Comparative study of vibration disease among operators of vibrating tools by factor analysis

M FUTATSUKA,¹ N YASUTAKE,¹ T SAKURAI,² AND T MATSUMOTO³

From the Department of Public Health,¹ Kumamoto University Medical School, Kumamoto 860, Department of Environmental Health,² Kurume University School of Medicine, Kurume 830, and Department of Public Health,³ Nagoya City University Medical School, Nagoya 466, Japan

ABSTRACT Principal component analysis was carried out to determine the interrelationships between subjective symptoms experienced by workers using various types of vibrating tools (brush saws (41), rock drills (39), chipping hammers (42) and chain saws (49)) and control groups (clerks (44), farmers (42)). The characteristics of the patterns of common factors extracted from these symptoms and the frequency distribution of the factor score of the main principal components were compared among the groups. From a wide variety of symptoms, a principal component related to peripheral nerves, muscles, and joints and a component related to peripheral circulation were extracted specifically and separately. The complaints of rock drillers reflected a peripheral circulatory factor and those of chain saw users presented a complex factor of nerves, muscle, and joints.

Vibration disease caused by using manual vibrating tools occurs in many occupations. This syndrome comprises not only the peripheral circulatory disturbances known as vibration induced white finger (VWF) but also disturbances of peripheral nerves, muscles, bones, and joints. A wide variety of different types of disturbance may arise from the succession of physical blows impacting on the hand holding a vibrating tool.¹⁻⁴ Among these disturbances, VWF has been examined intensively and is well described.^{5,6} Recently, however, the concept of vibration disease has been expanded to encompass the complex of symptoms associated with vibrating tools.⁷ The large number and the characteristic distribution of reports of these symptoms among operators of vibrating tools appear to be evidence that they are associated with certain types of tool vibration.⁸ Each symptom, however, has been discussed separately.

In the present study principal component analysis was carried out to determine the interrelationships among the subjective symptoms experienced by workers using various types of vibrating tools and characteristics of the patterns of common factors that were extracted from these symptoms, and the

frequency distribution of the factor score of the main principal components were compared for the different types of vibrating tools.

Subjects

Four occupational groups were selected as the groups exposed to vibration (1) brush saw operators

Fig 1 Vibration spectrum of vibrating tools (fore and aft).

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Table 1 Work conditions in the subject groups

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	Vibration exposure	Weight of tool (kg)	Temperature in work place (winter time)	Noise level (db A)	Incline of work place
Brush saw	4-6 hours/day 100-120 days/year	7-9	-5-8°C	90-105	15-30°C (mountain)
Rock drill	2-3 hours/day 250-300 days/year	22-33	17-20°C	106-117	Horizontal
Chipping hammer	3-4 hours/day 250-300 days/year	10-15	-2-10°C	100-113	Horizontal
Chain saw	2-4 hours/day 200-300 days/year	7-15	-5-8°C	105-118	0-20°C (mountain)

Table 2 Age and vibration exposure period of the subjects

	No	Vibration exposure period (y) (Mean ± SD)	Age (y) (Mean ± SD)
Brush saw	41	9.3 ± 5.0	41.9 ± 5.8
Rock drill	39	15.0 ± 5.5	41.3 ± 5.3
Chipping hammer	42	8.9 ± 1.9	42.4 ± 5.8
Chain saw	49	10.2 ± 3.6	45.9 ± 2.7
Clerks	44	—	42.8 ± 5.9
Farmers	42	—	43.9 ± 6.3

in forestry, (2) rock drill operators in a metal mine, (3) chipping hammer operators in a quarry, and (4) chain saw operators in forestry. Two control groups were also selected: (1) clerks in a regional forest office and (2) farmers with no exposure to vibration. The vibration spectra of the vibrating tools and the work conditions related to the effects of vibration are shown in fig 1 and table 1⁹⁻¹²; table 2 shows the exposure period and age of the subjects. As shown in table 2, the subjects were matched for age to take account of the fact that age is a confounding factor

Table 3 Prevalence rate of complaints in subject groups

		Brush saw		Rock drill		Chipping hammer		Chain saw		Clerk		Farmer	
		No	%	No	%	No	%	No	%	No	%	No	%
1	Raynaud's phenomenon	3	7.3	33	84.6*	13	31.0*	18	36.7*	1	2.3	1	2.4
2	Cold fingers	12	29.3	15	38.5	15	35.7	41	83.7*	10	22.7	8	19.0
3	Pain in fingers	9	22.0	6	15.4	19	45.2*	38	77.6*	1	2.3	5	11.9
4	Sensitivity to cold	18	43.9	17	43.6	23	54.8	37	75.5*	12	27.3	17	40.5
5	Numbness and pain of fingers in night	16	39.0	14	35.9	31	73.8*	43	87.8*	7	15.9*	16	38.1
6	Numbness of fingers	10	24.4	21	53.8*	23	54.8*	40	81.6*	1	2.3*	10	23.8
7	Decreased sensitivity of hands to hot stimulation	0	0.0	2	5.1	5	11.9	29	59.2*	0	0.0	0	0.0
8	Decreased sensitivity of hands to cold stimulation	0	0.0	7	17.9*	8	19.0*	29	59.2*	0	0.0	0	0.0
9	Hypaesthesia in stick sensation of hands	0	0.0	0	0.0	3	7.1	26	53.1*	0	0.0	1	2.4
10	Hypaesthesia in touch sensation of hands	1	2.4	17	43.6*	11	26.2*	30	61.2*	0	0.0	1	2.4
11	Hypaesthesia in pain sensation of hands	0	0.0	1	2.6	3	7.1	24	49.0*	0	0.0	0	0.0
12	Difficulty in buttoning clothes	1	2.4	4	10.3	8	19.0	23	46.9*	0	0.0	3	7.1
13	Hand tremor	3	7.3*	12	30.8	10	23.8	23	46.9*	1	2.3*	11	26.2
14	Difficulty in fine finger co-ordination	3	7.3	4	10.3	14	33.3*	34	69.4*	2	4.5	6	14.3
15	Drop things easily	1	2.4	6	15.4	4	9.5	24	49.0*	0	0.0	5	11.9
16	Weakened hand grip force	7	17.1	3	7.7	21	50.0*	40	81.6*	6	13.6	11	26.2
17	Tiredness in holding up arms for long period	7	17.1	13	33.3	24	57.1*	31	63.3*	4	9.1	11	26.2
18	Wrist pain	4	9.8	16	41.0	20	47.6*	36	73.5*	4	9.1	10	23.8
19	Elbow pain	2	4.9	9	23.1	26	61.9*	40	81.6*	3	6.8	9	21.4
20	Difficulty in bending and stretching elbow	1	2.4	2	5.1	15	35.7*	25	51.0*	1	2.3	6	14.3
21	Pain in shoulder when holding up arms	13	31.7	8	20.5	19	45.2*	35	71.4*	6	13.6	9	21.4
22	Neck pain when turning head	8	19.5	6	15.4	17	40.5	36	73.5*	8	18.2	9	21.4
23	Lower back pain	27	65.9	22	56.4	30	71.4	36	73.5	31	70.5	26	61.9
24	Headache or heaviness of head	14	34.1	9	23.1	19	45.2	32	65.3*	17	38.6	18	42.9
25	Dizziness	5	12.2	6	15.4	12	28.6	24	49.0	8	18.2	13	31.0
26	Increased irritability	14	34.1	4	10.3	19	45.2	32	65.3*	10	22.7	11	26.2
27	Forgetfulness	24	58.5	10	25.6	30	71.4*	38	77.6*	21	47.7	19	45.2
28	Wakefulness	13	31.7	6	15.4	18	42.9	33	67.3*	8	18.2	10	23.8
29	Sleep disturbances	9	22.0	14	35.9	18	42.9	36	73.5*	12	27.3	15	35.7
30	General fatigue	20	48.8	3	7.7*	21	50.0	41	83.7*	27	61.4	21	50.0
31	Getting tired easily	16	39.0	13	33.3*	27	64.3	40	81.6*	22	50.0	24	57.1
32	Shoulder stiffness	32	78.0*	18	46.2	34	81.0*	43	87.8*	32	72.7*	21	50.0
33	Tinnitus	10	24.4	15	38.5	20	47.6*	33	67.3*	9	20.5	8	19.0
34	Hearing difficulty	7	17.1	19	48.7*	21	50.0*	35	71.4*	8	18.2	9	21.4
35	Falling off of appetite	12	29.3	5	12.8	8	19.0	21	42.9*	4	9.1	8	19.0
36	Gastroenteric trouble	17	41.5	14	35.9	16	38.1	27	55.1	15	34.1	16	38.1
37	Shortness of breath doing heavy work	5	12.2	13	33.3	13	31.0	32	65.3*	15	34.1	12	28.6
38	Decline of vigour	26	63.4	8	20.5*	23	54.8	39	79.6*	21	47.7	24	57.1

*Statistically significant at 0.05 level in comparison with farmers.

for subjective symptoms.

Methods

All the subjects were interviewed in the middle of the 1970s by medical staff to elicit subjective symptoms using a 38 item questionnaire designed by the medical committee of vibration disease of the Japanese Association of Industrial Health. In scoring the items in the questionnaire (shown in table 3) the following ordinal scale for rating the frequency of each complaint within one year was used: "frequently" was given a score of 2 whereas "never" and "seldom" were given a score of 1.

The questionnaire data were analysed by factor analysis.^{13 14} Pearson correlation coefficients between all pairs of complaints in the four exposure groups were computed, and a correlation matrix (38 × 38) was obtained. This matrix was analysed using the principal factor method with iteration. The resultant factor matrix (38 × N, N = estimated number of factors) was rotated by the varimax method, and the new varimax factor matrix was used

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to categorise the 38 complaints. Factor scores for each subject in all six groups were also computed. Three factors were chosen on the basis of practical usefulness, and 48.3% of the variance was accounted for by the three extracted factors.

Some of the subjects were diagnosed as suffering from VWF or peripheral neuromuscular disorders of vibration disease from data obtained by using the method and criteria recommended by the Japanese Ministry of Labour.¹⁵

Results

PREVALENCE OF COMPLAINTS

Table 3 shows the prevalence rate of each complaint by subject group. The prevalence of Raynaud's phenomenon was 7.3% among brush saw operators, 84.6% among rock drill operators, 31.0% among chipping hammer operators, 36.4% among chain saw operators, and 2.3-2.4% in the non-exposed groups. In general, the highest prevalence rates were found in the chain saw operators. Many types of local complaints in the hands were higher in the

Table 4 Correlation matrix among 38 items complaints in the exposure groups

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19
1	1.000																	
2	0.227	1.000																
3	-0.029	0.499	1.000															
4	0.163	0.445	0.286	1.000														
5	0.055	0.300	0.418	0.246	1.000													
6	0.221	0.409	0.558	0.255	0.453	1.000												
7	0.056	0.360	0.460	0.260	0.297	0.352	1.000											
8	0.076	0.392	0.446	0.257	0.281	0.452	0.648	1.000										
9	-0.012	0.434	0.467	0.216	0.331	0.378	0.684	0.732	1.000									
10	0.224	0.427	0.378	0.303	0.280	0.459	0.500	0.727	0.590	1.000								
11	0.033	0.392	0.423	0.269	0.290	0.369	0.663	0.716	0.895	0.610	1.000							
12	0.056	0.360	0.460	0.289	0.268	0.381	0.613	0.648	0.569	0.561	0.586	1.000						
13	0.138	0.331	0.416	0.297	0.261	0.408	0.412	0.406	0.377	0.477	0.462	0.380	1.000					
14	-0.091	0.459	0.503	0.339	0.373	0.447	0.535	0.597	0.590	0.554	0.575	0.596	0.434	1.000				
15	0.068	0.290	0.301	0.250	0.288	0.284	0.485	0.464	0.582	0.486	0.520	0.520	0.296	0.489	1.000			
16	-0.093	0.440	0.531	0.372	0.409	0.333	0.496	0.454	0.473	0.412	0.461	0.467	0.319	0.589	0.367	1.000		
17	0.015	0.226	0.320	0.293	0.396	0.374	0.295	0.369	0.354	0.375	0.405	0.353	0.235	0.552	0.311	0.379	1.000	
18	0.174	0.356	0.453	0.255	0.284	0.526	0.462	0.550	0.411	0.490	0.399	0.462	0.410	0.543	0.421	0.393	0.372	1.000
19	0.044	0.344	0.490	0.289	0.413	0.394	0.455	0.543	0.499	0.480	0.457	0.426	0.246	0.534	0.386	0.502	0.455	0.468
20	-0.079	0.381	0.516	0.301	0.327	0.416	0.560	0.584	0.528	0.487	0.545	0.560	0.418	0.669	0.441	0.551	0.438	0.567
21	0.015	0.368	0.392	0.364	0.444	0.303	0.324	0.342	0.386	0.325	0.405	0.411	0.313	0.552	0.340	0.427	0.525	0.490
22	0.067	0.419	0.407	0.404	0.423	0.389	0.467	0.295	0.467	0.350	0.487	0.408	0.352	0.499	0.424	0.418	0.474	0.415
23	-0.001	0.179	0.217	0.203	0.257	0.220	0.177	0.069	0.149	0.035	0.174	0.055	0.131	0.160	0.200	0.108	0.190	0.148
24	0.097	0.309	0.331	0.401	0.387	0.292	0.331	0.269	0.297	0.235	0.347	0.360	0.295	0.409	0.318	0.366	0.394	0.335
25	0.123	0.241	0.350	0.261	0.360	0.399	0.389	0.267	0.350	0.325	0.400	0.357	0.461	0.361	0.305	0.332	0.353	0.319
26	-0.050	0.251	0.337	0.256	0.343	0.289	0.335	0.252	0.327	0.281	0.345	0.335	0.309	0.352	0.292	0.299	0.330	0.368
27	-0.121	0.274	0.291	0.416	0.243	0.214	0.249	0.266	0.308	0.196	0.267	0.279	0.142	0.362	0.329	0.403	0.367	0.232
28	-0.010	0.239	0.278	0.290	0.327	0.251	0.387	0.299	0.448	0.296	0.467	0.329	0.300	0.394	0.403	0.288	0.343	0.356
29	0.189	0.391	0.371	0.336	0.534	0.394	0.426	0.355	0.405	0.431	0.394	0.311	0.324	0.383	0.386	0.263	0.384	0.397
30	-0.151	0.415	0.455	0.418	0.415	0.312	0.376	0.271	0.361	0.213	0.319	0.347	0.238	0.492	0.394	0.468	0.347	0.311
31	-0.015	0.316	0.396	0.372	0.449	0.408	0.370	0.305	0.337	0.344	0.327	0.312	0.290	0.457	0.419	0.386	0.496	0.411
32	-0.103	0.170	0.231	0.281	0.405	0.113	0.107	0.102	0.195	0.118	0.224	0.173	0.189	0.319	0.232	0.252	0.224	0.230
33	0.107	0.309	0.313	0.134	0.230	0.310	0.305	0.320	0.337	0.373	0.325	0.362	0.342	0.450	0.350	0.253	0.303	0.386
34	0.141	0.333	0.414	0.222	0.243	0.304	0.308	0.292	0.284	0.313	0.240	0.366	0.234	0.367	0.383	0.331	0.213	0.343
35	0.053	0.255	0.204	0.251	0.244	0.098	0.366	0.276	0.323	0.253	0.373	0.398	0.296	0.401	0.281	0.318	0.235	0.174
36	0.097	0.214	0.164	0.235	0.193	0.221	0.215	0.134	0.203	0.161	0.220	0.157	0.190	0.308	0.171	0.198	0.275	0.193
37	0.132	0.398	0.380	0.415	0.365	0.423	0.438	0.410	0.366	0.466	0.350	0.498	0.386	0.590	0.424	0.488	0.424	0.439
38	-0.136	0.245	0.300	0.300	0.329	0.266	0.225	0.170	0.242	0.121	0.232	0.283	0.159	0.331	0.244	0.266	0.259	0.126

chipping hammer operators and rock drill operators but this was not the case for so called general complaints. The prevalence rate of symptoms in brush saw operators was the same as that in the farmers.

RELATION BETWEEN THE COMPLAINTS AND THE EXTRACTED FACTORS

Table 4 shows the correlation matrix of the 38 complaints in the four exposure groups. Table 5 shows the varimax rotated factor matrix under the estimation of three factors. Factor 1 had a high value of factor loading (0.7-0.8) with 36.9% contribution ratio in various types of complaints, especially those related to the peripheral nerves, muscles, and joints of the hands. Factor 2 mixed plus and minus values with no characteristic tendency except for relatively high minus values for items of peripheral sensation. Factor 3 was characteristic only of Raynaud's phenomenon, and had a high value.

FACTOR SCORE FOR THE EXTRACTED FACTORS AND THE RELATED CHARACTERISTICS

A factor score was calculated for each subject using formulas based on the principal factor analysis (see appendix). The mean values of the factor scores for

Fig 2 Mean values of factor score plotted in Z_1 - Z_3 dimension.

factors 1 and 3 are plotted in the Z_1 - Z_3 dimension as shown in fig 2. The brush saw group was located in the same area as the non-exposed groups. The rock

20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38
1.000																		
0.466	1.000																	
0.474	0.594	1.000																
0.203	0.265	0.279	1.000															
0.392	0.441	0.460	0.182	1.000														
0.458	0.406	0.499	0.095	0.414	1.000													
0.402	0.450	0.439	0.117	0.509	0.562	1.000												
0.394	0.343	0.392	0.290	0.430	0.186	0.434	1.000											
0.395	0.463	0.501	0.277	0.329	0.393	0.479	0.370	1.000										
0.369	0.432	0.477	0.281	0.396	0.312	0.430	0.385	0.490	1.000									
0.448	0.465	0.592	0.245	0.454	0.383	0.494	0.436	0.504	0.370	1.000								
0.458	0.449	0.516	0.337	0.368	0.412	0.463	0.450	0.496	0.516	0.572	1.000							
0.218	0.412	0.363	0.188	0.406	0.302	0.321	0.307	0.272	0.291	0.398	0.315	1.000						
0.335	0.208	0.299	0.139	0.314	0.304	0.300	0.179	0.264	0.304	0.287	0.242	0.270	1.000					
0.415	0.237	0.285	0.046	0.225	0.405	0.332	0.288	0.177	0.308	0.263	0.306	0.163	0.296	1.000				
0.287	0.367	0.432	0.199	0.402	0.335	0.254	0.203	0.434	0.273	0.346	0.244	0.267	0.292	0.130	1.000			
0.147	0.251	0.387	0.283	0.238	0.176	0.172	0.213	0.353	0.277	0.359	0.320	0.217	0.267	0.130	0.428	1.000		
0.479	0.473	0.480	0.197	0.385	0.426	0.311	0.258	0.350	0.405	0.405	0.480	0.200	0.347	0.335	0.330	0.385	1.000	
0.241	0.330	0.468	0.212	0.296	0.254	0.295	0.354	0.328	0.255	0.431	0.335	0.289	0.242	0.188	0.377	0.296	0.357	1.000

Table 5 Matrix of factor from the 38 items questionnaire

Complaints	Factor 1	Factor 2	Factor 3
1	0.0772	-0.2065	0.7735
2	0.5858	-0.0817	0.2479
3	0.6593	-0.0952	0.0466
4	0.5121	0.2204	0.1890
5	0.5743	0.2352	0.1592
6	0.6007	-0.1443	0.3892
7	0.6969	-0.3203	-0.1678
8	0.6864	-0.5326	-0.1425
9	0.7238	-0.3679	-0.2935
10	0.6586	-0.4727	0.1203
11	0.7237	-0.3487	-0.2537
12	0.6921	-0.3246	-0.1478
13	0.5586	-0.1905	0.2196
14	0.7906	-0.1260	-0.1660
15	0.6313	-0.1498	-0.1216
16	0.6659	-0.0635	-0.1961
17	0.6075	0.1147	-0.0026
18	0.6546	-0.2174	0.1945
19	0.6549	-0.1282	-0.0752
20	0.7418	-0.1662	-0.1614
21	0.6742	0.2379	-0.0150
22	0.7265	0.2727	0.0186
23	0.3165	0.3324	0.0516
24	0.5968	0.2874	0.0650
25	0.5964	0.0970	0.1741
26	0.5883	0.2670	-0.0150
27	0.5233	0.3316	-0.2024
28	0.6111	0.2505	-0.1233
29	0.6344	0.1443	0.2525
30	0.6579	0.3922	-0.1599
31	0.6643	0.2994	0.0571
32	0.4228	0.4276	-0.0786
33	0.5108	-0.0753	0.1308
34	0.4859	-0.0933	0.1994
35	0.4999	0.1855	-0.1264
36	0.4006	0.3087	0.1170
37	0.6764	0.0212	0.1844
38	0.4640	0.3849	-0.1481
Eigenvalue	14.0314	2.6558	1.6449
Ratio of contribution	0.3693	0.0699	0.0433

drill group's factor 3 scores were significantly high, as were the factor 1 scores for the chain saw group and the chipping hammer group. It was interesting to find that each exposure group was located in a different area in the Z_1 - Z_3 dimension.

Factor scores were calculated for each subject in the whole population from which the group of chain saw operators was drawn ($n = 463$). Figure 3 shows the frequency distribution of factor scores in three groups (with VWF, without VWF but with disturbances of peripheral nerves, muscles, and joints, and farmers). The group of chain saw operators had significantly high scores ($p < 0.01$) for both the VWF group ($n = 93$) and the peripheral neuropathies group ($n = 88$) at the same value in factor 1. As for factor 3, chain saw operators with VWF had significantly high scores ($p < 0.01$) and the group with peripheral neuropathies had the same score as the group of farmers.

Discussion

In many previous studies subjective symptoms have

Fig 3 Frequency distribution of factor score related to grade of symptom.

been observed that suggested the presence of some disorder. An awareness of the significance of these symptoms among those exposed to vibration may make these symptoms the most effective simple indicator of vibration induced damage. This should be followed by more advanced diagnostic procedures appropriate to the symptoms, however, although the validity of these procedures are uncertain at present. It may be valuable, therefore, to use subjective complaints to compare pathological patterns among different groups exposed to vibration and to discuss the relation between the complaints and the workloads.

It has been reported that the effects of vibration depend on the physical characteristics of the tools used, and that they vary not only with the dominant frequency but also with the harmonics. Depending on the dominant frequency, the following effects might be observed: at frequencies below 40 Hz and with amplitudes of several centimetres, osteo-articular lesions may occur; at frequencies between 40 Hz and 300 Hz and amplitudes of the order of

1 mm, vasomotor disturbances, notably of the hands, may appear after several years exposure; at frequencies of more than 300 Hz and amplitudes of the order of 0.01 mm, persistent disorders might appear after a few weeks. In practice many vibrating tools have a complex frequency distribution with wide ranges. Also some related working factors, such as temperature in the work place, working posture and weight of tools may modify the pathological findings in vibration disease. Matsumoto *et al* suggested that the circulatory system was largely influenced by exposure to vibration of high energy at middle to high frequency and by the handling of tools in a cold environment, and that the nervous system was affected by vibration energy at low to middle frequency, based on the results of a comparative study of some vibrating tools.¹⁷ In the present study we have tried to evaluate a wide variety of symptoms in subjects using vibrating tools by multivariate statistical methods. From a wide variety of symptoms a principal component related to peripheral nerves, muscle, and joints and a component for peripheral circulation were extracted specifically and separately. The complaints of the rock drillers reflected a peripheral circulatory factor whereas those of the chain saw operators and the chipping hammer operators presented a complex factor of nerves, muscles, and joints. It was considered that the peripheral circulatory factor might be effected by the weighted vibration level itself and that the factor related to peripheral nerves, muscles, and joints might be strongly affected by working conditions that were not always similar when operating the vibrating tools.

The validity of the analysis must depend on the reliability of the information gathered from the questionnaire. It would be interesting if material obtained from other groups exposed to vibration was analysed by the method seen here and compared with the results of objective tests in order to obtain more universally applicable results.

Requests for reprints to: Makoto Futatsuka, Department of Public Health, Kumamoto University Medical School, Kumamoto 860, Japan.

Appendix

Factor score was calculated for each subject with the following formula.

$$Z_1 = 0.006x_1 + 0.042x_2 + 0.047x_3 + 0.036x_4 + 0.041x_5 + 0.043x_6 + 0.050x_7 + 0.049x_8 + 0.052x_9 + 0.047x_{10} + 0.052x_{11} + 0.049x_{12} + 0.040x_{13} + 0.056x_{14} + 0.045x_{15} + 0.047x_{16} + 0.043x_{17} + 0.047x_{18} + 0.047x_{19} + 0.053x_{20} +$$

$$0.048x_{21} + 0.052x_{22} + 0.023x_{23} + 0.043x_{24} + 0.042x_{25} + 0.042x_{26} + 0.037x_{27} + 0.044x_{28} + 0.045x_{29} + 0.047x_{30} + 0.047x_{31} + 0.030x_{32} + 0.036x_{33} + 0.035x_{34} + 0.036x_{35} + 0.029x_{36} + 0.048x_{37} + 0.033x_{38} \\ Z_2 = -0.078x_1 - 0.031x_2 - 0.036x_3 + 0.083x_4 + 0.089x_5 - 0.054x_6 - 0.121x_7 - 0.201x_8 - 0.139x_9 - 0.178x_{10} - 0.131x_{11} - 0.122x_{12} - 0.072x_{13} - 0.047x_{14} - 0.056x_{15} - 0.024x_{16} + 0.043x_{17} - 0.082x_{18} - 0.048x_{19} - 0.063x_{20} + 0.090x_{21} + 0.103x_{22} + 0.125x_{23} + 0.108x_{24} + 0.037x_{25} + 0.101x_{26} + 0.125x_{27} + 0.094x_{28} + 0.054x_{29} + 0.148x_{30} + 0.113x_{31} + 0.161x_{32} - 0.028x_{33} - 0.035x_{34} + 0.070x_{35} + 0.166x_{36} + 0.008x_{37} + 0.145x_{38} \\ Z_3 = 0.471x_1 + 0.151x_2 + 0.028x_3 + 0.115x_4 + 0.097x_5 + 0.237x_6 - 0.102x_7 - 0.087x_8 - 0.179x_9 + 0.073x_{10} - 0.154x_{11} - 0.090x_{12} + 0.134x_{13} - 0.101x_{14} - 0.074x_{15} - 0.119x_{16} - 0.002x_{17} + 0.118x_{18} - 0.046x_{19} - 0.098x_{20} - 0.009x_{21} + 0.011x_{22} + 0.031x_{23} + 0.040x_{24} + 0.106x_{25} - 0.009x_{26} - 0.123x_{27} - 0.075x_{28} + 0.154x_{29} - 0.097x_{30} + 0.035x_{31} - 0.048x_{32} + 0.080x_{33} + 0.121x_{34} - 0.077x_{35} + 0.071x_{36} + 0.112x_{37} - 0.090x_{38}$$

References

- 1 Taylor W. *The vibration syndrome*. London: Academic Press, 1974.
- 2 Taylor W, Pelmear PL. *Vibration white finger in industry*. London: Academic Press, 1975.
- 3 Bianchi G, Frolov KV, Oledzki A. *Man under vibration suffering and protection*. Amsterdam: Elsevier Scientific Publication, 1981.
- 4 Brammer AJ, Taylor W. *Vibration effects on the hand and arm in industry*. New York: Wiley-Interscience Publication, 1982.
- 5 Griffin MJ. *Vibration injuries of the hand and arm: their occurrence and the evolution of standards and limits*. London: HSE, 1980. (Health and Safety executive research paper 9.)
- 6 Futatsuka M, Sakurai T, Ariizumi M. Preliminary evaluation of dose-effect relationships for vibration induced white finger in Japan. *Int Arch Occup Environ Health* 1984;54:201-21.
- 7 Yamada S, Takagi S. Vibration hazards. In: Sobue I, ed. *Naikagaku Taikei* 59.B. Tokyo: Hirokawa Shoten, 1976:248-80.
- 8 International Labour Office. *Protection of workers against noise and vibration in the working environment*. ILO code of practice. Geneva: ILO, 1977.
- 9 Futatsuka M. Epidemiological studies of vibration disease due to brush saw operation. *Int Arch Occup Environ Health* 1984;54:251-60.
- 10 Matsumoto T, Yamada S, Hisanaga N, Harada N, Kaneda K. On vibration hazards in rock-drill operators of a metal mine. *Jpn J Ind Health* 1977;19:256-65.
- 11 Gotoh T. Vibration disease due to chipping hammer among stone cutters. *Journal of the Kurume Medical Association* 1980;45:862-80.

- ¹² Futatsuka M, Ueno T. Analytical study on the vibration exposure and vibration induced white finger due to operating chain saw. *J Occup Med* (in press).
- ¹³ Okuno C. *Multivariate statistical methods*. Tokyo: Nikkagiren, 1976.
- ¹⁴ Wijting JP, Wollack S, Smith PC. A factor analytic study of subjective components of activation. *Perceptual and Motor Skills* 1970;**31**:635-40.
- ¹⁵ Futatsuka M. Classification of vibration disease in Japan. In: Gemne G, Taylor W, eds. *Hand-arm vibration and the central autonomic nervous system. Journal of Low Frequency Noise and Vibration* 1983;**1**:42-6. (Special issue.)
- ¹⁶ Drogicina EA, Razumov IK. Vibration. In: *Encyclopaedia of occupational health and safety*. Geneva: International Labour Office, 1972:1463-5.
- ¹⁷ Matsumoto T, Yamada S, Harada N. A comparative study of vibration hazards among operators of vibrating tools in certain industries. *Arch hig rada toksikol* 1979;**30**:701-7.

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- ³ Weinstein L, Swartz MN. Pathogenic properties of invading micro-organisms. In: Sodeman WA Jr, Sodeman WA, eds. *Pathologic physiology: mechanisms of disease*. Philadelphia: W B Saunders, 1974:457-72.