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ORIGINAL ARTICLE

A Data Driven Approach for Optimization of Rest Allowances

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ABSTRACT

Despite all technological improvement and automation in the production process, a majority of tasks are still performing by workers. Due to this challenge, the occurrence of musculoskeletal disorders (MSDs) is an expected common result of manual tasks. Fatigue is one of the common causes resulting MSDs. Hence, one of the strategies for resolving this issue is to schedule rest time to provide a recovery time for workforce from the physiological consequences of exertion. This study was aimed to suggest a pre-planned rest allowance at MAPNA Company, Tehran, Iran. Therefore, we designed an experiment in a workstation to obtain input data (postures and forces). Then, the collected data was used to simulate the working condition for all workers using 3DSSPP software. We considered maximum voluntary contraction (MVC) of involved muscles. So, the critical muscle was determined for all workers based on specific tasks. The rest time for a critical muscle of each worker was calculated using the Rohmert model. Results showed that optimally work time schedule based on the task specification and subsequent rest time could reduce MSDs. This approach provides a comprehensive view of workers and their tasks (for both sources p-value was less than 0.05). This approach can be used for any workstation to suggest pre-planned rest allowances.

KEYWORDS: *Rest Allowances, Optimization, Experiment Design, Musculoskeletal Disorders*

INTRODUCTION

Manual tasks in production systems lead to musculoskeletal disorders (MSDs) among workforces. Muscle fatigue is one of the main causes of MSDs [1]. Despite all technological improvements, there are a lot of manual tasks in manufacturing environments that are performed by workers [2]. In manufacturing environments, continual and prolonged use of muscles can lead to work-related musculoskeletal disorders (WMSDs) [3]. Muscle fatigue is one of the major and important causes of WMSDs [4]. Muscle fatigue relates to the hardship of work that everybody performs [5]. It defines as any reduction in force generation from muscles [6].

Muscle fatigue is an important challenge in manufacturing environments and it can cause both short and long-term disorders. It results in a situation where workers' performance reduces due to the less force and control on their muscles. Consequently, it can affect the quality of work [7]. As a practical solution for this problem, rest allowances are offered to decrease the hazard of WMSDs [8]. However, due to productivity measures, it is impossible to exactly follow pre-planned

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rest time. These changes in work-rest regimens always lead to muscle fatigue [9].

There was a similar challenge in one of the workstations at the MAPNA Company with respect to the risk of WMSDs. Thus, in the current study, we used a combination of designed experiments and simulations to determine an optimal range for work time and rest time recovery from muscle fatigue and physiological consequences of exertion. This method provides a flexible approach for evaluating WMSDs in the selected workstations.

METHODS

Workstation:

In the present study, participant was selected among the finish sanding station at the MAPNA factory. All seven workers in this station had a prolonged activity which ultimately results in WMSD. In this workstation, each worker uses three sanding machines (each sanding machine considered as a different task), to work on a different type of turbine blades. Therefore, all workers should stay in bad postures during working time. Table 1 shows the anthropometric features of seven workers. Workers posture during each tasks have been presented in Figures 1, 2, and 3.

Table 1. Anthropometric features of workers

Worker	Height (cm)	Weight (kg)	Age (year)
1	180	81	29
2	165	71	29
3	188	98	26
4	178	99	26
5	182	70	28
6	165	80	41
7	180	90	31
Average	176.8	84.1	30

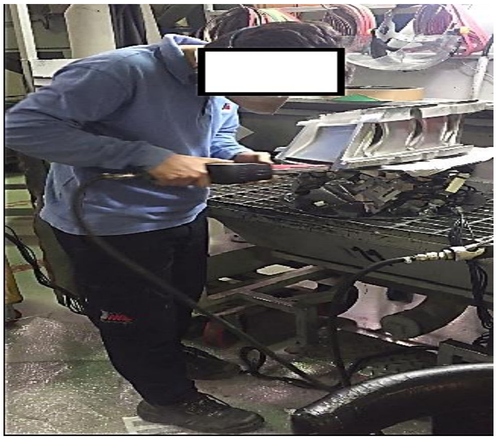

Fig 1. Task number one

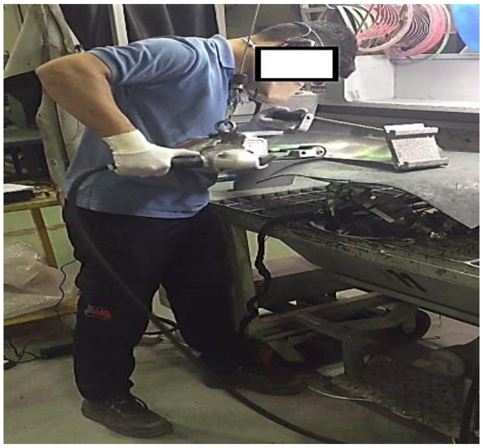

Fig 2. Task number two

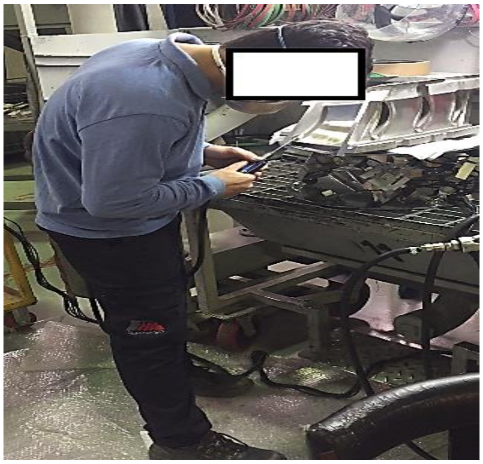

Fig 3. Task number three

Experiment design:

In order to collect data related to the experiment, all workers postures were recorded based on the five minutes time spans [10]. A force plate (made by DANESH SALAR IRANIAN Company, Tehran, Iran) was used to measure exerted forces in three axes during the work time (see Figure 4).

Fig 4. a 3D force plate

Biomechanical modelling:

After the collection of input data, biomechanical analyses were performed using 3DSSPP software [11]. The input data were classified into two groups 1: postures extracted from videos; 2: forces obtained using the force plate. Maximum voluntary isometric contraction (MVIC) as one of the key factors for the measurement of muscle were calculated. Moreover, the working conditions for all muscles involved in work considering the postures and forces were simulated using 3DSSPP software.

Maximum exertion time:

The Maximum Exertion Time (MET) was calculated for all muscles involved in work. Based on the ISO 2000 definition about MET, it displays the time that a muscle can tolerate a specified load (refer to Figure 5) [12]. Frey Law and Avin [13] plotted this graph based on joint-specific fatigue models.

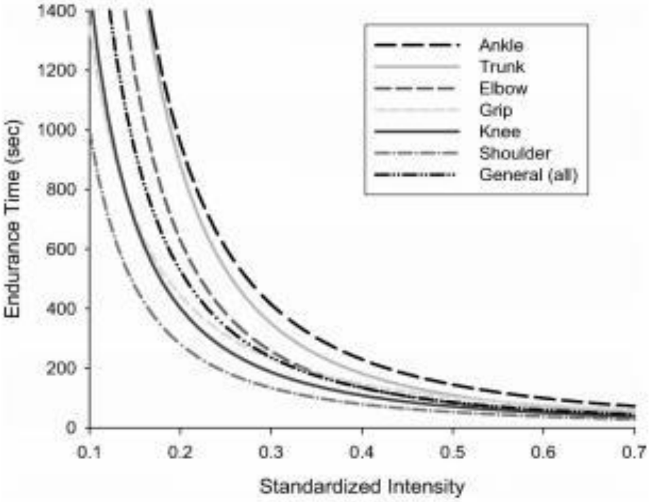

Fig 5. Endurance time of muscles

A series of torso, shoulder, elbow, and wrist muscles were involved in this workstation. Therefore, the MET was determined for these muscles.

Optimization of rest allowances:

The critical muscle with a minimum MET was identified to optimize the rest allowances for each worker based on different tasks. A model was used to identify the critical muscle as following (see Equation 1):

$$\text{Min } Z = \sum_{i=1}^{m} \text{MET}_{ij}\ X_{ij} \qquad j=1, 2,\dots, n \qquad (1)$$

$$\sum_{i=1}^{m} X_{ij} = 1 \qquad j=1, 2,\dots, n$$

$$X_{ij} = 0, 1$$

i: number of muscles involved in work
j: number of tasks

After identifying the critical muscle, the following range was considered as optimal work time for each worker (see Equation 2:

Optimal work time of task j = (0, min MET_i) (2)

This range calculates the optimal work time range. Whereas, exceeding this range leads to muscle fatigue or injuries. Therefore, the Rohmert model was used to calculate the rest time for this range [8]. Equation 3 shows this model:

$$\text{RA} = 18 \times \left(\frac{T_i}{\text{MET}}\right)^{1.4} \times \left(\frac{\%\text{MVC}}{100} - 0.15\right)^{0.5} \times 100 \qquad (3)$$

T_i: work time

We used the Rohmert [8] model due to ability of this model in providing realistic rest time compared to other models [4].

By determining the rest time concerning the most critical muscle, it can be concluded that this rest time is an optimal rest time because other muscles need less rest time than this amount.

Statistical analysis:

Statistical analyses were performed to evaluate the effect of anthropometric features of workers and different tasks on the response variable. Therefore, we considered optimal rest time as the response variable. Then, a block design was determined using MINITAB software (version 16). In this case, we considered workers as blocks to remove nuisance factors (anthropometric features). The normal probability plot was applied for assessing whether or not the data set is approximately normally distributed.

RESULTS

The maximum voluntary contraction of muscles involved in work for all workers based on the different defined tasks have been presented in Tables 2, 3, 4, 5, 6, 7, and 8.

Table 2. %MVC for worker 1

Tasks	**%MVC**			
	Wrist	Elbow	Shoulder	Torso
1	17	11	6	34
2	12	10	19	28
3	12	9	11	21

Table 3. %MVC for worker 2

Tasks	**%MVC**			
	Wrist	Elbow	Shoulder	Torso
1	15	10	10	25
2	13	7	14	22
3	7	6	9	25

Table 4. %MVC for worker 3

Tasks	**%MVC**			
	Wrist	Elbow	Shoulder	Torso
1	18	12	9	40
2	17	12	13	39
3	11	9	6	36

Table 5. %MVC for worker 4

Tasks	**%MVC**			
	Wrist	Elbow	Shoulder	Torso
1	13	11	9	56
2	17	11	12	45
3	10	9	7	35

Table 6. %MVC for worker 5

Tasks	**%MVC**			
	Wrist	Elbow	Shoulder	Torso
1	13	9	8	28
2	11	8	8	23
3	9	7	6	22

Table 7. %MVC for worker 6

Tasks	**%MVC**			
	Wrist	Elbow	Shoulder	Torso
1	12	9	9	22
2	10	8	9	21
3	9	6	3	21

Table 8. %MVC for worker 7

Tasks	**%MVC**			
	Wrist	Elbow	Shoulder	Torso
1	16	11	14	29
2	14	11	12	27
3	9	8	14	27

Based on the results, it can be concluded that the Torso muscle had the highest percentage of maximum voluntary contraction (MVC) among all workers based on different tasks. However, other muscles were significantly different from this range. The maximum exertion time for all workers has been presented in Tables 9, 10, 11, 12, 13, 14, and 15. The red color in these tables representing the most critical muscle. However, the green color shows the least critical muscle.

Table 9. MET for worker 1

Tasks	**MET in minute**			
	Wrist	Elbow	Shoulder	Torso
1	9.2	33.8	38.9	4.2
2	17.2	41.1	4.8	6.6
3	17.2	51.1	12.9	12.5

Table 10. MET for worker 2

Tasks	**MET in minute**			
	Wrist	Elbow	Shoulder	Torso
1	11.5	41.1	15.3	8.5
2	14.9	85.8	8.3	11.3
3	44.8	117	18.6	8.5

Table 11. MET for worker 3

Tasks	**MET in minute**			
	Wrist	Elbow	Shoulder	Torso
1	8.3	28.3	18.6	2.9
2	9.2	28.3	9.5	3.1
3	20.1	51.1	38.9	2.1

Table 12. MET for worker 4

Tasks	**MET in minute**			
	Wrist	Elbow	Shoulder	Torso
1	14.9	33.8	18.6	1.4
2	9.2	33.8	11.1	2.2
3	23.7	51.1	29.4	4.1

Table 13. MET for worker 5

Tasks	**MET in minute**			
	Wrist	Elbow	Shoulder	Torso
1	14.9	51.1	23.1	6.6
2	20.1	65.2	23.1	10.2
3	28.6	85.8	38.9	11.3

Table 14. MET for worker 6

Tasks	**MET in minute**			
	Wrist	Elbow	Shoulder	Torso
1	17.2	51.1	18.6	11.3
2	23.7	65.2	18.6	12.5
3	28.6	117	136	12.5

Table 15. MET for worker 7

Tasks	**MET in minute**			
	Wrist	Elbow	Shoulder	Torso
1	10.3	33.8	8.3	6.1
2	13.1	33.8	11.1	7.1
3	28.6	65.2	8.3	7.1

The Torso muscle was the most critical and the elbow was the least critical based on the attained results for workers 3, 4, 5, and 7. Regardless of differences in results of workers 1, 2, and 6, it can be concluded that in this workstation the Torso muscle was the most critical muscle and the elbow was the least critical muscle.

Table 16 shows the optimal work time for all workers based on three tasks. According to the outcomes of Table 16, each worker can perform any of the specified tasks up to the upper bound of the specified time limit. If they work more than this duration, it leads to musculoskeletal disorders and at least one of the muscles involved in the work will be injured.

Table 16. Optimal work time of workers

Worker	**Optimal work time(min)**		
	Task1	Task2	Task3
1	(0-4.2)	(0-4.8)	(0-12.5)
2	(0-8.5)	(0-8.3)	(0-8.5)
3	(0-2.9)	(0-3.1)	(0-2.1)
4	(0-1.4)	(0-2.2)	(0-4.1)
5	(0-6.6)	(0-10.2)	(0-11.3)
6	(0-11.3)	(0-12.5)	(0-12.5)
7	(0-6.1)	(0-7.1)	(0-7.1)

Results of Table 16 showed that optimal work times for all workers were significantly different. Therefore, the rest times should be determined separately for all workers based on different tasks. Table 17 shows the rest allowances for all workers:

Table 17. Optimal rest allowances of workers

Worker	**Optimal rest allowance(min)**		
	Task1	Task2	Task3
1	(0-7.6)	(0-4.1)	(0-4.3)
2	(0-5.6)	(0-3)	(0-5.6)
3	(0-8.6)	(0-8.6)	(0-9.5)
4	(0-11.4)	(0-9.3)	(8.2)
5	(0-6.4)	(0-5.1)	(0-4.7)
6	(0-4.7)	(0-4.3)	(0-4.3)
7	(0-6.7)	(0-6.1)	(0-6.1)

The rest times could not be followed as planned due to unpredicted events or time limitations. Table 17 shows that workers 3 and 4 need more rest time than other workers. That is because of difference in anthropometric features where their weights was indicated relatively higher than other workers. Table 18 shows the result of variance analysis:

Table 18. Variance analysis

Source	DF	SS	MS	F	P
Task	2	8.76	4.38	4.68	0.03
Worker	6	76.4	12.7	13.6	0
Error	12	11.2	0.93		
Total	20	96.4			

Table 18 shows that the p-value was less than 0.05 for both sources (task and worker). Therefore, it can be concluded that both sources had a significant effect on rest times. The normal probability plots of residuals showed no outlier in the model (block design) adequacy checking (refer to Figure 6).

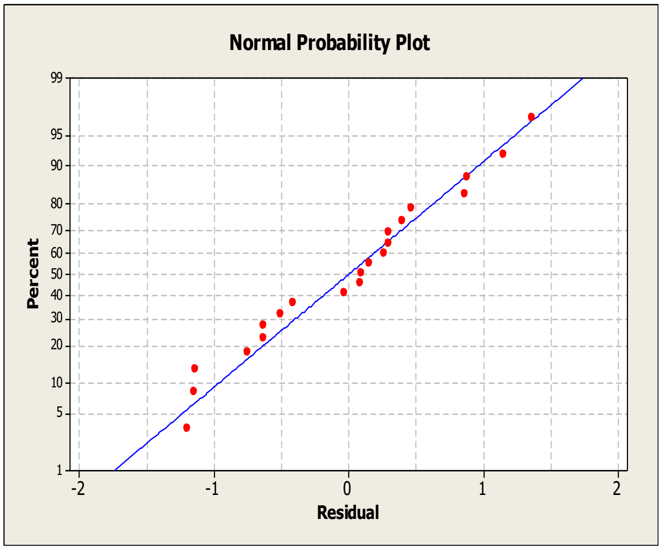

Fig 6. Normal probability plot

DISCUSSION

In the current study, we presented an easy-to-use approach to implement a pre-planned work-rest schedule. A separate work limit based on different tasks was calculated to decrease the risk of WMSD that happens due to muscle fatigue. This method considers workers’ anthropometric features and postures differences based on their level of skills and experience. The result of statistical analysis in Table 18 confirmed was in line with the impact of rest times both on task and worker’s performance. Therefore, a proper pre-planned rest time should be arranged considering all workers' anthropometric and tasks differences.

Table 17 shows enough rest time for all workers that they need to recover from muscle fatigue. However, it could not be implemented as planned in some cases. In this situation, the rest time could be decreased for the value of rest at different times. Rest value means how much muscle fatigue decrease during the rest time and it says that its value in the first quarter of rest time is about two-thirds of its total value [14]. So, whenever workers had no enough rest time, the first quarter of rest time can be considered.

CONCLUSION

The musculoskeletal disorders is one of the main causes of muscle fatigue. Other factors such as mental, social, and economic factors, may also contribute to fatigue, but in the current study, we used experiment, simulation design, and also statistical approach to evaluate muscle fatigue.

The results showed different maximum exertion times (MET) for those who were working in workstations. Moreover, statistical analysis showed a significant effect of the sources that for both of them (task and worker) p-value was than 0.05. Therefore, it is necessary to consider the situation of all workers in work-rest schedule design. In this regard, rest time should be planned based on the impact of tasks on muscle involved on that specific task. Optimally rest time design prevents muscles fatigues, maximum exertion time, and the risk of musculoskeletal disorders.

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