0.0001$ ).

Table 2. Vibration Exposure Dose Index (VDI) and SN Stage

	SN-0	SN-1	SN-2	SN-3	Total
VDI-1	81 (53.6)	38 (25.7)	20 (13.2)	12 (8.0)	151 (100.0)
VDI-2	36 (32.7)	31 (28.2)	30 (27.3)	13 (11.8)	110 (100.0)
VDI-3	29 (42.0)	15 (21.7)	16 (23.2)	9 (13.1)	69 (100.0)
VDI-4	23 (37.1)	8 (12.9)	17 (27.4)	14 (22.6)	62 (100.0)
VDI-5	15 (21.7)	15 (21.7)	16 (23.3)	23 (33.3)	69 (100.0)
Total	184 (39.9)	107 (23.2)	99 (21.5)	71 (15.4)	461 (100.0)

$\chi^2 49.6$  (Freedom=12)  $p=2 \times 10^{-6}$



$\chi^2 49.6$  (freedom=12)  $p=2 \times 10^{-6}$

Fig. 2. Ratio of SN stages (0-3) in each group of vibration exposure dose index (VDI)

## VIBRATION DOSE AND DISTURBANCE STAGE

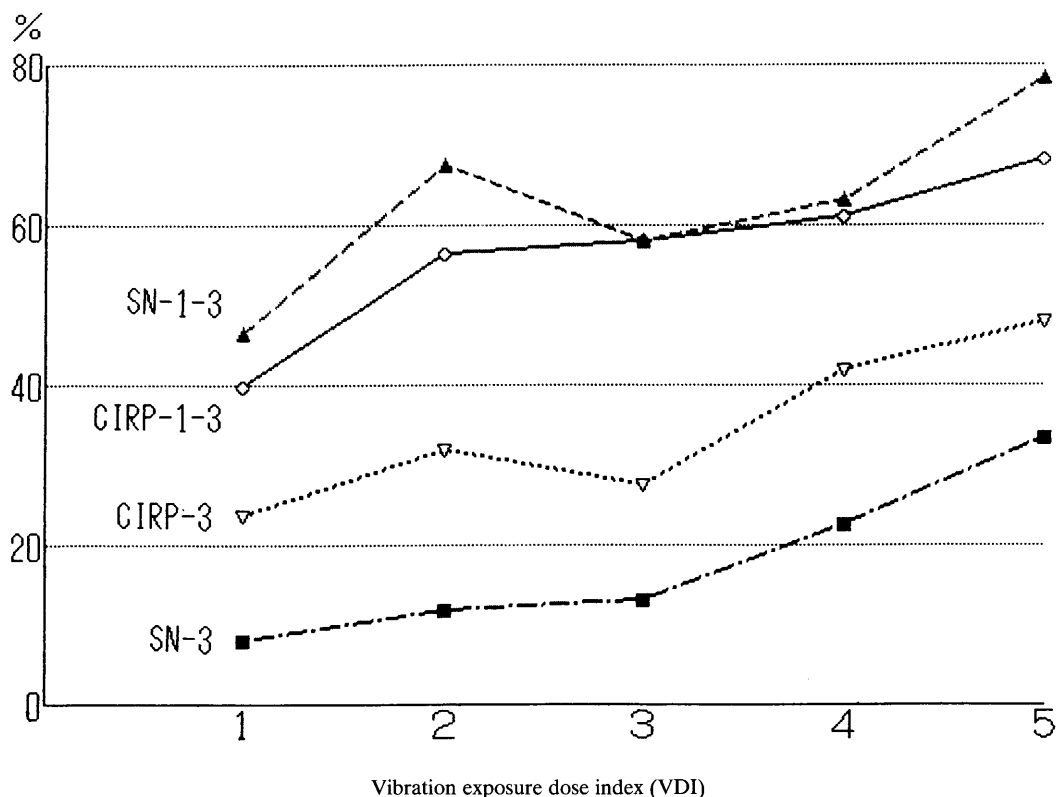


Fig. 3. Ratio of CIRP and SN stages in each vibration exposure dose index (VDI)

Fig. 3 summarizes the results in Tables 1 and 2. The most severe stages (CIRP-3 and SN-3) appeared at higher rate in VDI-4 and 5 than in VDI-1.

*Relations between examination results with subjective symptoms and VDI*

In Table 3, vibration exposure dose, age, examination results and prevalence of subjective symptoms are compared between VDI-1 and other VDI groups. Age was not statistically different among the groups.

As the number of the VDI increased, statistically significant differences from VDI-1 were observed in the following items in the examination results and subjective symptoms for the VDI indicated by numbers within parentheses:

vascular system: prevalence of CIRP (2-5), skin temperature (4, 5) (\*) and prevalence of hypersensitivity to cold (5),

(\*: value of skin temperature increased as VDI increased)

sensorineural system: vibrotactile perception threshold before cooling (3-5), after cooling (5), prevalence of numbness in hands (2, 4, 5), mean SN stage (2-5)

musculoskeletal system: grip strength (5), fingertip pinch strength (2-5), tapping ability (3), prevalence of morning finger stiffness (2, 5), prevalence of difficulty in fine finger movement (5), and difficulty in elbow joint movement (4).

*Relations between examination results with subjective symptoms and disturbance stages*

As shown in Table 4, years of exposure and exposure dose were statistically different in CIRP-2 and CIRP-3.

Age was different only in CIRP-3.

As the number of CIRP stage increased, statistically significant differences from CIRP-0 were evident in the following items in the examination results and prevalence of subjective symptoms for the CIRP stages indicated by numbers within parentheses:

vascular system: prevalence of CIRP and mean number of white fingers (1-3), skin temperature before and after cooling (2-3), nail press test after cooling (3) and prevalence of hypersensitivity to cold (2, 3)

sensorineural system: vibrotactile perception threshold before and after cooling test (3) and mean SN stage (3)

musculoskeletal system: grip strength, tapping ability, prevalence of morning finger stiffness, prevalence of difficulty in fine finger movement and difficulty in elbow joint movement (3).

Table 3. Examination Results and VDIs (Vibration Exposure Dose Indexes)

	VDI-1	VDI-2	VDI-3	VDI-4	VDI-5
Number of workers	151	110	69	62	69
Vibration exposure					
Years of exposure	4.5 ± 2.3	** 6.8 ± 2.1	** 9.4 ± 2.1	** 10.5 ± 1.8	** 12.6 ± 1.8
Exposure dose	2611 ± 1415	** 7571 ± 1477	** 12435 ± 1375	** 17120 ± 1432	** 27462 ± 5207
Age (years)	44.5 ± 6.8	43.1 ± 6.9	42.8 ± 5.9	43.6 ± 7.0	42.7 ± 6.4
Vascular system					
CIRP					
prevalence of CIRP (%)	60 (39.7)	** 62 (56.4%)	* 40 (58.0%)	** 38 (61.3)	** 46 (66.7%)
mean number of white fingers	5.8 ± 2.8	6.1 ± 3.0	5.5 ± 2.8	6.1 ± 2.8	6.3 ± 2.7
Mean CIRP stage	2.6 ± 0.8	2.6 ± 0.8	2.5 ± 0.9	2.8 ± 0.8	2.8 ± 0.9
Skin temperature (°C)					
before cooling	28.8 ± 4.3	28.4 ± 4.4	29.2 ± 3.8	(**) 30.6 ± 4.0	(*) 30.2 ± 3.6
after cooling	24.7 ± 5.1	23.2 ± 5.5	25.0 ± 4.2	25.7 ± 5.0	26.0 ± 5.8
Nail press test (seconds)					
before cooling	2.6 ± 1.2	2.8 ± 1.4	2.2 ± 1.0	2.3 ± 1.0	2.5 ± 1.2
after cooling	4.4 ± 2.2	4.2 ± 2.5	4.2 ± 2.2	4.4 ± 2.3	4.3 ± 2.6
Hypersensitivity to cold (%)	39 (25.8)	30 (27.2)	22 (31.9)	22 (35.5)	** 33 (47.8)
Sensorineural system					
Vibrotactile perception (dB)					
before cooling	12.4 ± 7.5	12.9 ± 9.0	* 14.7 ± 8.0	** 15.8 ± 8.6	** 17.1 ± 9.2
after cooling	24.2 ± 9.8	23.2 ± 10.0	26.5 ± 9.9	25.0 ± 10.8	** 27.5 ± 9.5
Numbness (%)	55 (36.4)	** 62 (56.4)	28 (40.6)	* 32 (51.6)	** 46 (66.7)
Mean SN stage	0.8 ± 1.0	** 1.2 ± 1.0	* 1.1 ± 1.0	** 1.4 ± 1.2	** 1.7 ± 1.1
Musculoskeletal system					
Grip strength (kg)	44.1 ± 9.8	44.5 ± 8.0	44.3 ± 8.5	42.3 ± 7.8	** 40.9 ± 8.8
Fingertip pinch strength (kg)	6.8 ± 2.1	** 6.2 ± 2.5	* 6.1 ± 2.3	** 5.6 ± 2.4	** 5.3 ± 2.1
Tapping ability (number/10 seconds)	48.3 ± 8.9	48.1 ± 6.6	** 46.1 ± 7.7	48.5 ± 7.5	47.0 ± 9.5
Morning finger stiffness (%)	33 (21.9)	* 41 (37.3)	13 (18.8)	21 (33.9)	** 31 (44.9)
Difficulty of fine finger movement (%)	15 (10.0)	12 (10.9)	7 (10.1)	12 (19.4)	** 20 (40.8)
Difficulty of elbow joint movement (%)	16 (10.6)	13 (11.8)	7 (10.1)	* 15 (24.2)	13 (18.8)

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As seen in Table 5, years of exposure and exposure dose were statistically different in SN-2 and SN-3.

Age was different only in SN-3.

As the number of the SN stage increased, statistically significant differences were evident in the following items in the examination results and subjective symptoms for the SN stages indicated by numbers within parentheses:

vascular system: mean number of white fingers (3), mean CIRP stage (3) and prevalence of hypersensitivity to cold (3)

sensorineural system: vibrotactile perception before cooling (1-3), after cooling (3), prevalence of numbness in hands (1-3)

musculoskeletal system: grip strength (3), fingertip pinch strength (3), prevalence of morning finger stiffness (1-3), prevalence of difficulty in fine finger movement (2, 3) and elbow joint movement (2, 3).

Table 4. Examination Results and CIRP Stages  
(Stages for the Classification of Cold-Induced Raynaud's Phenomenon)

	CIRP-0	CIRP-1	CIRP-2	CIRP-3
Number of workers	213	25	74	149
Vibration exposure				
Years of exposure	6.9 ± 3.7	8.0 ± 3.8	* 8.0 ± 3.3	** 8.8 ± 3.2
Exposure dose	9092 ± 8420	11824 ± 8358	* 11288 ± 7068	** 13248 ± 9216
Age (years)	42.7 ± 7.2	40.6 ± 7.2	44.1 ± 6.3	** 44.9 ± 5.8
Vascular system				
CIRP				
prevalence of CIRP (%)	0	** 25 (100)	** 74 (100)	** 149 (100)
mean number of white fingers	0	** 3.0 ± 1.9	** 4.9 ± 2.7	** 7.0 ± 2.5
Skin temperature (°C)				
before cooling	30.2 ± 3.9	28.8 ± 3.7	* 29.1 ± 4.4	** 28.5 ± 4.2
after cooling	26.5 ± 4.7	24.9 ± 4.5	** 23.3 ± 5.5	** 24.1 ± 5.1
Nail press test (seconds)				
before cooling	2.4 ± 1.1	2.3 ± 1.1	2.5 ± 1.2	2.6 ± 1.3
after cooling	3.8 ± 1.9	4.1 ± 2.4	4.3 ± 2.3	** 4.7 ± 2.7
Hypersensitivity to cold (%)	39 (18.3)	9 (36.0)	* 24 (32.4)	** 74 (49.7)
Sensorineural system				
Vibrotactile perception (dB)				
before cooling	12.8 ± 8.0	12.9 ± 6.3	13.5 ± 9.2	** 15.6 ± 8.8
after cooling	23.1 ± 10.0	25.0 ± 11.4	23.8 ± 9.5	** 27.6 ± 9.9
Numbness (%)	97 (45.5)	10 (40.0)	35 (47.3)	81 (54.4)
Mean SN stage	1.0 ± 1.1	0.8 ± 0.9	1.1 ± 1.0	* 1.3 ± 1.1
Musculoskeletal system				
Grip strength (kg)	44.2 ± 7.9	45.8 ± 7.3	43.1 ± 8.8	** 42.2 ± 7.8
Fingertip pinch strength (kg)	6.3 ± 2.3	6.0 ± 2.3	5.9 ± 2.2	6.1 ± 2.4
Tapping facility (number/10 seconds)	48.9 ± 7.7	49.1 ± 7.0	48.4 ± 8.0	** 45.5 ± 8.7
Morning finger stiffness (%)	46 (21.6)	8 (32.0)	23 (31.1)	** 66 (44.3)
Difficulty of fine finger movement (%)	22 (10.3)	2 (8.0)	11 (14.9)	** 31 (20.8)
Difficulty of elbow joint movement (%)	13 (6.1)	1 (4.0)	9 (12.2)	** 41 (27.5)

Table 6 is a summary of Tables 3, 4 and 5.

The vibration exposure dose has higher values in CIRP-2 and CIRP-3, and SN-2 and SN-3 than CIRP-0 and SN-0, respectively.

The following results are notable; a) three vascular variables (mean number of white fingers, mean CIRP stage and prevalence of hypersensitivity to cold) have higher values in SN-3; b) two sensorineural variables (vibrotactile perception and mean SN stage) have higher values in CIRP-3; c) prevalence of CIRP has higher value in both VDI (2 to 5) and CIRP (1 to 3); d) fingertip pinch strength has higher value in both VDI (2-5) and SN (3); e) as to four musculoskeletal variables, grip strength has lower value in both CIRP (3) and SN (3), and prevalence of morning stiffness, prevalence of difficulty in fine finger movement and difficulty in elbow joint movement have higher value in both CIRP (3) and SN(3). Decrease in grip strength and fingertip pinch strength was large in SN-3 and small in CIRP-3.

Table 5. Examination Results and SN Stages (Stages for the Sensorineural Disturbances)

	SN-0	SN-1	SN-2	SN-3
Number of workers	184	107	99	71
Vibration exposure				
Years of exposure	6.9 ± 3.4	7.3 ± 3.4	** 8.4 ± 3.6	** 9.5 ± 3.7
Exposure dose	8843 ± 7740	9952 ± 8383	** 12266 ± 8322	** 15286 ± 10247
Age (years)	43.2 ± 7.3	42.9 ± 6.3	43.6 ± 6.1	* 45.1 ± 6.1
Vascular system				
CIRP				
prevalence of CIRP (%)	87 (47.3)	65 (60.7)	55 (55.6)	41 (57.7)
mean number of white fingers	5.6 ± 3.0	5.4 ± 2.6	6.3 ± 2.9	** 7.4 ± 2.3
Mean CIRP stage	2.5 ± 0.9	2.6 ± 0.8	2.7 ± 0.9	** 3.0 ± 0.7
Skin temperature (°C)				
before cooling	29.1 ± 3.9	29.2 ± 4.0	29.6 ± 4.2	29.9 ± 4.4
after cooling	24.9 ± 4.8	25.0 ± 5.1	25.4 ± 5.6	25.3 ± 5.2
Nail press test (seconds)				
before cooling	2.5 ± 1.2	2.4 ± 1.2	2.6 ± 1.2	2.3 ± 1.1
after cooling	4.4 ± 2.5	3.8 ± 2.0	4.3 ± 2.3	4.3 ± 2.3
Hypersensitivity to cold (%)	48 (26.1)	32 (29.9)	31 (31.3)	** 35 (49.3)
Sensorineural system				
Vibrotactile perception (dB)				
before cooling	9.5 ± 5.2	** 13.9 ± 9.7	** 12.9 ± 6.4	** 24.9 ± 4.6
after cooling	23.4 ± 10.2	23.3 ± 9.9	25.3 ± 11.0	** 30.5 ± 6.3
Numbness (%)	0	** 107 (100)	** 99 (100)	** 71 (100)
Musculoskeletal system				
Grip strength (R) (kg)	44.5 ± 7.9	43.5 ± 7.6	43.7 ± 8.6	** 40.6 ± 7.8
Fingertip pinch strength (kg)	6.5 ± 2.3	6.3 ± 2.3	6.3 ± 2.2	** 4.8 ± 2.2
Tapping facility (number/10 seconds)	48.4 ± 7.4	47.7 ± 7.9	47.1 ± 8.9	47.1 ± 9.4
Morning finger stiffness (%)	33 (17.9)	** 40 (37.4)	* 34 (34.3)	** 37 (52.1)
Difficulty of fine finger movement (%)	17 (9.2)	18 (16.8)	** 15 (15.2)	** 16 (22.5)
Difficulty of elbow joint movement (%)	14 (7.6)	13 (12.1)	** 21 (21.2)	** 21 (29.6)



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Table 6. Examination Items and Subjective Symptoms in VDI 2-5, CIRP 1-3 and SN 1-3 with Significant Differences from VDI-1, CIRP-0 and SN-0, respectively

	VDI-1	VDI-2	VDI-3	VDI-4	VDI-5	CIRP-0	CIRP-1	CIRP-2	CIRP-3	SN-0	SN-1	SN-2	SN-3
Number of workers	151	110	69	62	69	213	25	74	149	184	107	99	71
Vibration exposure													
Years of exposure		**	**	**	**			*	**			**	**
Exposure dose		**	**	**	**			*	**			**	**
Age (years)									**				*
Vascular system													
CIRP													
prevalence of CIRP (%)		**	*	**	**		**	**	**				
mean number of white fingers							**	**	**				**
Mean CIRP stage						—	—	—	—				**
Skin temperature (°C)													
before cooling								*	**				
after cooling								**	**				
Nail press test (seconds)													
before cooling													
after cooling									**				
Hypersensitivity to cold (%)					**			*	**				**
Sensorineural system													
Vibrotactile perception (dB)													
before cooling			*	**	**				**		**	**	**
after cooling					**				**				**
Numbness (%)		**		*	**						**	**	**
Mean SN stage		**	*	**	**				*	—	—	—	—
Musculoskeletal system													
Grip strength (kg)					**				**				**
Fingertip pinch strength (kg)		**	*	**	**								**
Tapping ability (number/10 seconds)			**						**				**
Morning finger stiffness (%)		*			**				**		**	*	**
Difficulty of fine finger movement (%)					**				**			**	**
Difficulty of elbow joint movement (%)				*					**			**	**

## DISCUSSION

*VDI*

Which time-dependency should be used to evaluate cumulative vibration effects was discussed (Griffin: 1990).<sup>9)</sup> In epidemiological studies among Japanese forest workers using chain saws, time-dependency was expressed as total operation time (Miyashita: 1982)<sup>10)</sup>, hours per day, days per year, and years or total hours in a lifetime (Futatsuka: 1984,<sup>11)</sup> Suzuki: 1983).<sup>12)</sup>

Griffin (1982)<sup>9</sup>, Brammer (1982)<sup>13</sup> proposed an equation for the evaluation of daily work exposure. Lately, daily exposure duration is expressed as a 4- or 8-hour energy equivalent frequency-weighted root-mean-square acceleration,  $a_{hw(eq,4h)}$  or  $a_{hw(eq,8h)}$ , which is given in the International Organization for Standardization (ISO) 5349 draft (1986)<sup>5</sup> and the British standard 6482 draft (1987)<sup>14</sup>, respectively. Zhou et al. (1990)<sup>15</sup> used the formula " $[a_{hw(eq,4h)} \times Y \text{ (years)} \times D \text{ (days)}]^2$ ". Xu et al. (1990)<sup>16</sup> used the formula " $a_{hw(eq,4h)} \times 300 \text{ (days/year)} \times Y \text{ (years)}$ ". Tominaga (1993)<sup>17</sup> used the formula " $a_{hw(eq,4h)} \times Y \text{ (years)}$ ". Lundström et al (1992)<sup>18</sup> used the formula " $VD_{tot} = (a_{hw}) \cdot t_d \cdot k \cdot t_y$ ", where  $t_d$  is daily exposure hours,  $k$  is 200 days/year and  $t_y$  is years. Bovenzi (1994)<sup>19</sup> calculated life-time dose by the formula "Life time dose =  $[\sum (a_{h,w}^2 \cdot t_h)^{0.5} t_d \cdot t_y]^2 \cdot m^2 \cdot h^3/s^4$ " as suggested by Griffin. We used the formula " $VD = a_{hw(eq,4h)} \times D \text{ (days)} \times Y \text{ (years)}$ ".

Which formula is most useful in evaluating cumulative vibration effects is still controversial.

#### *VDI and stages*

Most severe stages (CIRP-3 and SN-3) appeared at high rate in VDI-4 and 5 than in VDI-1.

#### *VDI and examination results with symptoms*

Eckenvall et al. (1989)<sup>20</sup> indicated dose-response for both vascular and neurological disorders. Lundström et al. (1992)<sup>18</sup> reported a dose-response relationship for SN stage. In our results, dose dependency was indicated by the successively higher mean values of prevalence of CIRP, vibrotactile perception, mean SN stage, and lower mean value of fingertip pinch strength with increasing VDI.

Increase of VDI was accompanied by increase of prevalence of CIRP, but not by increase in mean number of white fingers and the mean CIRP stage (both reflecting the severity of CIRP). It seems that cumulative vibration exposure dose influences the first onset of CIRP, and after the onset other factors may influence the development of white finger attacks.

Increase of VDI with increase of skin temperature seems to contrast with the fact that decrease of skin temperature is associated with development of CIRP. This contrary can not be interpreted in the present study.

#### *Stage and examination results with symptoms*

Stage dependency was indicated by the successively lower mean value of skin temperature with increasing stage of CIRP and increasing vibrotactile perception threshold with increasing SN stage.

Färkkilä (1987)<sup>21</sup> posed the question whether changes in muscle force form part of the hand-arm vibration syndrome. Our results indicated affirmatively that decrease of grip strength and fingertip pinch strength, and increase of prevalence of difficulty in fine finger movement were associated with severe sensorineural disturbance.

## CONCLUSION

The 1973 national survey in private forests was reexamined with respect to vibration exposure dose and the Stockholm Workshop Scale.

Formula " $VD = a_{hw(eq,4h)} \times D \text{ (days)} \times Y \text{ (years)}$ " and VDI (vibration dose index) were used for evaluating the cumulative vibration exposure dose. VD had higher values in CIRP-2 and 3, and SN-2 and 3 than CIRP-0 and SN-0, respectively. VDI had a correlation is observed between VDI and with mean value of prevalence of CIRP, vibrotactile perception, mean SN

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stage, and fingertip pinch strength. The most severe stages (CIRP-3 and SN-3) appeared at higher rate in VDI-4 and 5 than in VDI-1. A correlation was observed between skin temperature and CIRP stage, and between vibrotactile perception and SN stage.

The following valuables had higher values in the VDI, CIRP and SN stage groups indicated in parentheses than in VDI-1, CIRP-0 and SN-0, respectively; skin temperature (CIRP-2 and 3), nail press test (CIRP-3), prevalence of hypersensitivity to cold (VI-5, CIRP-2 and 3, and SN-3), vibrotactile perception (VDI-4 to 5, CIRP-3 and SN-1 to 3), prevalence of numbness in hands (VDI-2, 4 and 5, and SN-1 to 3), grip strength (VDI-5, CIRP-3 and SN-3), fingertip pinch strength (VDI-2 to 5 and SN-3), tapping ability (VDI-3 and CIRP-3), prevalence of morning finger stiffness (VDI-2 and 5, CIRP-3, and SN-1 to 3), prevalence of difficulty of fine finger movement (VDI-5, CIRP-3 and SN-2 and 3), prevalence of difficulty of elbow joint movement (VDI-4, CIRP-3, and SN-2 and 3).

Decreases of muscle strength and difficulty in fine finger movement were associated with severe sensorineural disturbance.

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