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# UPPER LIMB MUSCLE FATIGUE PREDICTION USING REGRESSION ANALYSIS: A CASE STUDY IN AUTOMOTIVE INDUSTRY IN MALAYSIA

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**Abstract.** A study was conducted to investigate the effect of task activities on biceps brachii and upper trapezius muscle response during repetitive tasks at tyre assembly in an automotive industry. The aim of the study is to determine time duration before fatigue occurs to both muscles and to compare the muscle activities during the repetitive process. Thirty electromyography (EMG) readings were taken from three selected samples at the tyre lifting assembly line. Readings were taken in the whole duration of two hours and thirty minutes per sample activities. The results indicated that similar root-mean-square (RMS) values of voltage patterns were obtained for the three samples and show that time duration before fatigue occurs to muscles on a particular task could be predicted.

*Keywords:* Muscle fatigue; regression analysis; electromyography; tyre assembly

**Abstrak.** Kajian ini dijalankan untuk mengenal pasti aktiviti tugasan terhadap biceps brachii dan tindak balas otot atas trapezius semasa tugasan berulang semasa melakukan pemasangan tayar dalam industri automotif. Matlamat ini adalah untuk mengenal pasti jangka masa untuk kelesuan bagi kedua-dua otot dan seterusnya membuat perbandingan dengan aktiviti otot semasa proses tugasan yang berulang dilakukan. Sebanyak 30 bacaan electromiografi (EMG) diambil daripada tiga sampel yang dipilih di bahagian pemasangan mengangkat tayar. Bacaan diambil dalam tempoh dua jam tiga puluh minit untuk setiap sampel. Keputusan mendapati bahawa nilai *root mean square* (RMS) voltan bagi ketiga-tiga sampel adalah sama. Daripada kajian ini, dapat disimpulkan bahawa masa untuk kelesuan bagi otot untuk tugasan tertentu boleh diramalkan.

*Kata kunci:* Kelesuan otot; analisis regresi; elektromiografi; pemasangan tayar

## 1.0 INTRODUCTION

The major physical function of muscles is to exert force [1]. The magnitude of the force that physical human muscle could produce had been reported as being proportional to the product of the size and the number of muscle fibers within the muscle. This relationship, between muscle cross sectional area and tension, is dubious because little increased in the size of a muscle is often found following a physical training

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program that result in as much as 100 percent increase in strength [2]. When a muscle contraction is sustained, muscle becomes fatigued, and force production is affected by underlying fatigue and recovery effects in the neuromuscular system [3–6].

Muscle fatigue was defined by S. Marthur *et al.* [7] as a reduction in the force generating capacity of a muscle due to muscular activities. In the context of ergonomics and work physiology, muscle fatigue is defined as any exercise-induced reduction in the maximal capacity to generate force or power [8]. Several other definitions suggested fatigue occurs when there are changes in EMG readings, or changes in perceived effort level for a given force level [9–11].

The presence of work-related musculoskeletal disorders (MSDs) including disorders or injuries of the back, trunk, upper extremities and lower extremities in automotive industrial employees is commonly recognized and seems to grow rather rapidly [12]. Since most manual work requires the active use of the arms and hands, the structures of the upper extremity are particularly vulnerable to soft tissue injury. Work related upper extremity disorders are typically associated with repetitive manual tasks with forceful exertions, such as those performed at assembly lines. Repetitive manual tasks impose repeated stresses to the upper body, i.e. the muscles, tendons, ligaments, nerves tissues and neurovascular structures.

Jobs that require a worker to perform highly repetitive motion contribute to the onset of Cumulative Trauma Disorder (CTD) [13]. Specifically, the more repetitive the task, the more rapid and frequent are the muscle contraction. Muscles contract at high velocity develop less tension than contracting at a slower velocity for the same load. Carpal Tunnel Syndrome appears to be induced more by the repetitiveness of the task than by the force level [14]. Another research done by Loupajarni (1979) on repetitions revealed that the prevalence of tenosynovitis and humeral tendonitis is significantly higher for workers in assembly work [15]. In general, repetitive task in modern industries has been proved debilitating to many millions of workers.

In summary, repetitive task in modern industry has proven to be one of the factors that could cause musculoskeletal disorder among workers. Thus, the aim of the study is to investigate the time duration before fatigue occurs for the biceps brachii and trapezius muscle during repetitive tasks at a tyre assembly. This study could be beneficial to industrial engineers or ergonomists whose tasks might involve designing the job with reference to human capabilities and limitations.

Hypothesis development:

Hypothesis 1:

$H_o$ : There is no linear relationship between trapezius and time
$H_1$ : There is a linear relationship between trapezius and time

Hypothesis 2:

$H_o$ : There is no linear relationship between biceps brachii and time
$H_1$ : There is a linear relationship between biceps brachii and time

## 2.0 METHODOLOGY

The current methodology used electromyography to obtain data from samples based on specific procedures and were analysed using the regression analysis. Electromyography is the discipline that deals with the detection, analysis and use of the electrical signal of muscles that is affected by its anatomical and physiological properties and the control scheme of the nervous system [16]. Currently there are three common applications of the EMG signal [17]. The first to determine the activation timing of muscles, the second is to estimate the force produced by the muscles and to obtain an index for the rate at which a muscle become fatigue. EMG manifestations of muscle fatigue are a continuous process that begin at the onset of activity and may be detected much earlier than the time of mechanical inability to sustain the contractions [18]. Electromyographic analysis has been proposed as one method evaluating this kind of fatigue [19–20] as there are changes in the action potential conducted velocities, an increase in amplitude of surface EMG and a shift to lower frequency of power density a spectrum as a muscle fatigue [21].

### 2.1 Sample

In this study, samples were taken from the tyre assembly line that involved three male workers between the ages of 25–35 years who had no history of upper extremity complaints or other musculoskeletal problems.

### 2.2 Procedures

EMG surface electrodes were used to measure biceps brachii and trapezius muscles activities and were selected because they are the primary muscles used in repetitive task at the tyre assembly. Ten measurements were taken for each sample within two and a half hour job duration. Electromyography readings were obtained using DataLab 2000 System.

### 2.3 Statistical Analysis

Regression analysis was carried out to examine the relationship between a dependent variable (time) to independent variable using the general linear regression equations.

$$Y = \beta_0 + \beta_1 x + \in \quad (1)$$

The $\beta_0$ and $\beta_1$ are parameters (constant), usually unknown and need to be estimated, whereas $\in$ measures the error/residual which explains the random variation in response, or provides inexplicable clarification by the model.

## 3. 0 RESULTS AND DISCUSSIONS

### 3.1 Experimental Results

Figure 1, 2, and 3 show the RMS versus time for the three samples. The results indicated that the RMS measurements decrease with the time mainly reflected the fatigue pattern for the task under study. It could be seen that the rate of fatigue obtained for an individual sample varied and these could be the consequence of a change in muscle temperature [22] and the differences in fibre types or the differences in muscle fibre recruitment pattern [23–24].

The results also indicated that RMS decay overtime during sustained contraction. It showed that the time duration before fatigue occurred for both muscles decreased rapidly in an exponential pattern. This suggests that lifting activities directly exerted force on biceps brachii and trapezius muscles.

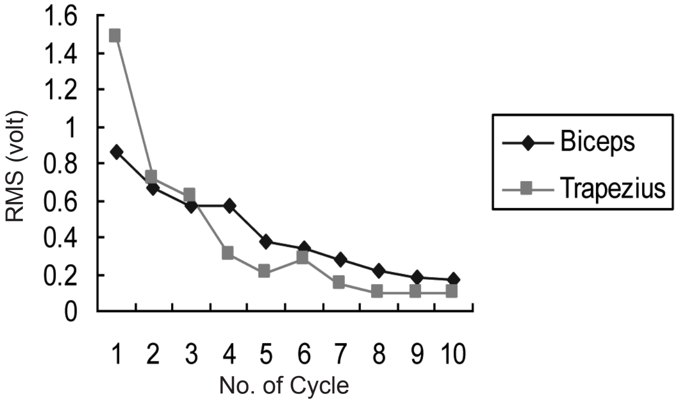

**Figure 1** RMS value for Sample 1

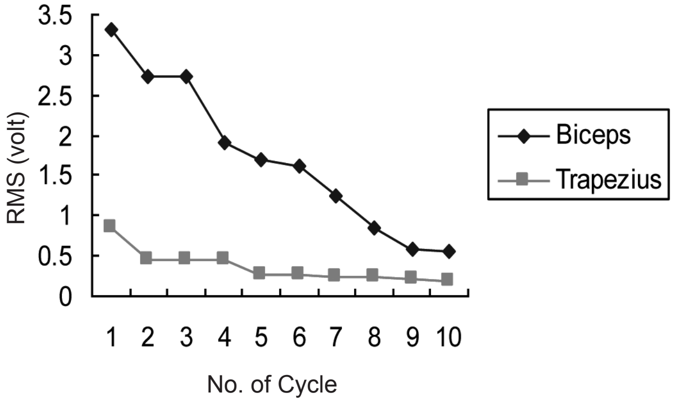

**Figure 2** RMS value for Sample 2

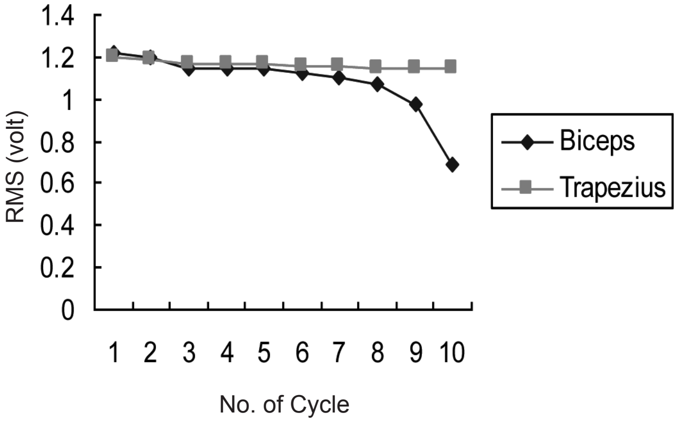

**Figure 3** RMS value for Sample 3

## 3.2 Regression Analysis

### *3.2.1 Regression Analysis on Trapezius Muscle (R= Correlation Coefficient)*

The time duration before fatigue occured were different for each muscles and therefore it could not be defined arbitrarily. It could be determined through an analysis of the correlation coefficient for successive time points (values of EMG parameters) and the regression function [25].

**Table 1** Model summary of trapezius muscles

| Model | R | R Square | Adjusted R Square | Std. Error of the Estimate |
|---|---|---|---|---|
| 1 | 0.858(a) | 0.736 | 0.706 | 0.238127960 |

a Predictors: (Constant), TIME

Table 1 summarized the regression analysis model of trapezius muscle for the three samples. The regression analysis R represents the absolute value of the correlations coefficient and shows how well the model fits into a set of data where a Pearson correlation is used. In summary, R in the model represents the absolute value of the correlation coefficient, while R square explains the variability by squaring the correlations coefficient between the dependent variable, RMS and independent variable with time (R = 0.858 ). Adjusted R square is an estimation of how well the model would fit into another data set from the same population. The adjusted R square is the preferred value as it is more accurate than R. From Table 1, the observed value is 0.706 which means that 70.6% variation in trapezius is contributed by the independent variables, time. Hence, 70.6% of the regression model can be explained by the changing of the true model. Adjusted R square large (≥ 0.7) indicates that the model is more reliable and adequate to describe the relationship. Table 2 shows ANOVA result of trapezius muscle.

**Table 2** ANOVA table of trapezius muscle

| Model | | Sum of Squares | df | Mean Square | F | Significant |
|---|---|---|---|---|---|---|
| 1 | Regression | 1.266 | 1 | 1.266 | 22.32 | .001 |
| | Residual | .454 | 8 | .057 | | |
| | Total | 1.719 | 9 | | | |

ANOVA table is used to test several equivalent null hypotheses; that there is no linear relationship in the population between the dependent variable and the independent variables. The table explains the estimation of variability that can be used to test the null hypothesis. For example in this study, the null hypothesis is that there is no linear relationship between RMS of trapezius muscle and time. If the null hypothesis is true, the ratio between RMS of trapezius and time mean square is close to 1. Large values of the F ratio indicate that the sample means vary more than we expect if the null hypothesis were true. Table 2 shows that the ratio of the two means square, labelled F is 22.32. Since the value is larger than 1, the null hypothesis can be rejected, and thus there is a linear relationship between trapezius and time. Table 3 shows the coefficients (unstandardized and standardized) of trapezius muscle.

**Table 3** Coefficients of trapezius muscle

| **Model** | | **Unstandardized Coefficients** | | **Standardized Coefficients** | **t** | **Significant** |
|---|---|---|---|---|---|---|
| | | **B** | **Std. Error** | **Beta** | | |
| 1 | (Constant) | 5.985 | 1.184 | | 5.055 | .001 |
| | TIME | –.478 | .101 | –.858 | –4.724 | .001 |

The coefficients for the independent variables are listed in column B in Table 3. A negative coefficient means that the predicted value of the dependant variable decreases when the value of the independent variable increases.

The model equation for trapezius is:

$$Y = 5.985 - 0.478x \tag{2}$$

The Y in equation (2) is the predicted muscle fatigue for trapezius muscle and $x$ is the time. The time taken for each cycle in the second job rotation was substituted in Equation (2) to predict the time-to-fatigue in this job rotation. Table 4 and Figure 4 show the predicted value of RMS after substituting the time taken in the second job rotation for the population under investigation.

The predicted RMS values decrease as time increases. Thus, we can conclude that muscle has a negative relationship with time and this is in line with the original finding.

### *3.2.2 Regression Analysis on Biceps Brachii Muscle*

Table 5 shows value of 0.974 for R indicates that 97.4% variation in biceps brachii is contributed by the independent variables. Hence, 97.4% of the regression model can be explained by the changing of the true model. Adjusted R square is large (≥ 0.7) indicated the model is reliable and adequate to describe the relationship.

**Table 4** Predicted RMS for trapezius muscle

| No. of cycles | Time EMG data taken in 2nd job rotation (min) | Predicted Trapezius RMS (volt) |
|---|---|---|
| 1 | 15 | −1.185 |
| 2 | 25 | −5.965 |
| 3 | 45 | −15.525 |
| 4 | 65 | −25.085 |
| 5 | 85 | −34.645 |
| 6 | 105 | −44.205 |
| 7 | 115 | −48.985 |
| 8 | 125 | −53.765 |
| 9 | 135 | −58.545 |
| 10 | 145 | −63.325 |

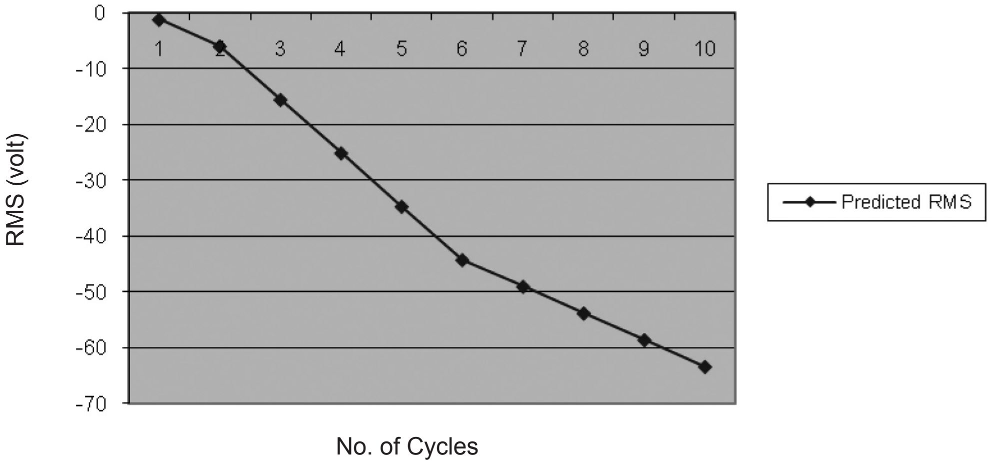

**Figure 4** Predicted RMS for trapezius muscle

**Table 5** Model summary of bicep brachii muscles

| Model | R | R Square | Adjusted R Square | Std. Error of the Estimate |
|---|---|---|---|---|
| 1 | .974(a) | .948 | .942 | .056256051 |

a Predictors: (Constant), TIME

Table 6 indicates that F value is 142.286, which is larger than 1. Therefore we can reject the null hypothesis and there is a linear relationship between biceps brachii and time. The coefficients for the independent variables are listed in column B. A negative coefficient means that the predicted value of the dependant variable decreases when the value the independent variable increases.

**Table 6** ANOVA table of bicep brachii muscle

| Model | | Sum of Squares | df | Mean Square | F | Significant |
|---|---|---|---|---|---|---|
| 1 | Regression | .466 | 1 | .466 | 142.286 | .000(a) |
| | Residual | .025 | 8 | .003 | | |
| | Total | .491 | 9 | | | |

**Table 7** Coefficients of bicep brachii muscle

| Model | | Unstandardized Coefficients | | Standardized Coefficients | t | Significant |
|---|---|---|---|---|---|---|
| | | B | Std. Error | Beta | | |
| 1 | (Constant) | 3.809 | 0.28 | | 13.619 | 0 |
| | TIME | –0.29 | 0.024 | –0.974 | –12.136 | 0 |

The model equation for Biceps Brachii muscle is:

$$Y = 3.809 - 0.290x \tag{3}$$

The Y is the predicted muscle fatigue for biceps brachii muscle and $x$ is the time. The time taken in the second job rotation is substituted in Equation (3) in order to predict the time-to-fatigue of biceps brachii muscle. Table 8 and Figure 5 show the predicted value of RMS after substituting the time taken in the second job rotation.

This indicates that the RMS value decreases gradually as time increases. Thus, we can conclude that the muscle has a negative relationship with time.

**Table 8** Predicted RMS for biceps brachii muscle

| No. of cycles | Time EMG data taken in 2nd job rotation | Predicted Biceps Brachii RMS (volt) |
|---|---|---|
| 1 | 15 | –0.541 |
| 2 | 25 | –3.441 |
| 3 | 45 | –9.241 |
| 4 | 65 | –15.041 |
| 5 | 85 | –20.841 |
| 6 | 105 | –26.641 |
| 7 | 115 | –29.541 |
| 8 | 125 | –32.441 |
| 9 | 135 | –35.341 |
| 10 | 145 | –38.241 |

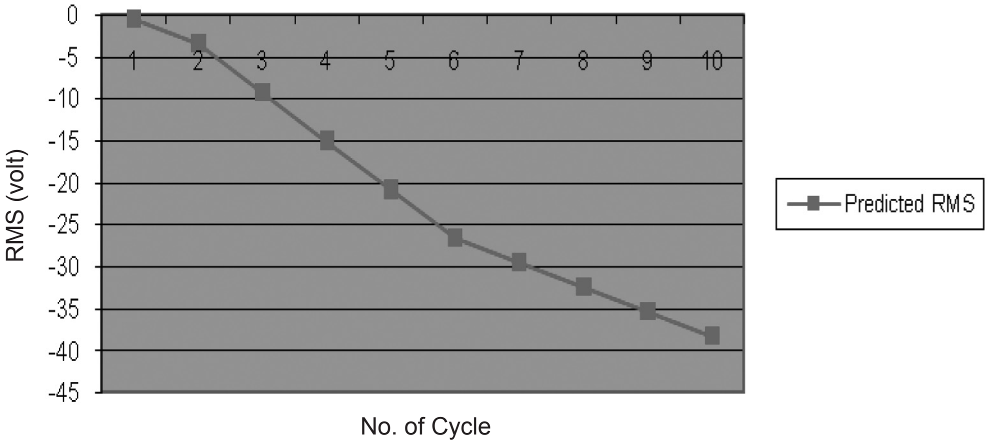

**Figure 5** Predicted RMS for bicpes brachii muscle

It could be established that the gradient of muscle fatigue for biceps brachii muscle are steeper (–3.8 volt/minute) than trapezius muscle (–2.3 volt/minute) for the first sixth cycle in the second job rotation. The same pattern obtained for cycle 6 to cycle 10 with gradient of –3 volt/minute for biceps brachii muscle and –2 volt/minute for trapezius muscle. The result also indicated that both muscles decreased in their performance rapidly during the first sixth cycle and decreased gradually after sixth cycle (after 105 minutes).

The fatigue finding is in line with the statement of Esposito *et al.* (1996). Nagata *et al.* (1990) and Silverstein *et al.* (1986) [9–11] who stated that fatigue occurred when there were changes in EMG reading or changes in perceived effort level for a given force level. Therefore referring to the above statement, the finding indicated that biceps brachii and trapezius muscle could experience fatigue after 105 minutes of tyre lifting.

## 4.0 CONCLUSION

In conclusion, this investigation has shown that time to reach fatigue for biceps brachii and trapezius muscles in tyre lifting can be analyzed and predicted. Further study could be conducted to determine the validity of the model with increased samples and also comparing the behaviour and activities of other upper limb muscle using the regression model developed. The results showed that after cycle 6 (105 minutes) the RMS value decreased constantly for both muscle (biceps brachii and trapezius).

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