ORIGINAL ARTICLE

DEVELOPMENT OF A REGRESSION MODEL FOR RELATIONSHIP BETWEEN PSYCHOPHYSICAL AND BIOMECHANICS FACTORS OF PUSH ACTIVITIES

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ABSTRACT

In aerospace industries, many working tasks require their workers to perform the works in push-pull activities. The workers need to push or pull the mould tool in a long distance in to a workplace. Performing these activities continuously throughout the working hours, may lead to an early initiation of musculoskeletal disorders (MSDs) symptoms as workers developed muscle fatigue particularly concerning the hand muscles. Grip strength is the force applied by the hand to pull objects and is a part of hand strength. Repetitive usage of hands will create an imbalance between closing and opening (antagonist) muscles, which can lead to problem such as carpal tunnel syndrome (CTS). The primary purpose of this study was to develop a regression model based on psychophysical and biomechanical factors that contributes to fatigue, in which the models can predict the relationship between the input parameters and output responses. The methodology used for this study focused on three types of data collection which were questionnaire and observation which conducted as the preliminary study to prove the problems that have been stated and experimental was conducted by using surface Electromyography (sEMG) and Tekscan system to evaluate the muscle fatigue and hand grip pressure force of the Lay-up workers who were performing push activity. This study investigates the hand grip pressure force for the right hand and left hand within 5 minutes and 10 minutes of time exposure while workers pushing the mould tool, and study the relationship between time exposure with hand grip pressure force and muscle fatigue. The input parameters evaluated were time exposure, hand side and body mass index (BMI); while the output responses are muscle fatigue (voltage), hand grip pressure force (left hand), and hand grip pressure force (right hand). Two polynomial equations were successfully developed and validated. The modelling validation runs were within 90% prediction interval of the developed models and their residual errors compared to the predicted values were less than 10%. The significant parameters that influenced the output responses were also identified. Muscle fatigue was influenced by time exposure, hand side, BMI, and interaction between hand side and BMI; while hand grip pressure force was influenced by time exposure, hand side, BMI, interaction between time exposure and hand side, interaction between time exposure and BMI, and interaction between hand side and BMI

Keywords: *MSDs, CTS, sEMG, Grip strength, Psychophysical, Biomechanical*

INTRODUCTION

In the manufacturing industry, many tasks involving manual material handling processes such as lifting heavy products, reaching materials, pushing or pulling excessive loads and bending forward of back part of body when doing tasks due to those tasks require a large degree of freedom and stable position. Pushing and pulling activities are one of the activities for manual material handling that can increase the risks of back pain problems and discomfort in the hands (Kuijer et al., 2007). The pushing and pulling activities are the continuous activity for a large segment of the workforce, including hospital workers, manufacturing workers, construction workers, or even forest workers (Jellad et al., 2013).

The pushing and pulling activities that take place by the workers on the other hand can contribute to discomfort and pain of hands especially in the arms and wrists area. This is due to the requirement of the activity that need the workers to grip the objects or products by using the hands, such that the workers applying pressures and forces to those objects for movement.

Muscle fatigue, it seems, can refer to a motor deficit, a perception or a decline in mental function, it can describe the gradual decrease in the force capacity of the muscle or the endpoint of a sustained activity, and it can be measured as a reduction in muscle force, a change in electromyography activity or an exhaustion of contractile function. Such broad usage is problematic, however, because fatigue in this context can encompass several phenomena that are each the consequence of different physiological mechanisms, which reduces the likelihood that the cause of muscle fatigue can be identified. To avoid this limitation, most investigators appeal a more focused definition of a muscle fatigue as an exercise-induced reduction in the ability of muscle to produce force or power, whether or not the task can be sustained (Bigland-Ritchie et al., 1986; Søgaard et al., 2006).

The hand force is considered either as the grip force or the press force. The grip force Fg is a clamp-like force exerted by the hand when enclosing a handle, which is compensated within the hand by a gripping motion acting in the opposite direction towards a dividing plane as shown in Figure 1. The press force Fp is the force exerted by the hand away from the operator's arm towards the work surface area, which is not compensated within the contacting surface of the hands.

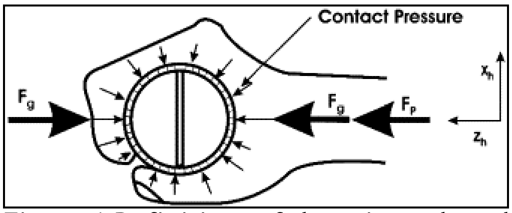

Figure 1 Definitions of the grip push and contact forces (Welcome et al., 2004).

Nevill and Holder (2000) investigated the relationships between handgrip strength and individual factors such as age and body size. The studies found that the most appropriate body size component affecting the grip strength was stature. Correlations of grip strength with age and body weight were also discovered. Handgrip strength increased with body weight until it reached peak value at a body weight of approximately 90 kilograms (kg) for female and 100 kg for male subjects.

In aerospace industry, almost all the jobs are performed in standing position and this can lead to muscle fatigue. At XYZ Sdn Bhd, a main manufacturing process is coming from lay-up process line where the operators are performing the task manually. This lines required workers to perform pushing and pulling activity in awkward posture for period of time. All workers worked on a 8 hours shift schedule. The shift is changed every week which is worked both; day and night shift. It was observed that the workers spent about 80% of the working hours in awkward posture to do their tasks (only neutral standing during setup ply and sitting during breaks) throughout the 8 hours working period. This is due to the activities that required the workers to push the panel every 45 minutes with awkward posture from furnace (Autoclave) to workplace (Clean Room). For instance, workers also need to push the panel in the workplace (Clean Room) before the panel is fixing to the floor. Thus, the process would be practicable in awkward posture as it requires frequent bending forward of the workers back.

Furthermore, there are complaints of intense pain in those body parts from the workers of lay-up process lines which are spine, shoulder, hand arm, wrist, and fingers. When such activities require handgrip force to move the objects, it may contribute to one of the significant effects which is known as Carpal Tunnel Syndrome (CTS) (Dun et al., 2007). The operators are also tend to experience muscle fatigue while performing the jobs that may take to serious injuries known as Musculoskeletal Disorders (MSDs). MSDs are often caused by awkward postures, excessive force and repetition due to limited work area, standing for prolonged period of time and heavy equipment (Lei et al., 2005). The top management of XYZ Sdn Bhd is worried about the declining health quality of the operators which can affect their productivity and hence decreases the efficiency of the manufacturing operations.

Thus, this research is proposed to investigate the ergonomic factors and psychophysical experience that contribute to worker's fatigue and discomfort experience in the aerospace industry while performing the jobs involving push activities, analyze the biomechanical factors for worker's fatigue through and actual experiment felt and to develop and validate the regression model using ergonomic approach in studying the relationship of the worker's fatigue and hand grip pressure force.

METHODS

Participants

A total of six production workers from the lay-up department of an aerospace company are recruited as subjects in the study. The workers are selected from the push and pull section that always occupied with a back pain injuries. Moreover, this section is the most important section for the company because 80% of the company's profit comes from this section. To fulfil the basic requirement of this study, only workers who performed processes jobs in awkward posture and get involved in the push and pull activities are allowed to participate in the study.

Instrumentations

The surface Electromyography (sEMG ME3000P4, MEGA Electronics, Finland) and MegaWin Software were used to record, store and analyze all the data regarding the muscle activity of the subjects. The sEMG system is equipped with electrodes to detect the myoelectric signal of a subjects' muscle while performing jobs in awkward postures. The electrodes are attached conscientiously to the subject's skin to measure the activity in the six muscles: left and right thoracolumbar fascia, left and right middle trapezius, and left and right triceps. In the measurement and analysis of awkward working posture, the selected muscle is chosen based on the statistical data analysis from a questionnaire that has been answered from 20 workers before the experimental work is made. The selected muscle is also suggested by the established guidelines (HHS, 1992) and recent review article (Reid et al., 2010). The setting of sEMG system during the measurement is based on surface EMG for the Non-Invasive Assessment of Muscles (SENIAM) (Stegeman and Hermens, 2007).

Tekscan's Grip Pressure Measurement System is a device used to measure and evaluate the static and dynamic pressure in gripping and grasping objects. Tekscan's patented, paper-thin (0.1mm), flexible sensors are minimally intrusive and have fast scanning rates. This enables difficult gripping applications such as vibrations and transients from power tools can be easily measured. This grip sensor can be used on hand or built-in with glove and can instrument both left and right hands. Figure 2 shows the Tekscan's grip pressure measurement system used during this study.

Figure 2 Tekscan tactile grip force and pressure measurement (Grip system).

Data Analysis
In developing and formulating regression model, Design Expert 8.0.6 software was used and Response Surface Methodology (RSM) data analysis was carried out through this study. Montgomery (2008), stated RSM includes a collection of mathematical and statistical techniques that can be used for modelling and optimizing of processes. Several steps has been followed in order to analyze the data collected (Vaughn & Polnaszek, 2007). The output responses data for each experimental run were entered into the respective run number matrix. The software recognizes which model chooses for further analysis. The identification and selection is based on the sequential sum of square. This analysis compares the models by showing the statistical significance of adding model terms to those already in the model. The highest degree model that has a p-value less than 0.10 should be chosen as the model to represent the model. Then, the selected model was analyzed using ANOVA where the significant of the model, significant parameters, and interaction factors were determined. The Prob>F value is small or less than 0.1 indicates that the model or factors has a significant effect on the output response. Finally, the final equation of the model was generated through the analysis. This final equation of the model then been validated by using quantitative validations to analyzed the results. This validation runs should meets the following two conditions:

1. To determine if the model can predict the validation run outcome based on specific output parameters within 90% of its predictive interval
2. The accuracy of a process model can be assessed using residual error method with respect to the validation run (Baluch, Abdullah & Mokhtar, 2010). The residual error was calculated based on the percentage difference between the validation run value and predicted value over the predicted value. This percentage value should be less than 10% to represent the accuracy of the model.

RESULTS AND DISCUSSION

Through this study, psychophysical factor (muscle fatigue) and biomechanical factor (hand grip pressure force), has been proven as a factors lead to driver fatigue among the Malaysian. Hence, this study will developed the regression model based on these factors as to solve the driver fatigue problems. This section will discussed the development, formulating and validation of the regression modeling through RSM data analysis.

Regression Modeling of Muscle Fatigue
All the data of the measurement of muscle fatigue, μV are recorded. Table 1 shows the data for the muscle fatigue. This data is used in developing and formulating the mathematical modeling.

Table 1 Experimental run and results of muscle fatigue (μV)

Run	Factor 1	Factor 2	Factor 3	Response 1
	A:Time Exposure (min)	B:Hand side	C:BMI (kg/m²)	Muscle Fatigue (μV)
1	5.00	Right	Underweight	173.58
2	10.00	Left	Normal	534.16
3	5.00	Right	Normal	272.08
4	10.00	Right	Underweight	205.28
5	5.00	Left	Normal	516.84
6	5.00	Right	Overweight	743.15
7	10.00	Left	Normal	573.93
8	10.00	Right	Normal	303.41
9	10.00	Right	Overweight	886.48
10	5.00	Left	Overweight	868.21
11	5.00	Left	Overweight	893.13
12	5.00	Left	Normal	524.59
13	5.00	Left	Underweight	362.12
14	5.00	Right	Normal	289.49
15	10.00	Right	Overweight	852.04
16	5.00	Right	Overweight	778.63
17	10.00	Right	Normal	324.63
18	5.00	Left	Underweight	378.29
19	10.00	Left	Overweight	902.14
20	10.00	Left	Overweight	935.25
21	10.00	Left	Underweight	436.72
22	10.00	Left	Underweight	497.43
23	5.00	Right	Underweight	184.37
24	10.00	Right	Underweight	234.83

Twenty-four (24) experimental runs are carried out as reflected in Table 1. The muscle fatigue or the sEMG signal amplitude (voltage) of the workers while pushing activity for each experimental run is analyzed using an EMG tool. In this experiment, three factors and one response are studied; time exposure, hand side, and body mass index (BMI). Meanwhile, muscle fatigue is the response of this experiment. This study is used the historical data as the design type because this study focused on finding the main effect and developed the model relationship between all of the factors involved. The muscle fatigue measurements that had been collected per subject were used as the output response for the process.

Determination of Appropriate Polynomial Equation to Represent Regression Model

Sum of squares sequential model (SMSS) and lack of fit test are carried out to determine the appropriate polynomial equations to show the relationships between the input parameters (factors) and output response (muscle fatigue). Table 2 represents the SMSS analysis, while Table 3 shows the lack of fit test for the model. These two analyses suggested the relationship between factors and response can be modelled using 2FI (factor of interaction).

Table 2 Sequential model sum of squares (SMSS) analysis for muscle fatigue model

Sequential Model Sum of Squares [Type 1]						
Source	Sum of Squares	df	Mean Square	F	p-value	
				Value	Prob > F	
Mean vs Total	6.690E+006	1	6.690E+006			
Linear vs Mean	1.567E+006	4	3.917E+005	185.38	< 0.0001	
2FI vs Linear	30404.59	5	6080.92	8.74	0.0006	Suggested
Quadratic vs 2FI	0.000	0				Aliased
Residual	9742.69	14	695.91			
Total	8.296E+006	24	3.457E+005			

Table 3 Lack of fit test for the muscle fatigue model

Source	Sum of Squares	df	Mean Square	F Value	p-value Prob > F	
Linear	34400.22	7	4914.32	10.26	0.0003	
2FI	3995.63	2	1997.81	4.17	0.0421	Suggested
Quadratic	3995.63	2	1997.81	4.17	0.0421	Aliased
Pure Error	5747.07	12	478.92			

ANOVA for Response Surface 2FI Model

Table 4 shows the ANOVA analysis for the 2FI model. The "Model F-value" of 255.02 implies that the model is significant. There is only a 0.01% chance that a "Model F-value" this large could occur due to noise. This implies that the model represents the data within the required 90% confidence interval. Values of "Prob > F" less than 0.1000 indicates model terms are significant. Values greater than 0.1000 indicate the model terms are not significant. In this case, time exposure, hand side, BMI, and interaction between hand side and BMI, are the significant influencing factors of the resultant muscle fatigue.

Table 4 ANOVA analysis of the 2FI model for muscle fatigue

ANOVA for Response Surface 2FI Model						
Source	Sum of Squares	df	Mean Square	F Value	p-value Prob > F	
Model	1.597E+006	9	1.775E+005	255.02	< 0.0001	significant
A-Time Exposure	20522.97	1	20522.97	29.49	< 0.0001	
B-Hand side	1.971E+005	1	1.971E+005	283.20	< 0.0001	
C-BMI	1.349E+006	2	6.746E+005	969.39	< 0.0001	
AB	34.85	1	34.85	0.050	0.8262	
AC	1923.33	2	961.66	1.38	0.2833	
BC	28446.41	2	14223.21	20.44	< 0.0001	
Residual	9742.69	14	695.91			
Lack of Fit	3995.63	2	1997.81	4.17	0.0421	significant
Pure Error	5747.07	12	478.92			

Polynomial Equation for Muscle Fatigue

From the surface response modelling, the 2FI polynomial equation developed to relate the input parameters to the muscle fatigue is shown in Table 5 for equation in terms of actual factors. The equation in terms of actual factors can be used to make predictions about the response for given levels of each factor. Here, the levels should be specified in the original units for each factor.

Table 5 Polynomial equation for muscle fatigue model

Hand side	**Left**
BMI	Underweight
Muscle Fatigue = +318.79250 + 13.31300 * Time Exposure	
Hand side	Left
BMI	Normal
Muscle Fatigue = +491.07125 + 6.17450 * Time Exposure	
Hand side	Left
BMI	Overweight
Muscle Fatigue = +793.50125 + 14.15750 * Time Exposure	
Hand side	Right
BMI	Underweight
Muscle Fatigue = +92.43750 + 14.27700 * Time Exposure	
Hand side	Right
BMI	Normal
Muscle Fatigue = +243.86375 + 7.13850 * Time Exposure	
Hand side	Right
BMI	Overweight
Muscle Fatigue = +701.66375 + 15.12150 * Time Exposure	

Regression Model Validation

At the final stage of the analysis, the regression model validation activity is carried out to quantify the accuracy of the model through comparisons of experimental data with the prediction of the model (final equation) (Oosterveer, 2015). Table 6 shows the validation results of the three sets of parameter settings. The results show that the validation data fall within the 90% prediction interval. Besides, the residual errors of these three validation runs are ranging from 0.064% to 6.030%. Hence, this model is accurate enough to predict the resultant muscle fatigue as the residual error values are less than 10%.

Table 6 Validation data of muscle fatigue model

Input Parameters			Prediction (μV)	90% PI Low (μV)	90% PI Hi (μV)	Actual (μV)	Error (%)
Time Exposure	**Hand Side**	**BMI**					
5.00	Left	Underweight	385.358	330.055	440.66	362.12	6.030
7.50	Left	Underweight	418.64	395.408	366.692	418.91	0.064
10.00	Right	Overweight	852.879	797.576	908.181	886.48	3.940

Regression Modeling of Hand Grip Pressure Force

All of the data of the measurement of hand grip pressure force of the subjects are recorded in the Table 7. The table is crucial to assist in formulating the mathematical modelling of the hand grip pressure force. (24) experimental runs are carried out as listed in table The hand grip pressure force of the both hands for each experimental run is analyzed by using Tekscan tactile force and pressure measurement (grip system). Three factors are studied as the input parameters, which are time exposure, hand side, and BMI, while hand grip pressure force as the output response in this experimental runs.

Table 7 Experimental run and results of hand grip pressure force (N)

Run	Factor 1	Factor 2	Factor 3	Response 1
	A:Time Exposure (min)	**B:Hand Side**	**C:BMI (kg/m²)**	**Handgrip Force, (N)**
1	5.00	Right	Underweight	181.31
2	10.00	Left	Normal	355.45
3	5.00	Right	Normal	361.94
4	10.00	Right	Underweight	168.92
5	5.00	Left	Normal	343.99
6	5.00	Right	Overweight	2421.54
7	10.00	Left	Normal	357.14
8	10.00	Right	Normal	356.89
9	10.00	Right	Overweight	2412.51
10	5.00	Left	Overweight	2500.32
11	5.00	Left	Overweight	2524.24
12	5.00	Left	Normal	345.15
13	5.00	Left	Underweight	198.13
14	5.00	Right	Normal	359.83
15	10.00	Right	Overweight	2403.01
16	5.00	Right	Overweight	2413.35
17	10.00	Right	Normal	353.21
18	5.00	Left	Underweight	201.34
19	10.00	Left	Overweight	2403.21
20	10.00	Left	Overweight	2418.95
21	10.00	Left	Underweight	177.89
22	10.00	Left	Underweight	176.64
23	5.00	Right	Underweight	183.22
24	10.00	Right	Underweight	169.59

Determination of Appropriate Polynomial Equation to Represent Regression Model

In order to determine the appropriate polynomial equation to represent the relationship between the input parameters and the output response (hand grip pressure force), the sequential model sum of squares (SMSS) and lack of fit test are carried out as shown in Table 8 and Table 9 respectively. The results from these two analysis show that the relationship between factors and output response can be modelled using 2FI (factor of interaction).

Table 8 Sequential model sum of squares (SMSS) analysis for hand grip pressure force model

Sequential Model Sum of Squares [Type 1]						
Source	**Sum of Squares**	**df**	**Mean Square**	**F Value**	**p-value Prob > F**	
Mean vs Total	2.358E+007	1	2.358E+007			
Linear vs Mean	2.521E+007	4	6.304E+006	10244.62	< 0.0001	
2FI vs Linear	7956.29	5	1591.26	5.97	0.0037	**Suggested**
Quadratic vs 2FI	0.000	0				Aliased
Residual	3734.44	14	266.75			
Total	4.880E+007	24	2.033E+006			

Table 9 Lack of fit test for the hand grip pressure force model

Source	Sum of Squares	df	Mean Square	F Value	p-value Prob > F	
Linear	11183.03	7	1597.58	37.76	< 0.0001	
2FI	3226.74	2	1613.37	38.13	< 0.0001	**Suggested**
Quadratic	3226.74	2	1613.37	38.13	< 0.0001	Aliased
Pure Error	507.70	12	42.31			

ANOVA for Response Surface 2FI Model

Determination of the significant factors and significant interaction affecting the hand grip pressure force of the hand's subjects are done by carrying out ANOVA on the 2FI response surface model. Table 10 shows the ANOVA for response 2FI surface model. P-value less than 0.1 indicates that the model is significant. Hence, time exposure, hand side, BMI, interaction between time exposure and hand side, interaction between time exposure and BMI, and interaction between hand side and BMI term are the significant influencing factors of the resultant hand grip pressure force.

Table 10 ANOVA analysis of the 2FI model for hand grip pressure force

ANOVA for Response Surface 2FI Model						
Source	**Sum of Squares**	**df**	**Mean Square**	**F Value**	**p-value Prob > F**	
Model	2.522E+007	9	2.802E+006	10506.08	< 0.0001	significant
A-Time Exposure	3288.87	1	3288.87	12.33	0.0035	
B-Hand Side	1964.39	1	1964.39	7.36	0.0168	
C-BMI	2.521E+007	2	1.260E+007	47252.59	< 0.0001	
AB	1159.68	1	1159.68	4.35	0.0559	
AC	3505.63	2	1752.82	6.57	0.0097	
BC	3290.98	2	1645.49	6.17	0.0120	
Residual	3734.44	14	266.75			
Lack of Fit	3226.74	2	1613.37	38.13	< 0.0001	significant
Pure Error	507.70	12	42.31			
Cor Total	2.523E+007	23				

Polynomial Equation for Muscle Fatigue

From the surface response modelling, the 2FI polynomial equation developed to relate the input parameters to the hand grip pressure force as shown in Table 11. The table shows the equation in terms of actual factors. The equation in terms of actual factors can be used to make predictions about the response for given levels of each factor. Here, the levels should be specified in the original units for each factor.

Table 11 Polynomial equation for hand grip pressure force model

Hand Side	**Left**
BMI	Underweight
Handgrip = +235.96375 - 6.32850 * Time Exposure	
Hand Side	Left
BMI	Normal
Handgrip = +366.86875 - 2.19150 * Time Exposure	
Hand Side	Left
BMI	Overweight
Handgrip = +2565.69750 -13.86900 * Time Exposure	
Hand Side	Right
BMI	Underweight
Handgrip = +181.51625 - 0.76750 * Time Exposure	
Hand Side	Right
BMI	Normal
Handgrip = +332.69625 + 3.36950 * Time Exposure	
Hand Side	Right
BMI	Overweight
Handgrip = +2474.91250 - 8.30800 * Time Exposure	

Regression Model Validation

The analysis continues with the mathematical model validation to determine whether the developed response surface model can predict the hand grip pressure force is successfully performed or not. Three sets of process parameters are chosen as validation runs based on point prediction capability of the software.

Table 12 shows the validation results of the three sets parameter settings.

Table 12 Validation data of hand grip pressure force model

Input Parameters			Prediction (N)	90% PI Low (N)	90% PI Hi (N)	Actual (N)	Error (%)
Time Exposure	**Hand Size**	**BMI**					
5.00	Left	Underweight	204.32	170.08	238.56	198.13	3.030
7.50	Left	Underweight	188.50	156.34	220.66	187.50	0.531
10.00	Right	Overweight	2391.83	2357.59	2426.07	2412.51	0.865

The result indicates that the hand grip pressure force of validation runs data fall within the 90% prediction interval and the residual errors are ranging from 0.531% to 3.030% in absolute value which are less than 10%. This model is accurate enough to predict the resultant hand grip pressure force within 90% CI and the residual error relative to predicted values are less than 10%.

CONCLUSION

The relationship between the psychophysical and biomechanical factors parameters (time exposure, hand side and BMI) and the developed muscle fatigue and hand grip pressure force are successfully developed and validated. Table 13 summarized the significant parameters that influenced the output responses. Besides, the study successfully validated the mathematical models by the quantitative means of comparing the validation run results with the 90% PI of the model and the residual errors are calculated to predict the accuracy of the models. The model validations runs must fell within the 90% PI of the model and the residual errors are less than 10%.

Table 13 The significant input parameters and interaction influencing the respective model

Developed Models	Significant Parameters	Significant Interaction Factors
Muscle Fatigue	• Time exposure • Hand side • BMI	• Hand side and BMI
Hand Grip Pressure Force	• Time exposure • Hand side • BMI	• Time exposure and hand side • Time exposure and BMI • Hand side and BMI

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COMPETING INTERESTS

There is no conflict of interest.

REFERENCES

1. Baluch, Nazim Hussain, Che Sobry Abdullah, and Shahimi Mohtar. "Maintenance management performance-An overview towards evaluating Malaysian palm oil mill." *The Asian*

Journal of Technology Management (2010).

2. Bigland-Ritchie, B., F. Furbush, and J. J. Woods. "Fatigue of intermittent submaximal voluntary contractions: central and peripheral factors." *Journal of Applied Physiology* 61, no. 2 (1986): 421-429.

3. Dun, Shouchen, Robert A. Kaufmann, and Zong-Ming Li. "Lower median nerve block impairs precision grip." *Journal of Electromyography and Kinesiology* 17, no. 3 (2007): 348-354.

4. Hansen, Lone, Jørgen Winkel, and Kurt Jørgensen. "Significance of mat and shoe softness during prolonged work in upright position: based on measurements of low back muscle EMG, foot volume changes, discomfort and ground force reactions." *Applied ergonomics* 29, no. 3 (1998): 217-224.

5. Jellad, Anis, Hanene Lajili, Soumaya Boudokhane, Houda Migaou, Sarra Maatallah, and Zohra Ben Salah Frih. "Musculoskeletal disorders among Tunisian hospital staff: Prevalence and risk factors." *The Egyptian Rheumatologist* 35, no. 2 (2013): 59-63.

6. Kuijer, P. Paul FM, Marco JM Hoozemans, and Monique HW Frings-Dresen. "A different approach for the ergonomic evaluation of pushing and pulling in practice." *International journal of industrial ergonomics* 37, no. 11 (2007): 855-862.

7. Lei, Ling, Patrick G. Dempsey, Jian-guo Xu, Lin-na Ge, and You-xin Liang. "Risk factors for the prevalence of musculoskeletal disorders among Chinese foundry workers." *International Journal of Industrial Ergonomics* 35, no. 3 (2005): 197-204.

8. Montgomery, Douglas C. *Design and analysis of experiments*. John Wiley & Sons, 2008.

9. Nevill, Alan M., and Roger L. Holder. "Modelling handgrip strength in the presence of confounding variables: results from the Allied Dunbar National Fitness Survey." *Ergonomics* 43, no. 10 (2000): 1547-1558.

10. Oosterveer, Peter. "Promoting sustainable palm oil: viewed from a global networks and flows perspective." *Journal of Cleaner Production* 107 (2015): 146-153.

11. Reid, Christopher R., Pamela McCauley Bush, Waldemar Karwowski, and Samiullah K. Durrani. "Occupational postural activity and lower extremity discomfort: A review." *International Journal of Industrial Ergonomics* 40, no. 3 (2010): 247-256.

12. Rahim, Abdul Hadi Abdol, Abdul Rahman Omar, Isa Halim, Alias Mohd Saman, Ibrahim Othman, Mas Alina, and Suhadiyana Hanapi. "Analysis of muscle fatigue associated with prolonged standing tasks in manufacturing industry." In *Science and Social Research (CSSR), 2010 International Conference on*, pp. 711-716. IEEE, 2010.

13. Sancho-Bru, Joaquín L., A. Perez-Gonzalez, M. Vergara, and D. J. Giurintano. "A 3D biomechanical model of the hand for power grip." *Journal of biomechanical engineering* 125, no. 1 (2003): 78-83.

14. Sartika, Sari Julia, and Siti Zawiah Dawal. "Investigation on lower leg muscles activity and discomfort on prolonged standing task." In *Technical Postgraduates (TECHPOS), 2009 International Conference for*, pp. 1-4. IEEE, 2009.

15. Seo, Na Jin, and Thomas J. Armstrong. "Investigation of grip force, normal force, contact area, hand size, and handle size for cylindrical handles." *Human Factors: The Journal of the Human Factors and Ergonomics Society*50, no. 5 (2008): 734-744.

16. Soderberg, Gary L., and Thomas M. Cook. "Electromyography in biomechanics." Physical Therapy 64, no. 12 (1984): 1813-1820.

17. Søgaard, Karen, Simon C. Gandevia, Gabrielle Todd, Nicolas T. Petersen, and Janet L. Taylor. "The effect of sustained low-intensity contractions on supraspinal fatigue in human elbow flexor muscles." *The Journal of physiology* 573, no. 2 (2006): 511-523.

18. Vaughn, N. A., and C. Polnaszek. "Design-Expert® software." *Stat-Ease, Inc, Minneapolis, MN* (2007).