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Statistical Analysis of Human Body Parameters for Determining Optimal Work and Rest Cycle

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Abstract

It is a normal practice in industry to assign tasks to the workers not considering seriously the age, gender, height and other parameters of the workers. The rest breaks, overtime work, prolonged repetitive tasks are given to the workers which are not scientifically assessed depending on the worker's health condition. Due to these reasons, the workers may experience discomfort at the workplace leading to fatigue and at later stages, reduced efficiency. There are many research works available in the literature to provide occupational safety and health measures regarding this; one such measure is scheduling of rest breaks in between the work cycle to overcome fatigue. Not much work is carried out in the literature regarding scientifically scheduling the rest breaks in Indian industrial work environment. This paper focuses on identifying and analyzing the human body parameters that are important indicators to ensure that appropriate task is assigned to the worker based on his parameters. This work scientifically assesses the human body parameters of workers individually and suggests the basis for providing optimum rest breaks to the workers. For this purpose, workers working in various industries have been asked to participate in the treadmill test and stress profiles are obtained. Using these profiles, a mathematical model is developed to obtain optimal rest schedules by considering the human body parameters.

Keywords: *Fatigue, rest breaks, heart rate, VO_{2max}.*

1.0 Introduction

Over the years occupational safety and health had been the talk all over the world and is considered to be very significant factor as it deals with the welfare of people at workplace. Many researchers are working to find the factors that affect health issues due to workplace hazards (Van Dieen, 1988). Some studies also aim at providing adequate rest breaks in between the working window to overcome the fatigue accumulated due to work. This became one of the solutions to improve workplace safety and avoid occupational hazards/ accidents (Luz Elena Ariza1, 2005). This is the reason for many countries to reduce their annual working hours when compared to the past.

Rest breaks are short term leisure times given in between the work to overcome the fatigue accumulated; rest breaks are allotted differently for different jobs based on difficulty, age, gender, etc[7]. Allotting excess breaks may lead to idle time and sums up with inefficacy of the company where as allotting inadequate rest break leads to excessive accumulation of fatigue in worker. This may affect his health and in turn may lead to lesser productivity (Arlinghaus, 2012). This makes it necessary to find the optimum rest break to be allotted during the work schedule. Literature provides ample empirical data that proves the theory of rest-breaks. It also showed that break times sometimes resulted in increased creativity. This led the workers ideate different ways to work and to tackle the problems as the mind gets detached from work stress. However, rest breaks do not typically mean zero work[6]. During rest breaks, workers can

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engage themselves in small activities done by hand such as documenting the assembly carried out or making visual quality checks of the components produced or any other activity that involves less stress.

Extensive tiredness felt while performing tasks is known as fatigue. There are many factors that influence fatigue - improper sleeping pattern, highly repetitive works, carrying excessive loads, prolonged working in uncomfortable posture, etc[5]. If a person gets fatigued more often, then he may undergo serious health injuries such as cumulative trauma disorders, Musculoskeletal disorders, repetitive strain injuries broadly known as workplace injuries[1]. This may lead to frequent absenteeism in workers, reduced labour productivity and in the longer run, cognitive heath issues.

Frequent short breaks in work were proved to be effective to overcome fatigue by many researchers. To find the optimum rest times, there are many techniques that can be employed during research – such as questionnaire study of workers where workers are asked few questions regarding their discomfort level and self-assessing the work by themselves after various time trials. Another concept of dividing the workers in two groups and conducting an experiment on these workers to analyze their body parameters. Literature presents maximum heart rate, maximum volume of oxygen consumed (VO_{2max}), Resting Heart Rate (RHR) and Maximum heart rate (MHR) as some of the important body parameters that have to be considered for analysis[13]. RHR is the number of beats per minute by the heart during at rest normal resting of the person. This ranges between 60bpm-100bpm. MHR is the number of beats per minute of the heart while a person is working. The estimated value of MHR is directly related to the age of the person and is shown in Eq.1.

$$MHR = 220 - \text{Age (years)} \qquad \ldots 1$$

Recovery heart beat (HRR) is the number of heart beats dropped per minute after an extensive workout. The normal drop of heart beat for a healthy person should be between 15bpm-20bpm in first minutes and it increases later on as per the literature[12].

VO_{2max} is the maximum amount of oxygen consumed during an event of increasing intensity; it is expressed in litres per min (L/min) or millilitres of oxygen per kilogram of body mass per minute (mL/(Kg.min)) and is most commonly used by athletics[8]. It can be calculated using the formula given in Eq. 2.

$$VO_{2\max} \approx \frac{HR\max}{HR\text{rest}} \times 15.3mL/(kg.\text{min}) \qquad \ldots 2$$

The above-mentioned parameters are used to find the cardio-fitness of a person and these parameters depend upon age, gender, regular habits etc.

2.0 Problem Background and Objective

Literature review and interaction with some of the manufacturing industries where extensive physical work is involved revealed that the work is not uniformly distributed to the workers during their working hours[3]. Sometimes, due to unavailability of skilled labour, unskilled workers are assigned the tasks and this is done irrespective of the workers' age, gender, height, weight and other physiological considerations[11]. This not only reduces productivity but also leads to fatigue resulting in development of cumulative trauma disorder and musculoskeletal disorder[10]. The rest/ relaxation time allowed for each individual will be different based on the physiological parameters of the workers. Such allocation of work increases labour productivity and efficiency. This paper deals with the study of human body parameters to assess the optimum rest times.

The objectives of this study are:

- To identify and analyze the dependable factors that influence the work-rest cycle.
- To model the relationship between these factors
- To analyze the data collected from various respondents and determine the optimum work-rest cycle.

3.0 Methodology

Stress test is test often taken up by athletes to track their fitness. It is also employed by doctors to treat their patients having heart problems. Stress test is an increasing intensity exercise done either on treadmill or ergo-cycle with the speed of the equipment increasing gradually after specified time intervals[4]. Conduction of this test may be difficult without the presence of experts, as it involves running by the person until he reaches his maximum heart rate. While doing so, some people may get unconscious or start having pain in few parts of the body such as legs or heart[12]. Hence, presence of expert is required during the test. However, for laboratory purpose, trained personnel are sufficient to conduct this test.

The work involves identification of people who are willing to take part in this experiment; the experiment being the test on the treadmill. For this purpose, a questionnaire with key questions related to heart, blood pressure and other medical history is given to the participants and their details are collected. Once these details are collected, the participants are checked for any known health conditions and such people are allowed to participate in test. Only such participants who did not have any health problems were chosen to be part of this study. They were allowed to exercise on the treadmill which is the same equipment as used in multi-specialty hospitals. It is Dash 4000 display along with the treadmill. The experiments have been conducted following some of the predesigned protocols and all the data are recorded by Dash 4000. After the completion of the test, the participants are advised few minutes of rest overcome stress and data of the person is collected post-exercise too.

This paper involves data collection from the participants when they are subjected to stress test on the treadmill. This method is similar to the stresses developed in real life events[8]. Initially the medical history of the participants was collected along with their daily physical and work activities.

There were participants with blood pressure and diabetic background. They were regularly exercising to maintain their health. After collecting the details, the participants were explained about the rules and procedure of the test. Small practice sessions on walking on the treadmill were provided to the participants to make them feel comfortable on the treadmill. The participants were allowed for stress test after this. The test was conducted both in lab condition and in hospitals. Participants were from Bangalore and Kalaburgi cities of Karnataka state. Bangalore-based participants were asked to perform the stress test in the laboratory using Dash 4000 treadmill test set up. Three private hospitals were identified and permission was obtained to collect the stress test data of selected participants. In total, 318 participants underwent stress test and the output data was collected from the stress test machine into the spread sheet. Data has been arranged accordingly considering the variables – age, gender, height, weight, RHR, MHR, HRR and VO_{2max}.

The data is analysed using SPSS software. The variables considered for analysis are age, height and weight of the participants along with RHR, MHR and VO_{2max}. Table 1 shows the data collected (truncated) from the stress test.

The descriptive statistics of the data is obtained from the software and is presented in Table 2.

The variables are checked for correlation and verified for linearity. The correlation matrix is shown in Table 3.

From correlation matrix, the coefficient between MHR and age is –0.718; hence there exists a strong negative relationship. The coefficient of height, and weight is low; these variables are having low relationship.

The level of relationship between dependent variable and the developed model is explained by model summary. Age, weight and height are taken as independent variables over the MHR. R-squared is the square of correlation coefficient. It is known as coefficient of determination which attributes to explainable variation present in the data. The higher the value of R-squared, more is known about the data variability. Table 4 presents the model summary for the collected data. R-squared value is 0.952. This shows the model is adequate.

Analysis of Variance (ANOVA) is performed to determine the significance of the model. The results are presented in Table 5.

a. Dependent Variable: MHR

b. Predictors: (Constant), weight, age, height

Variations caused by the developed model are shown in regression row of Table 5. Here F statistic is applied and the p-value of 0.000 is obtained, which explains that model is significant. The 95% confidence interval for slope of the linear regression line is computed and presented in Table 6. From this table, the regression equation for MHR is given in Eq.3.

Table 2: Descriptive statistics of the data

Parameter	Min	Max	Mean	Std. deviation
Age	20	60	43.12	9.980
Height	148	190	165.18	7.869
Weight	18	176	70.24	14.734
RHR	53	115	79.72	12.771
MHR	146	199	170.04	10.404
VO_{2max}	23	53	33.67	6.786

Table 3: Correlation matrix

	MHR	Age	Height	Weight	
Pearson	MHR	1.000	-0.718	0.181	-0.086
Correlation	Age	-0.718	1.000	0.047	0.253
	Height	0.181	0.047	1.000	0.447
	Weight	-0.086	0.253	0.447	1.000
Sig.	MHR	-	0.000	0.001	0.063
(1-tailed)	Age	0.000	-	0.200	0.000
	Height	0.001	0.200	-	0.000
	Weight	0.063	0.000	0.000	-

Table 1: Stress test data

	Age	Gender	Height (cm)	weight (Kg)	RHR	MHR	HRR	$VO_{2\ max}$
1	30	M	170	73	61	187	122	46.90
2	27	M	170	66	70	199	149	43.50
3	29	M	172	69	62	193	128	47.63
: :								
318	30	F	167	77	58	197	147	51.97

$$Y = 192.032 - 0.787 (Age) \quad ... 3$$

The normal probability plot of regression standardized residuals is shown in Figure 1. It is observed that the residuals appear to generally follow straight line pattern.

4.0 Results and Discussion

Table 4: Model summary table

	Model Summary		
Model	R	R Square	Adjusted R Square
1	0.976	0.952	0.948

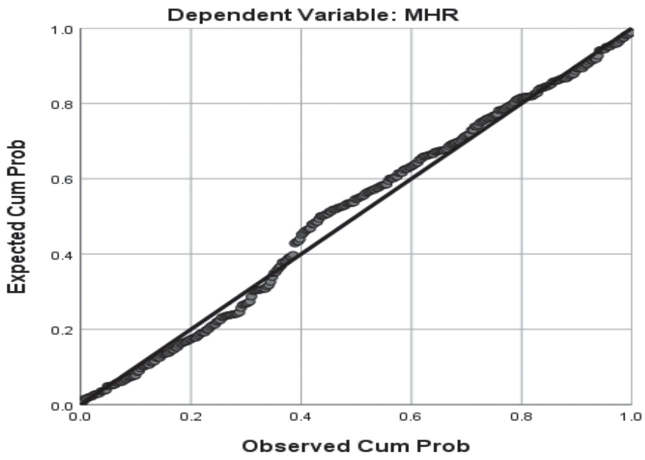

Figure 1: Normal probability plot of regression standardized residuals

Table 5: ANOVA table for the model. (n = 318)

	ANOVA[a]					
	Model	Sum of Squares	df	Mean square	F	Sig.
1	Regression	20145.982	4	5036.496	111.271	0.000[b]
	Residual	14167.401	313	45.263		
	Total	34313.384	317			

Table 6: Confidence interval and regression coefficients

Model	Unstandardized Coefficients		Standard-ized co-efficients	t	Sig.	95.0% Confidence Interval for B		Correlations		
	B	Std. Error	Beta			Lower bound	Upper bound	Zero-order	Partial	Part
(Constant)	192.032	11.796	-	16.279	.000	168.823	215.241	-	-	-
Age	-.787	.040	-.755	-19.805	.000	-.865	-.709	-.718	-.746	-.719
Height	.092	.069	.070	1.329	.185	-.044	.229	.181	.075	.048
Weight	-.010	.030	-.014	-.325	.745	-.068	.049	-.086	-.018	-.012

a. Dependent Variable: MHR

Table 7: Age and gender-wise grouped data of MHR, HRR and VO_{2max}

Age (years)	Gender	MHR in bpm		HRR in bpm		VO_{2max} in mL/kg/min	
		Min	Max	Min	Max	Min	Max
20-30	M	180	199	53	62	41.79	54.97
	F	170	190	48	56	37.16	52.85
31-40	M	170	189	51	58	33.31	44.67
	F	165	180	44	52	31.56	41.90
41-50	M	161	184	46	54	24.48	34.57
	F	153	178	38	42	22.62	31.42
51-60	M	154	169	38	43	21.46	30.08
	F	146	167	32	39	22.95	29.46

Multiple linear regression analysis was performed on the data to predict the MHR of the person based upon his age, height, and weight. This generic equation is given in Eq.4.

$$Y = a + (b1 \times X1) + (b2 \times X2) + (b2 \times X3) \quad \text{... 4}$$

Where y – MHR, the dependent variable

a – intercept.

$X1$, $X2$, $X3$ – independent variables age, height and weight of the person respectively

$b1$, $b2$, $b3$ – Un-standardized regression coefficients of independent variables.

The multiple linear regression equation for MHR is given by Eq. 5.

$$y = 192.032 - 0.787,\ b1 + 0.092,\ b2 - 0.01\ b3 \quad \text{... 5}$$

VO_{2max} plays a vital role in finding the fitness of the person; more the oxygen consumed by the person during the exercise the more amount of oxygen will be supplied to muscle to retain in the task for longer time.

The MHR, HRR and VO_{2max} as observed from the stress test are grouped by age and gender and are presented in Table 7.

Analysis of MHR, HRR and VO_{2max} from Table 7 along with the multiple linear regression in equation 7, shows that people between age group of 20-30 years have higher MHR, HRR and VO_{2max} when compared to other age group people. The ability to work for longer times without much rest breaks is more in this group of people. The mean value of workload measured in Metabolic Equivalent of Task (MET) for the participants was 7.44 MET. From this it is inferred that for any work that requires workload above 7 MET, a rest break of 5 minutes to be provided for every one-hour work cycle. Some of the physical activities that require more than 7 MET are carpentry, wood cutting, farm chores, digging, prolonged standing and pushing loads of more than 200kg[14].

5.0 Conclusion

This paper focused on determining optimal rest schedule to overcome the fatigue that was developed during work. For this purpose, stress test data was collected from 318 participants and the data was analyzed. Data regarding age, gender, height and weight of the participants were collected and stress test output in terms of MHR, HRR and VO_{2max} are analyzed. The grouped data of MHR, HRR and VO_{2max} based on age and gender are also analyzed. Regression model for MHR is developed and presented. The rest break depending on the type and amount of work carried out is determined and illustration about the same is also provided.

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