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Estimation of Fatigue Index for a Pump Assembly Operation Using Ergonomics Study

Ashok. P[1], Madhan Mohan. G[2], Nagandra Pandi. G[3]

[1]*Department of Production Engineering, PSG College of Technology, Coimbatore, India*
[2] *Department of Production Engineering, PSG College of Technology, Coimbatore, India*
[3] *Department of Production Engineering, PSG College of Technology, Coimbatore, India*

Email: [1]pak.prod@psgtech.ac.in, [2]gmm.prod@psgtech.ac.in

Abstract-This study aims to estimate the fatigue index of pump assembly operation. Workers from pump assembly operation were mostly affected by musculoskeletal injury due to prolonged work nature and poor workplace environment. Data were collected with the help of the Nordic musculoskeletal questionnaire and direct observations. The statistical analysis carried out reveals that 67.39% of pump assembly operation workers reported MSDs. In total, 46workers from different age, experience and more number of factors were considered for this study. Based on this study the most painful and fatigue muscles were identified. The clinical test of muscles was conducted for locating Electromyogram (EMG) electrode. The data collected from EMG were processed in lab Chart, which gives the relationship between cycle and Fatigue index. The critical point time, when the employee enters into the fatigue zone was identified and highlighted in the plot between cycle and fatigue index.

Keywords: Fatigue index, EMG, Biceps brachii, Muscle fatigue, critical point time

1. INTRODUCTION

Musculoskeletal disorders (MSDs) are an important public health problem in both developed and developing countries, with substantial impact on quality of life and a substantial economic burden in compensation costs, lost wages and productivity. Psychosocial demands have also been identified as possible risk factors for MSDs. Non-occupational factors such as obesity, sports activities and gender have also been associated with MSDs, but the findings of previous studies have been inconsistent. The aim of this study was to identify the factors associated with MSDs among workers who were employed in pump manufacturing industry[1]. Musculoskeletal disorders (MSDs) can affect the body'smuscles, joints, tendons, ligaments and nerves. Work is important in lives of men and women; nonetheless, it can become a health hazard when it is carried out in an inappropriate way [2]. During working hours, industrial workers are exposed to a number of physical tasks that create fatigue, pain, and discomfort, leading to musculoskeletal disorders (MSDs). The International Labour Organization (ILO) and theWorld Health Organization (WHO) regard MSDs as a work relateddisease, which is also referred to as a “new epidemic”that should be researched and solved. Employers are mostly fromthe rural areas and unaware of an ergonomic workingenvironment, workstation design and working postures. In addition, the Odds ratio is used to describe the probability of each category risk factor to cause MSD among pump manufacturing industry [03]. Univariate and multivariable logistic regression were used to calculate the odds ratios (ORs) and antecedent 95% confidence intervals (95% CIs) for the independent factors for LBP among pump manufacturing industry in the study [04]. In the multivariable analysis, age and BMI were handled as continuous variables, while other categorical variables were dichotomized. All variables were included in the multivariable analysis [05]. The number of workers was 46 people in total and the purpose of the study and its benefits were explained to those involved in this study [06].The statistical analysis carried out reveals that 67.39% of pump manufacturing industry workers reported MSDs. The study also investigates the association between the personal characteristics, physical workload, psychosocial factors and workplace characteristics with complaints of the lower back, upper back, shoulder, neck, hand/wrist, thigh, knee and foot among pump manufacturing industry [07]. The selected muscles were implement to the clinical test for Electromyogram testing. By this test several data of muscles were collected like MVC, Load carried cycle data of RMS, MPF and MDF. The collecteddata wereanalysed and local fatigue index were estimated also correlate with Borg's scale of fatigue index.

2. METHODS

A. Survey data collection and analysis

This study was conducted among pump manufacturing industryworkers located in Coimbatore in the state of Tamil Nadu, India. Observations were carried out during the study period regarding the working environment, work nature and risk factors. The workplace comprises various manufacturing sections like winding, machining, painting, inspection and assembly, etc. The study is confined to a limited strength of 46 pump manufacturing industry under the age groups from 18 to 71. The number of workers was 46 people in total and the purpose of the study and its benefits were explained to those involved in this study. All are full-time workers performing pump manufacturing and assembly for at least 7 h/day. The managers and other office workers belonging to pump manufacturing industry were excluded from this study because they do not have a heavy or more physical workload. Data was collected using the Nordic based Questionnaire specifically designed for the current study. The questionnaire consists of information on worker background, psychological, illness history and other work-related information. Worker background includes age, gender, marital status, work experience, alcohol and tobacco consumption status. Psychological questions like job satisfaction and job stress; work-related information like working hours, rest time, repetitive motion (for upper and lower extremities, lower back), and awkward posture (for upper and lower extremities, lower back) were also included. The questionnaire also analyzes about the frequency of pain distribution in overall anatomical sites such as the neck, shoulder, upper and lower back, upper and lower extremities. In work related section, questions such as frequencies of repetitive motion for upper and lower extremities, and the current work activity that involves awkward posture for anatomical sites and its frequencies are recorded as well. This survey was performed in the month of January 2019. In this study, data are collected with a set of questionnairesand by direct observations. The risk factors are studied through directobservation during working hours. Participants about their work. They were asked to choose any one from the following choices: low, moderate and high. Finally, subjects were asked to quantify the overall discomfort in body regions with regard to the assessment values. The data collections and investigations are carried out only for the pump manufacturing industry(n = 46).The statistical analyses were performed using $\chi 2$ tests and

95% confidence intervals (CI). X^2 tests were usedto assess the relationship between sociodemographic andworkplace factors (independent variables) and reportedmusculoskeletal complaints (dependent variable). Prevalence(%) and 95% CI were used to find the prevalenceof musculoskeletal pain in different anatomical sites byage group and years of work experience. Thedata examined are from various anatomical sites includingthe neck, shoulder, upper/lower back, upper/lower, wrist, hips and knee/foot.So, to analyze it better, the age and experience groupis considered in the present study. All the statistical analysis with frequency distributionsof respondent, psychosocial factors and theprevalence of MSD were carried out using SPSS v1.0software package. Descriptive statistics were determinedfor demographic, occupational and health characteristicsof the study population. The prevalence of MSD was evaluated for all three categories of kitchenworkers. The Odds ratio and 95% confidence intervalswere evaluated using Binary Logistic regression analysisto determine the association of MSD with independentvariables like personal factors, health factors andwork-related factors of all three work categories.

Table 1.
Relationship between the sociodemographic, health and workplace factors and reported musculoskeletal disorders (MSDs) (n = 46)

		n(46)	**MSD Yes(31)**	**MSD No(15)**	**Chi.sq.value**	**DoF**	**p value**
Health status	Good	42	28	14	0.115	2	0.734
	Average	4	3	1			
	Bad	0	0	0			
Level of stress	Low	28	21	7	3.372	2	0.185
	Moderate	17	10	7			
	High	1	0	1			
Tired	Yes	28	21	7	1.885	1	0.170
	No	18	10	8			
Experience	<5	31	22	9	0.629	2	0.730
	5-10	3	2	1			
	>10	12	7	5			
Satistification	Low	23	15	8	0.836	2	0.659
	Moderate	13	10	3			
	High	10	6	4			
Micro breaking	Yes	46	31	15	-	1	0.726
	No	0	0	0			
Repetitive work	Yes	16	11	5	0.021	1	0.886
	No	30	20	10			
Awkward posture	Yes	28	24	4	10.932	1	<0.005
	No	18	7	11			
Excessive force	Yes	22	18	4	3.994	1	0.046
	No	24	13	11			
Elbow pain	Yes	18	11	7	0.531	1	0.466
	No	28	20	8			
Shoulder pain	Yes	18	12	6	0.007	1	0.933
	No	28	19	9			

		n(46)	MSD Yes(31)	MSD No(15)	Chi.sq.value	DoF	P value
Age	<25	30	22	8	1.390	2	0.499
	26-45	7	4	3			
	>45	9	5	4			
Education	Primary	1	1	0	0.954	3	0.812
	Intermediate	3	2	1			
	High school	5	4	1			
	Above high school	37	24	13			
BMI	Underweight	9	7	2	1.000	2	0.606
	Normal	33	22	11			
	Overweight	4	2	2			
Marital	Single	32	21	11	0.149	1	0.699
	Married	14	10	4			
Smoking	Yes	7	6	1	1.261	1	0.261
	No	39	25	14			
Exercise	Yes	18	10	8	1.885	1	0.170
	No	28	21	7			

3. EMG EXPERIMENTS AND SIGNAL COLLECTION

The selected muscles for the EMG test were examined to find the location and orientation of EMG electrode. The EMG electrodes were placed in their respective locations on the muscles. The volunteer was asked to apply their maximum effort on the Maximum voluntary Contraction (MVC) setup to capture the maximum output when the employee give their maximum effort in mV. Then, the asked to carry the 4kg load cycle continuously.

EMG signals of every cycles were observed continuously and compared with the MVC. By that selected muscles and study of movements of workers would be demonstration in ergonomics lab with EMG test.The following **figure 2** shows that the EMG signal from labchart software which is used to find the EMG signal of muscles in millivolt(mV).The signal shows maximum voluntary contraction (MVC) of subject.

Figure.1 MVC setup for EMG test

It shows maximum effort by the subject it consider as 100% of subject.The following **figure 3** shows that the EMG signals of handling 4kg weight by the subject 1 by cycles it represent that the No of cycles and percentage of effort is proportionally increased in the graph. It takes nearly 20 cycles without rest to reach its 80% of effort.

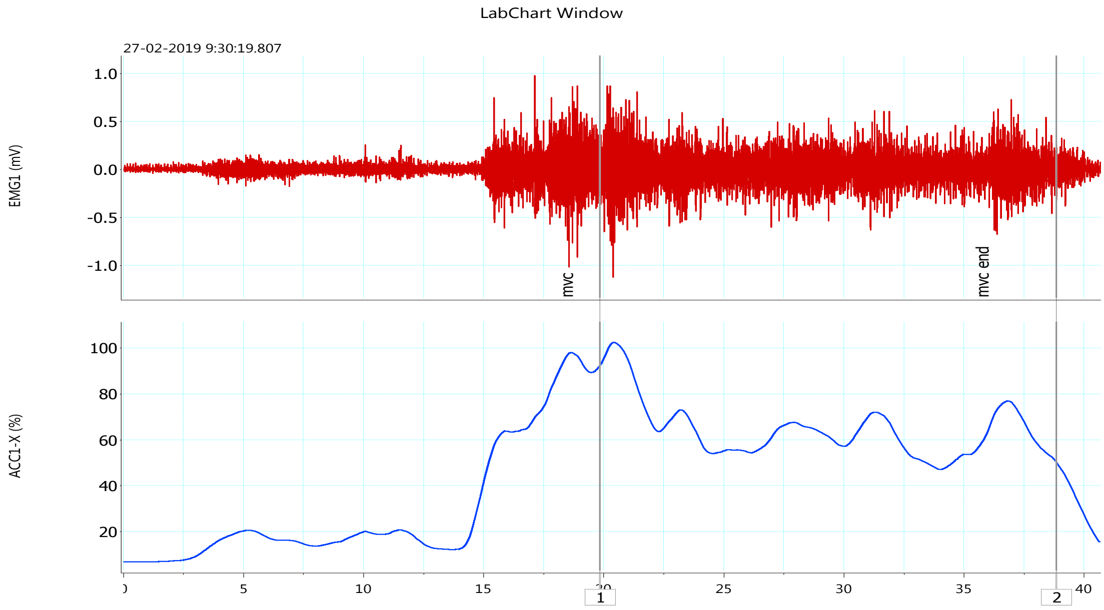

Figure.2 Maximum voluntary contraction (MVC) of Subject

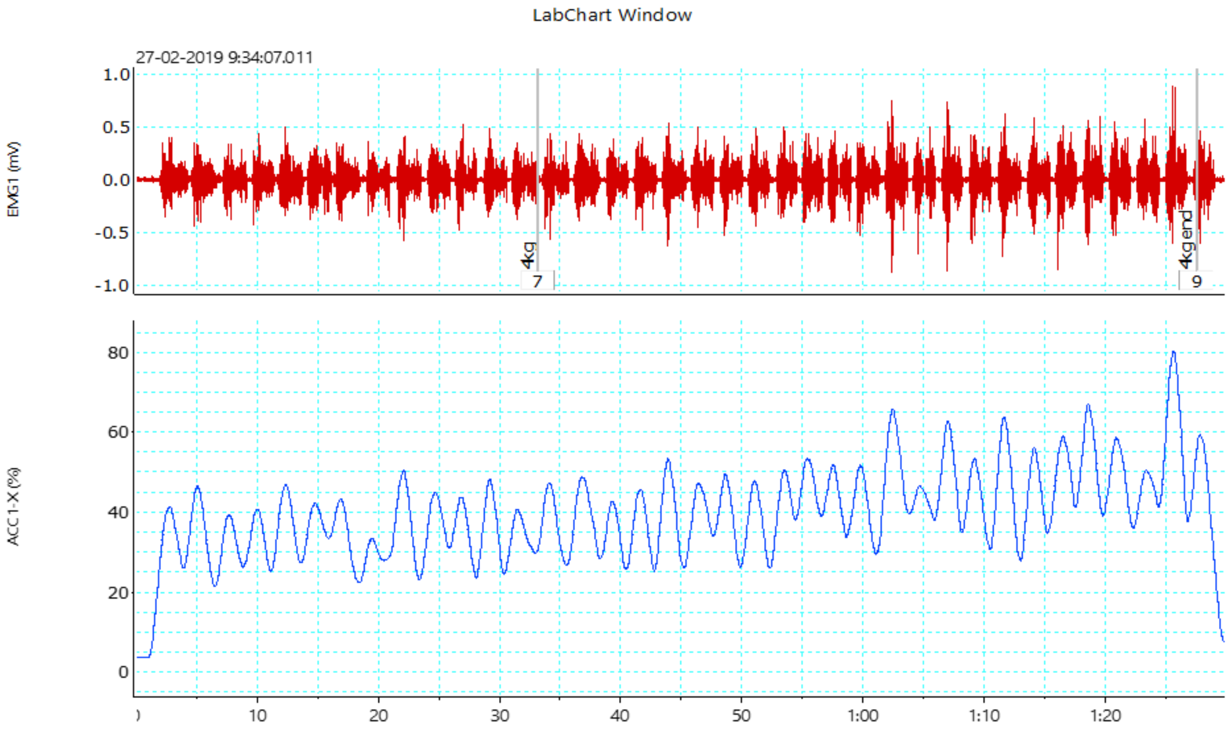

Figure.3 EMG signal for 4kg load cycle of Subject

B. EMG Experiments signal analysis

The Root Mean Square (RMS) value, mean power frequency, median power frequency and the maximum value of EMG signal were identified for each and every cycles, which are shown in **Table.2**. The fatigue index is generate by the factors of EMG signal like percentage of effort, RMS value, mean power frequency and median power frequency by the analysis of this signals. When the fatigue index is within the limit which is an indication that the employee is not giving his maximum effort to do the job. Also it is called as safety zone. If the employee gives his maximum effort to do the work is called as fatigue zone. When the employee is in fatigue zone he should take rest for some time for continuing the work. The **Figure.4** shows the plot between the cycle and RMS value of EMG signal were generated from the data of 4 Kg load carried cycle which is gives equations for the estimation of fatigue index.A trend line of the RMS, cycle were determined for extrapolating purpose for the estimation of fatigue index.

Table.2 EMG signal analysed data of subject

EMG signal	Mean (mV)	RMS (mV)	Mean power frequency (mV)	Median power frequency (mV)	Maximum value (mV)
MVC	0.0014763	0.1311649	87.83393	66.24224391	0.8681406
4 Kg (cycle)					
	0.001417	0.074313	83.8783	70.0466	0.44
	0.001466	0.083146	75.59641	56.54485	0.428656
	0.00143	0.07076	86.50607	72.23049	0.386891

	0.001398	0.077067	86.15714	69.58686	0.399266
	0.001472	0.080725	91.33787	76.50835	0.538484
	0.001465	0.078683	82.40274	68.00706	0.493625
	0.001509	0.085817	87.96514	67.23666	0.421438
	0.001436	0.079566	83.1283	71.58931	0.486578
	0.001468	0.085499	78.76039	61.29846	0.498438
	0.0015	0.095174	81.74036	68.48681	0.440688
	0.001426	0.113662	88.65284	66.57829	0.749203
	0.001412	0.106818	88.67242	68.51424	0.739578

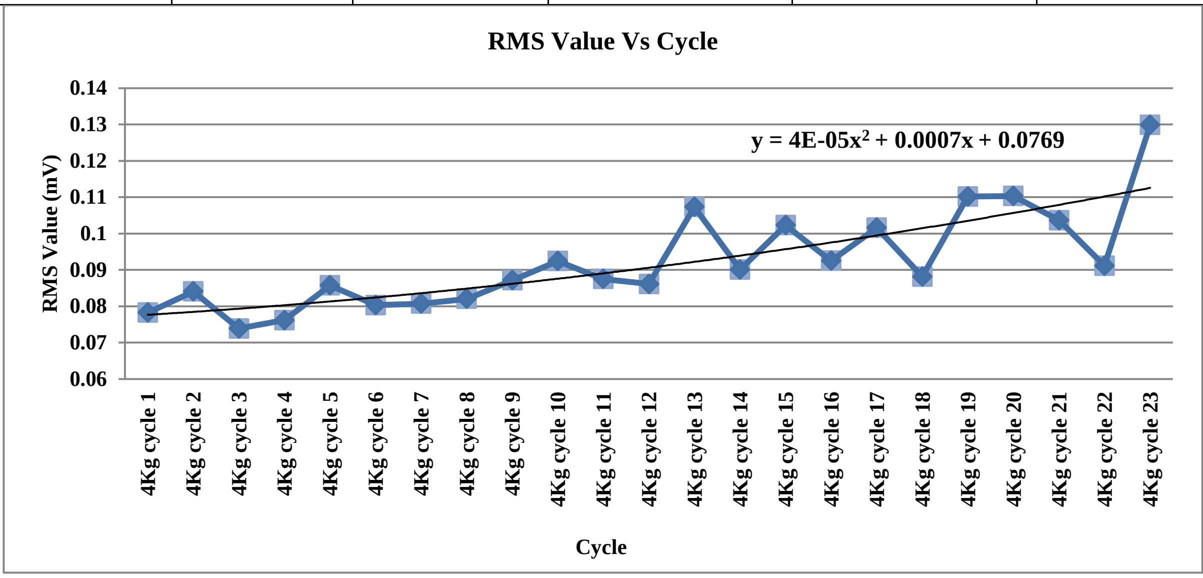

Figure.4RMS cycle 4Kg load carried cycle for Subject

C. Fatigue index generation

The following equations were taken and derived from the data tables and graphs of polynomial equations it shows that the fatigue zone cycle time by solving the equations.Example equation from Subject 4Kg load carried cycle's graph.Consider Y=MVC because of the find maximum effort obtained cycles XSolving the both equations, X would be a 29 cycles also actual practical cycles was 23 cycles.

$$y = 4x^2 \times 10^{-5} + 0.0007x + 0.0769$$

MVC=Y= 0.1311649

So, consider the equation analysis and actual practical values are remains same. Fatigue index to be generated by this value also predict the Critical point time (CPT)which denotes the employee into the fatigue zone.

4. RESULTS

There was significant difference (p <0.005) between groups in awkward posture. The various factors like age, education, marital status, exercise/ games activities, stress due to work and getting tired at work. Cigarette smoking and current health status was reported as not significant. The odds ratio and 95% CI (Confidence Interval) reported perfect association between reported MSD and other factors. Regarding health factor, it was identified that awkward posture among pump manufacturing industry workers had a higher OR and it reports the increase in risk of developing MSD (OR = 9.486; 95% CI = 2.277-39.036) and reported that it was significant associated with MSD.The Odds ratio (OR) represents the probability of MSD occurrence comparing to the reference groups. The confidence interval (95%CI) represents the interval level (maximum and minimum). This infers that the probability of causing MSD increases with increase in age (p < 0.005). Using this survey biceps brachii muscles were selected for the EMG test. The experimental results shows employee stopped the work at 23rd cycle. But, based the results from the extrapolation the employee can continue the work till 29th cycle.

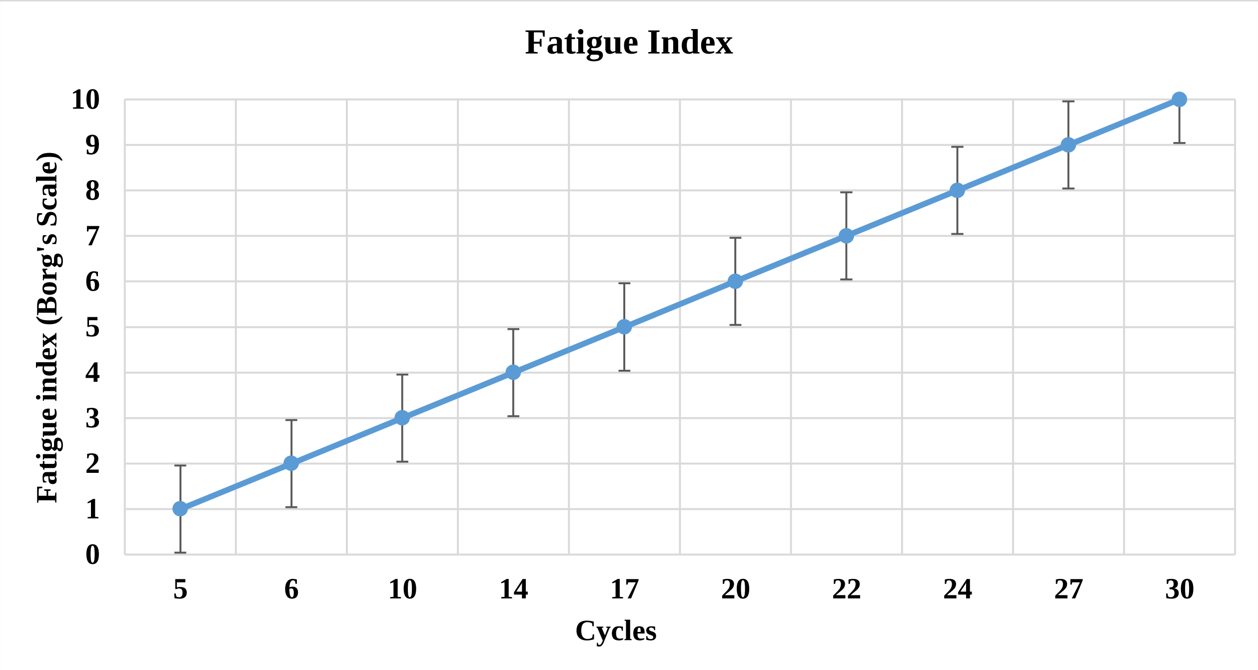

Figure .5 Fatigue index for 4kg cycle

5. DISCUSSIONS

This study investigates the risk factors associated with the work and the work-related musculoskeletal disorders caused for the individuals who work in the pump manufacturing industries in Tamil Nadu, India. The currentstudy, results infer that 67.39% of workers are prone to MSD.This finding was higher than the prevalence of MSD among HSP workers (62.5%) women rebar workers (57.7%) and underground mine workers in Zambia (42.6%). An anatomical sites infer that foot pain score was highest with 48.11%,wrist region 44.63%, knees of 44.01% , lower back pain score of 43.47%, upper back pain score 38.84%, shoulder region of 38.69%, hip pain score of 37.24%, elbow pain of 34.63% and neck region 32.31%. This result shows the extrapolating and experimental results have an acceptable deviations in the fatigue index graph which generated for the pump manufacturing industries employees. Also this is the fatigue index only used for the age between 22 to 28 years.

6. CONCLUSIONS

The present study concludes that discomfort regions wereidentified among the pump manufacturing industries workers with a higherprevalence ratio of discomfort level. Thus the pump manufacturing industries workers participatingin this research were found to have both MSDs andergonomic risks, which do not appear to interfere withjob performance or daily life. By following the same procedure the fatigue index and fatigue for different muscles can be generated. Still, it is suggested thatergonomic studies and engineering controls should be usedto reduce WMSDs and discomfort levels among pump manufacturing industriesworkers in South India.In future a global fatigue index can be generated by adopting the same method.

7. REFERENCES

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