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Effect of hand arm vibrational exposure in a Manufacturing Industry

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ABSTRACT

Carpal Tunnel Syndrome is a symptomatic compression neuropathy of the median nerve at the level of the wrist/hand characterized physiologically by evidence of increased pressure within the carpal tunnel and decreased function of the nerve at that level. It is characterized by patients as producing numbness, tingling, hand & arm pain and muscle dysfunction. CTS is caused by physical occupational activities, such as repeated and forceful movements of the hand and wrist or use of hand-held, powered, vibratory tools. Present work is focused on studying CTS on the workers engaged in manufacturing industry. The risk factor considered in this study is hand arm vibrational exposure. The study is conducted on 116 workers comprising of all men (mean age of 36.827±5.98 years). The objective of present work is to study the effect of hand arm vibrational exposure on the workers of manufacturing industry by comparison of potential CTS symptoms and effect of different exposure levels of vibration on occurrence of CTS in actual industrial environment.

1. INTRODUCTION

Carpal tunnel syndrome (CTS) is a peripheral mono-neuropathy of the upper limb, caused by compression of the median nerve as it passes through the carpal tunnel into the wrist. Workers were exposed to vibration from machines like grinders, sanders, jig saws, impact wrenches, chain saws, jack hammers, chipping hammers etc. of manufacturing industry. A total of 232 hands (both hands) have been used for data collection. The study was conducted by questionnaire, physical examination, vibration exposure evaluation and on job observation. Health questionnaire form was designed according to the information required like age, height, weight, duration of job, levels of potential symptoms, level of vibrational exposure etc (appendices). Also the standardized health surveillance guidelines were used to authenticate the design and potential CTS symptoms considered in present study. Job categorization is then done according to level of repetition, force involved, consulting the concerned industrial experts and also by interviewing the workers. To get the general statistical data about age, weight, Body Mass Index (BMI) and employment duration at particular site of workers from collected data, the mean and standard deviation values have been calculated as shown in Table: 1.1

Table 1.1: Age, weight, height, body mass index (BMI) and employment duration

Time: Mean and standard deviation

Factor of concern	**Statistics**
Number of workers	116
Age(years)	36.827±5.98
Weight(kg)	64.01±4.75
Height(cms)	168.51±3.43
BMI(kg/m^2)	22.55±1.74
Employment time at present site(years)	7.20±2.86

2. POTENTIAL CTS SYMPTOMS BASED ANALYSIS

For the analysis of potential CTS symptoms among the workers of manufacturing industry exposed to the vibration one way ANOVA test has been used. One way ANOVA test is used where more than two population data sets are undertaken or observed. In this present study the three populations sets i.e. three levels of severity has been considered for six potential CTS symptoms. Hypothesis testing using ANOVA is done by determining the critical value of the test statistic for a given value of α. If the test statistic is less than the critical value, H_0 is accepted and, if it is greater than the critical value H_0 is rejected.

Table 2.1: Potential symptoms severity based on physical examination

Potential Symptoms	**Mild**	**Moderate**	**High**
Wrist pain	61	46	9
Hand pain	74	33	9
Difficulty in grasping	84	29	3
Weakness	35	49	31
Numbness	4	45	67
Tingling	37	56	23

The one way- ANOVA test is used to check the statistical significance of potential CTS symptoms data obtained during the survey.

Table 2.2: The one way ANOVA table with calculated values

Source	SS	D.F.	Mean Square	F
A(Symptoms , or Explained)	SS Between =2124	J - 1 = 3-1 =2	SS Between/(J -1) = 1062	MSbetween / MSwithin =2.07
Error (or Residual)	SS Within = 7662.3	N - J = 18 –3 =15	SS Within /(N - J) = 510.82	----
Total	SS Total = 9786.3	N - 1 = 18 –1 =17	SS Total / (N -1) = 575.66	----

For α = 0.05, the critical value of F with degree of freedom (2, 15) is 3.68 (Montgomery, 2005) and calculated F value has came out to be 2.07 as shown in table 2.2. F calculated is less than F critical. So the hypothesis is accepted. So the potential symptoms considered in present study significantly contribute in the occurrence of the carpal tunnel syndrome.

3 ANALYSIS BASED ON VIBRATIONAL EXPOSURE

Analysis based on vibrational exposure among the workers working on the machines producing vibration in manufacturing industry has been done by the Chi square test and Correlation analysis. Chi square test is done for the categorical data that result from classifying the objects in two different ways i.e. it is used to examine the significance of association (contingency) between two kinds of classification. The main purpose of this test is to study that whether two classifications are associated or not. Correlation analysis is done to see the relation between two measures. Two measures are correlated if they have something in common. In this present study it is used to check the impact of potential CTS symptoms over the two different levels of vibrational exposure and it is required to see if these two are associated or not.

3.1 CHI- SQUARE TEST

The chi-square ($\chi 2$) is the most common test due to its significance for relating nominal variables. The purpose of the $\chi 2$ test is to answer the question by comparing observed frequencies with the expected frequencies derived under the hypothesis of independence .
The expected frequencies are computed as follows where sample size ≥ 50, Expected frequency should be ≥ 5 and the constraints on the cell frequencies if any should be linear, i.e., they should not involve square and higher powers of the frequencies such as $\Sigma f_o = \Sigma f_t = N$.

Table 3.1: A 2 × 2 contingency table set-up used for Chi Square test

Description	Level 1	Level 2	Total
Symptom Present (Test positive)	a	b	a + b
Symptom not Present (Test negative)	c	d	c + d
Totals	a + c	b + d	a+b+c+d= n

Potential symptoms related to CTS are tingling, numbness, weakness, difficulty in grasping, hand pain and wrist pain. For all these potential CTS symptoms the 2 × 2 contingency tables, observed frequency tables, expected frequency tables and $\chi 2$ calculation tables are made. First of all out of 116 workers, for wrist pain and no wrist pain data from health surveillance data following 2 × 2 contingency table (table 3.1) is developed.

Table 3.2: Exposure level based (2 × 2) contingency table of wrist pain data for chi square test

Symptom	Level 1	Level 2
Wrist pain	35	20
No wrist pain	40	21

Observed, expected and $\chi 2$ calculations have been shown in table 3.3 3.4 and 3.5.

Table 3.3: Survey based observed frequency data for wrist pain

	Column 1	Column 2	Total
Row 1	35	20	55
Row 2	40	21	61
Total	75	41	116

Table 3.4

	Column 1	Column 2	Total
Row 1	E_1=55x75/116=35.56	E_2=55x41/116=19.43	55
Row 2	E_3=61x75/116=39.43	E_4=61x41/116=21.56	61
Total	75	41	116

Table 3.5

fo	ft	$(fo- ft)^2$	$(fo- ft)^2/ft$
35	35.56	0.3136	0.0081
40	39.43	0.3249	0.0082
20	19.43	0.3246	0.0167
21	21.56	0.3136	0.0145

Now, (2 × 2) contingency table of hand pain data for chi square test is setup in table 3.6 from the health surveillance data.

Table 3.6: Exposure level based (2 × 2) contingency table of hand pain data for chi square test

Symptom	Level 1	Level 2
Hand pain	26	16
No hand pain	49	25

Table 3.7: Survey based observed frequency data for hand pain

	Column 1	Column 2	Total
Row 1	26	16	42
Row 2	49	25	74
Total	75	41	116

Table 3.8: Expected frequencies for hand pain in workers

	Column 1	Column 2	Total
Row 1	E_1=42x75/116=27.16	E_2=42x41/116=14.84	42
Row 2	E_3=74x75/116=47.84	E_4=74x41/116=26.16	74
Total	75	41	116

Table 3.9: Calculated χ2 values of hand pain in workers

fo	ft	$(fo- ft)^2$	$(fo- ft)^2/ft$
26	27.16	1.3456	0.0495
49	47.84	1.3456	0.0281
16	14.84	1.3456	0.0906
25	26.16	1.3456	0.0514

For difficulty in grasping the (2 × 2) contingency table is setup in table 3.10 from the health surveillance data for the calculation of χ2 value.

Table 3.10: Exposure level based (2 × 2) contingency table of difficulty in grasping data for chi square test

Symptom	Level 1	Level 2
Difficulty in grasping	16	16
No difficulty in grasping	59	25

Observed, expected and χ2 calculations have been shown in table 3.11, 3.12 and 3.13.

Table 3.11: Survey based observed frequency data for difficulty in grasping

	Column 1	Column 2	Total
Row 1	16	16	32
Row 2	59	25	84
Total	75	41	116

Table 3.12: Expected frequencies for difficulty in grasping in workers

	Column 1	Column 2	Total
Row 1	E_1=32x75/116=20.69	E_2=32x41/116=11.31	32
Row 2	E_3=84x75/116=54.31	E_4=84x41/116=29.69	84
Total	75	41	116

3.13: Calculated χ2 values of difficulty in grasping in workers

fo	ft	$(fo- ft)^2$	$(fo- ft)^2/ft$
16	20.69	29.6691	1.0631
59	54.31	29.6691	0.4050
16	11.31	29.6691	1.9448
25	29.69	29.6691	0.7408

For the calculation of χ2 value for weakness, (2 × 2) contingency table is developed in table 3.14 from the data obtained from health surveillance.

Table 3.14: Exposure level based (2 × 2) contingency table of weakness data for chi square test

Symptom	Level 1	Level 2
Weakness	56	28
No weakness	19	13

Table 3.15: Survey based observed frequency data for weakness

	Column 1	Column 2	Total
Row 1	56	28	84
Row 2	19	13	32
Total	75	41	116

Table 3.16: Expected frequencies for weakness in workers

	Column 1	Column 2	Total
Row 1	E_1=84x75/116=54.13	E_2=84x41/116=29.69	84
Row 2	E_3=32x75/116=47.84	E_4=32x41/116=26.16	32
Total	75	41	116

Table 3.17: Calculated $\chi 2$ values of weakness in workers

fo	ft	$(fo- ft)^2$	$(fo- ft)^2/ft$
56	54.31	2.8561	0.0525
19	20.69	2.8561	0.1380
28	29.69	2.8561	0.0961
13	11.31	2.8561	0.2525

Exposure level based (2 × 2) contingency table of numbness data for chi square test is setup in table 3.18.

Table 3.18: Exposure level based (2 × 2) contingency table of numbness data for chi square test

Symptom	Level 1	Level 2
Numbness	64	30
No numbness	11	11

Observed, expected and $\chi 2$ calculations have been shown in table 3.19, 3.20 and 3.21.

Table 3.19: Survey based observed frequency data for numbness

	Column 1	Column 2	Total
Row 1	64	30	94
Row 2	11	11	22
Total	75	41	116

Table 3.20: Expected frequencies for numbness in workers

	Column 1	Column 2	Total
Row 1	E_1=94x75/116=60.78	E_2=94x41/116=33.22	94
Row 2	E_3=22x75/116=14.22	E_4=22x41/116=7.78	22
Total	75	41	116

Table 3.21: Calculated $\chi 2$ values of numbness in workers

fo	ft	$(fo- ft)^2$	$(fo- ft)^2/ft$
64	60.78	10.3684	0.1705
11	14.22	10.3684	0.7291
30	33.22	10.3684	0.3121
11	7.78	10.3684	1.3326

For the calculation of $\chi 2$ value for tingling, (2 × 2) contingency table is developed in table 3.22from the data obtained from health surveillance.

Table 3.22: Exposure level based (2 × 2) contingency table of tingling data for chi square test

Symptom	Level 1	Level 2
Tingling	53	25
No tingling	22	16

Observed, expected and $\chi 2$ calculations have been shown in table 3.23, 3.24 and 3.25.

Table 3.23: Survey based observed frequency data for tingling

	Column 1	Column 2	Total
Row 1	53	25	78
Row 2	22	16	38
Total	75	41	116

Table 3.24: Expected frequencies for tingling in workers

	Column 1	Column 2	Total
Row 1	E_1=78x75/116=50.43	E_2=78x41/116=27.75	78
Row 2	E_3=38x75/116=24.57	E_4=38x41/116=13.43	38
Total	75	41	116

Table 3.25: Calculated $\chi 2$ values of tingling in workers

fo	ft	$(fo- ft)^2$	$(fo- ft)^2/ft$
53	50.43	6.6049	0.1309
22	24.57	6.6049	0.2688
25	27.57	6.6049	0.2395
16	13.43	6.6049	0.4918

3.2 IMPACT OF POTENTIAL CTS SYMPTOMS ON VIBRATIONAL EXPOSURE USING CORRELATION ANALYSIS

Data from health surveillance in manufacturing industry workers is classified according to vibrational exposure and potential CTS symptoms. To study the correlation between two vibrational exposure levels a hypothesis is assumed that the vibrational exposure level affect the occurrence of potential CTS symptoms. The two levels of vibrational exposures of root mean square values of acceleration has been defined, one ranging from 0 m/s^2 to 13 m/s^2 (level 1) and another from 13 m/s^2 & above (level 2).

Table 3.26: Vibrational exposure level based potential symptom data for correlation analysis

Vibrational Exposure Levels	Hand pain	Wrist pain	Weakness	Numbness	Tingling
Level 1 (X)	35	26	56	67	53
Level 2 (Y)	20	16	28	35	25

The values of $\sum X^2$, $\sum Y^2$ and $\sum X.Y$ are calculated from survey based potential CTS symptoms data from table 3.27 to get the correlation coefficient (r).

Table 3.27: Calculated corresponding values of dependent and independent variables

X	Y	X^2	Y^2	XY
35	20	1225	400	700
26	16	676	256	416
56	28	3136	784	1568
67	35	4489	1225	2345
53	25	2809	625	1325
$\sum X=237$	$\sum Y = 124$	$\sum X^2=12335$	$\sum Y^2= 3290$	$\sum XY = 6354$

Standard value of significance test 't' for degree of freedom 3, at 5% level is equal to 2.35. Since calculated value of t (22.30) is more than standard value (2.35), so the hypothesis is rejected. It concludes that vibrational exposure levels do not affect the occurrence of potential CTS symptoms.

3.3 ANALYSIS BASED ON EMG SIGNALS

(A) DATA ACQUISITION FROM BIOPAC MP45

Myoelectric signal represents the electrical activity of muscles and signal value is represented in micro volts obtained by surface electromyography (sEMG) technique. sEMG signals have been taken by BIOPAC MP-45 data acquisition unit. The MP unit is an electrically isolated data acquisition unit, designed for biophysical measurements. The MP45 receives power from the computer (USB port). The MP Unit has an internal Microprocessor to control data acquisition and communication with the computer. The MP Unit takes incoming signals and converts them into digital signals that can be processed with the computer. There are analog input channels (two on MP45), one of which can be used as a trigger input.

In these present study 41 workers from each of the levels of vibrational exposure has been examined by the BIOPAC MP45 instrument. To take readings from the muscles of a subject three electrodes are used. The negative electrode (white) is placed on APB muscle and positive electrode (red) is placed 6 to 10 cm away from negative electrode. The third electrode (black) is grounded. An EMG reading of APB muscle of dominant hand is recorded for 3 minutes (180 sec.) for a series of clenching fist as hard as possible, and then followed by release. For analysis, the readings are taken from 20 seconds to 40 seconds from each workers EMG signals.

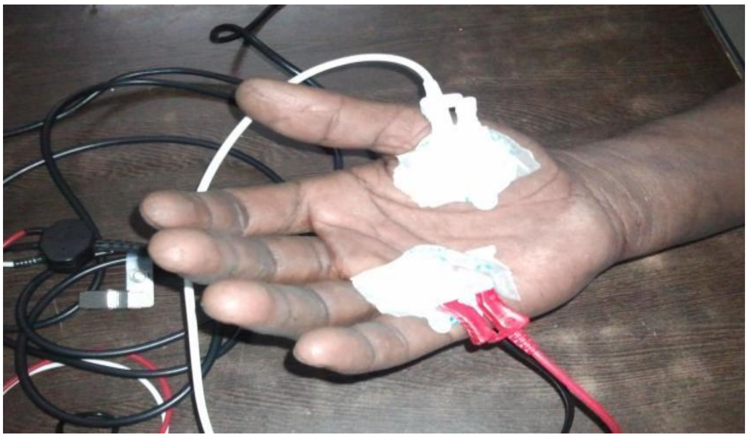

Figure 3.1: Electrodes placement during the EMG data collection

From the EMG data the values of Raw-EMG, Integrated-EMG and Root-mean square EMG are obtained. Raw-EMG i.e. the unprocessed signal of amplitude between 0-6 mV measured from peak to peak and represents the amount of muscle energy measured. Raw-EMG signal helps mostly in qualitative analysis.

Integrated-EMG is calculation of area under the rectified signal. Values are summed over the specified time then divided by the total number of values. Values will increase continuously over time. It quantifies the muscle activity.

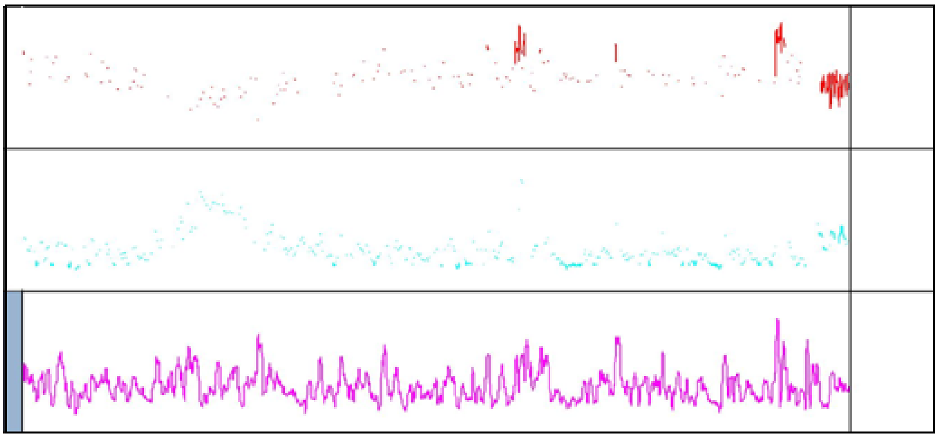

Figure 3.2: EMG Signals

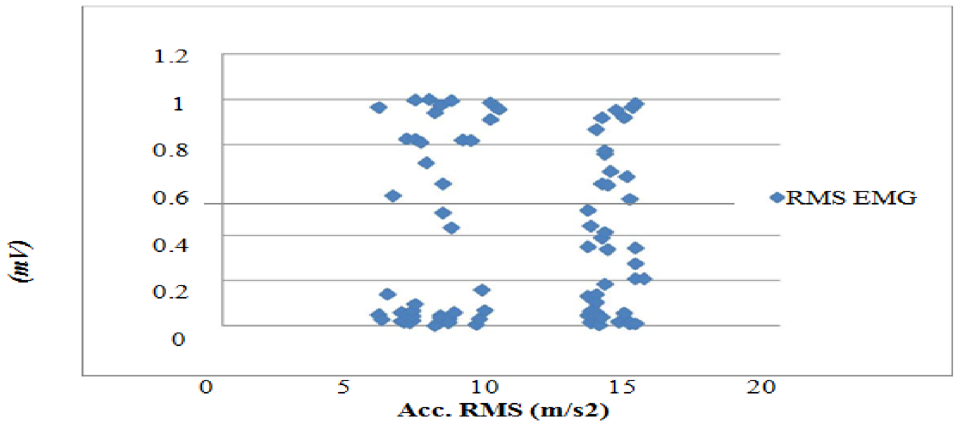

Figure 3.3: Comparison graph between Acceleration RMS and G RMS values of two vibrational exposure levels.

From the comparison graph (figure 3.3) it can be seen that for both the levels of vibrational exposure the spread of the root mean square values of electromyogram signals are almost equal. These signal values are dense below the 0.2mV. Above the 0.2mV the values of the signals show almost the same pattern of spread. From this analysis it can be concluded that EMG signals show the spread uniformly in both the levels and are not distinguished by the levels of vibrational exposure. So the workers APB muscle from both the vibrational exposure levels is affected by the exposure of vibration.

C) COMPARISON OF VIBRATIONAL EXPOSURE AND EMG SIGNALS

A comparison was done between the workers of two levels of vibrational exposure group in the manufacturing industry. The average root mean square values of the electromyogram signals and the average acceleration root mean square values of vibration for two levels are cumulatively shown in table 3.28.

Table 3.28 Acceleration RMS and EMG RMS values of workers

Sr. No.	Acc RMS (m/s^2)	RMS EMG(mV)	Sr. No.	Acc RMS (m/s^2)	RMS EMG(mV)	Sr. No.	Acc RMS (m/s^2)	RMS EMG(mV)
1	5.6	0.049098	30	8.2	0.433758	59	13.6	0.918607
2	5.6	0.964954	31	8.2	0.994942	60	13.6	0.387403
3	5.7	0.027711	32	8.3	0.058554	61	13.7	0.758832
4	5.9	0.139986	33	8.6	0.81998	62	13.7	0.4130005
5	6.1	0.57471	34	8.9	0.818214	63	13.7	0.773468
6	6.4	0.058513	35	9.1	0.005609	64	13.7	0.18382
7	6.4	0.021342	36	9.2	0.03033	65	13.8	0.33805
8	6.5	0.017347	37	9.3	0.158493	66	13.8	0.621415
9	6.6	0.82598	38	9.4	0.067459	67	13.9	0.681817
10	6.6	0.047391	39	9.6	0.985581	68	14.1	0.952929
11	6.7	0.013061	40	9.6	0.911077	69	14.2	0.01667
12	6.8	0.022486	41	9.9	0.956571	70	14.4	0.919631
13	6.8	0.042653	42	13.1	0.130824	71	14.4	0.056571
14	6.8	0.06528	43	13.1	0.349139	72	14.5	0.658968
15	6.9	0.997127	44	13.1	0.509888	73	14.6	0.016542
16	6.9	0.82426	45	13.1	0.0464916	74	14.6	0.55985
17	6.9	0.095548	46	13.2	0.440604	75	14.6	0.008449
18	7.1	0.810447	47	13.2	0.01459	76	14.7	0.964954
19	7.3	0.720081	48	13.2	0.063682	77	14.8	0.009121
20	7.4	0.999245	49	13.2	0.063162	78	14.8	0.273978
21	7.6	0.00144	50	13.4	0.13882	79	14.8	0.981555
22	7.6	0.941545	51	13.4	0.058018	80	14.8	0.344149
23	7.8	0.045596	52	13.4	0.866911	81	14.8	0.208147
24	7.8	0.035272	53	13.4	0.024314	82	15.1	0.208147
25	7.8	0.974562	54	13.4	0.103528			
26	7.9	0.498579	55	13.4	0.041538			
27	7.9	0.627258	56	13.5	0.003139			
28	8.1	0.030379	57	13.6	0.627489			
29	8.1	0.014874	58	13.6	0.037281			

For the comparison of the data obtained in table 3.28 a graph is plotted between the average root mean square values of the electromyogram signals and the average acceleration root mean square values of vibration for the two levels of vibrational exposure.

4.1 RESULTS AND CONCLUSIONS

Mechanical vibrations endured repeatedly over long periods of time by human subjects produce disabilities. In this present work effect of hand arm vibration exposure has been studied on human body in terms of potential CTS symptoms. ANOVA, Chi square test, Correlation analysis and electromyogram signal analysis were used to achieve the objectives. Following conclusions have been made from this dissertation:

[1] ANOVA test results show that calculated F value is less than the critical value for all the potential CTS symptoms. Hence all the potential symptoms contribute towards the occurrence of carpal tunnel syndrome.

[2] Chi square test revealed that all the potential CTS symptoms are insignificant except difficulty in grasping. Hence, all the potential CTS symptoms except difficulty in grasping can occur over the long exposure of the vibration and their occurrence does not depend over the level of vibrational exposure.

[3] Correlation analysis on low and high levels of vibrational exposure reveals their ineffectiveness on potential CTS symptoms since ‘t’ calculated is more than standard value. So Correlation as well as Chi square test concludes that occurrence of potential CTS symptoms is not dependent either upon high or low level of vibrational exposure.

[4] From comparison between the average acceleration RMS values of vibrational exposure and average RMS values of EMG signal of workers of manufacturing industry, it was found that spread of the EMG signals for both levels of vibrational exposure are almost similar. So the workers APB muscle from both the vibrational exposure levels is affected by the exposure of vibration.

4.2 RECOMMENDATIONS

The current study served as a demonstration of a new approach for assessing the CTS risk factors and symptoms caused by the exposure of vibration. Below are the recommendations for preventing CTS symptoms occurrence among the manufacturing workers.

[1] A continuous check on the risk factor (hand arm vibration) analyzed in this study has a good prospect in reducing the CTS occurrence.

[2] A preferential job allocation policy means assigning a particular job to workers according to efficacy and physical strengths can be applied, so that workers can feel comfort in their job.

[3] A job rotation policy can be implemented to reduce the stress in particular area of body.

[4] An employee wellness program like health risk assessments, schedule workshops on relaxation, stress management and work life balance to improve their efficiency.

[5] Workers can perform hand/wrist simple stretching exercises before the shift begins and/or during the first 5 – 20 minutes of each shift and after the lunch break.

[6] Workers can be provided with the vibrational resistive gloves while performing their job.

[7] Awareness sessions to perform a job/task with right posture must be held repetitively.

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