The Effects of Energy Expenditure on the Mental Fatigue of Construction Workers

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Abstract

This study aims to determine the significant factors that affect the mental fatigue of construction workers in the Philippines. Studies revealed that workers in the construction site routinely exceed generally accepted physiological thresholds for manual work leading to fatigue. They typically carry out highly demanding physical tasks with various types of stresses resulted from awkward posture, excessive force demands, repetitive actions and excessive energy expenditure. Due to this labor-intensive nature of construction work, many construction workers face excessive demands beyond their physical capabilities. Thus, they are prone to be exposed to significantly high level of mental fatigue as well as other safety risks. This study aims to focus on the physiological measures of energy expenditure of workers leading to fatigue. Factors that were considered in the study are activity metabolic rate, heart rate, age, and body mass index. To objectively measure the mental fatigue experienced by the construction workers during the whole 8-hour shift, the Deary Liewald reaction time software was used. Statistical analysis is also employed to determine the significant differences in the factors identified among the 5 construction trades such as labor, mason, carpentry, steal work and plumbing using ANOVA. Correlation analysis is also used to identify relationship of factors to the fatigue level of construction workers. Results of the study revealed that all factors considered in the study have significant relationship to the fatigue experienced by workers among the 5 construction trades. And in order to develop measures to minimize mental fatigue level of workers, a suitable work-rest schedule is designed through the application of Monte Carlo simulation model having 9,125 runs, which generated a year worth of data for the 25 construction workers.

Keywords
Mental fatigue, energy expenditure, construction

1. Introduction

Due to the rise of construction industry, the number of employees in the workforce also accelerates. Over the forecast period for years 2016 to 2020, the pace of global construction industry will accelerate to an annual average of 3.4%, with the industry reaching a value of US$10.0 trillion in 2020. In the United States alone, approximately 10.3 million people are part of the construction workforce in 2016 (Ahmed & Rahman, 2015; Statistics Portal, 2018). The construction industries in the Middle East and Africa region are predicted to be the fastest growing in 2016-2020, overtaking the Asia-Pacific region, which held the top spot in 2011-2015. However, Asia-Pacific's share of the global construction industry will continue to rise, reaching close to 49% in 2020, up from 40% in 2010 (Market Reports Store, 2015). As one of the largest industries in the world, the construction workers are exposed to harsh and dangerous situations, which lead to poor judgment, poor quality of work, and reduction in productivity, and increased risk of accidents (Ahmed & Rahman, 2015; Cheng et al., 2012). Construction workers either work only on short contracts or at a construction site for a limited period, which leads to unfamiliarity with the workplace thus enhancing the risk of injury (Chang, F.L., 2007). They typically carry out highly demanding physical tasks with various types of stresses.
resulted from awkward posture, excessive force demands, repetitive actions and excessive energy expenditure (Maiti, R., 2008). Given these factors, they are prone to be exposed to significantly high level of fatigue as well as other safety risks (Gumasing & Pacheco, 2018; Gumasing & Sasot, 2019). From a study by Everette et al. (2002), it was revealed that 20% to 40% of different craft workers on a construction site routinely exceed generally accepted physiological thresholds for manual work leading to fatigue. The impact of fatigue is likely to be more serious under the construction environment, which is usually regarded as dynamic and risky (Pinto, A., 2011).

Fatigue is a state of physical and mental exhaustion. In many industries, fatigue leads to overall decrease in productivity. However, in construction, the decrease in alertness and energy levels caused by fatigue can be very dangerous. Fatigue can be classified into two: mental fatigue and physical fatigue. Physical fatigue is the transient inability of muscles to maintain optimal physical performance, and is made more severe by intense physical exercise while mental fatigue is a transient decrease in maximal cognitive performance resulting from prolonged periods of cognitive activity. In view of the mental nature of fatigue, it is possible that fatigue may impair cognitive functions and influence health and safety adversely. Although existing studies have suggested an association between fatigue and cognitive function in different populations (Boksem, M., 2005; Moore, R., 2012) few studies have examined this relationship in the construction industry (Zhang, M., 2015).

To further understand the importance of safety and health of construction workers, several studies have been done. According to Strasser (2003), the assessment of workers' physiological conditions is a crucial prerequisite in every ergonomics study and devices capable of assessing worker's physiological conditions and, eventually, work physiological demands can play a crucial role in enhancing construction workforce productivity, safety, and wellbeing (Gatti, U., 2014). Currently, numerous techniques are available to assess work physiological demands of construction such as questionnaires, oxygen consumption and heart rate monitoring (Abdelhamid, T., 2002; Rwamamara, R., 2010). However, there is no published study—most especially in the Philippine setting— that tackles the relationship of occupational risks in terms of mental fatigue to the physiological demands of work depending on various construction trades. They usually involve only a certain task or job type; for instance, rebar workers (Yi, W., 2013), specific lifting tasks (Antwi-Afaria, M., 2017), and the likes.

Given these conditions, the paper intends to determine the significant factors that affect mental fatigue experienced by the workers using physiological measures of energy expenditure. This is needed in order for the researcher to design a work-rest schedule to adjust the physical workload of workers to prevent overstrain, fatigue, and injuries.

2. Methodology

2.1. Data Gathering

The researchers have standardized the sample set by considering two factors: project size and different job trades. The chosen project observed by the researchers had 31 construction workers on site. However, only 25 workers were included in the study. They were classified into 5 construction trades: plumber, laborer, mason, carpenter, and steel man. The researchers selected 5 workers from each trade to be able to evaluate each trades without bias. Other trades such as foreman and time-keeper were removed from the study since they are assigned with simpler tasks and only one person is assigned per site. This study is also limited to small-medium scale project since the focused project by the researchers only involved construction work of 9 townhouses.

To process and select the factors that will be considered in the study, the following sequence of steps was performed. First, the researchers conducted a thorough investigation and analysis from previous researches and studies. Then, survey forms and questionnaires were administered to the construction workers, managers, healthcare practitioners and similar stakeholders in order to determine the factors that will be considered in the study. Next, an onsite observation was done in the study to investigate the exposure of the construction workers to the fatigue-related risks. All the data were gathered using the apparatuses, devices and instrumentation. A fitness tracker was used to obtain real time data for heart rate and activity metabolic rate. For the heart rate, the real-time monitoring helped the researchers in gathering a much accurate data since the fitness tracker determines the highest heart rate and the lowest
which shall give the average beats per minute in every task. Other factors such as age and BMI of the respondents were also gathered in the study.

Moreover, in order to measure the mental fatigue level of the respondents, Deary Liewald reaction time software was used. This test was developed to measure the average length of time for an individual to respond to visual or auditory stimulus. The test represents the alertness and motor speed of an individual and will be used to represent the level of mental fatigue of the respondents since according to previous studies, the mental fatigue is one of the main reasons for the decline in response inhibition. And reaction time is one of the best measures for response inhibition of a person (Guo, Z., 2018). Welford (1968, 1980) also found that reaction time gets slower when the subject experiences fatigue. For this study, two types of reaction time were considered: Simple Reaction Time (SRT) and Choice Reaction Time (CRT). SRT is measured to determine the response time of an individual when performing cognitive tasks without decision making involved while CRT a more complex test which measures the capability of an individual to respond when a choice is presented.

2.2. Statistical Analysis

To determine which among the contributing factors (i.e. age, body mass index, heart rate, activity metabolic rate) have a significant difference among the different construction trades, the researchers had use one-way ANOVA, at level of significance of 0.05%. Next, correlation analysis was also employed to determine the strength of relationship between the factors considered in the study to the mental fatigue of the respondents. And to further illustrate the relationship between the factors to the mental fatigue of workers, multiple regression analysis was applied in the study. This tool helped the researchers to come up with a predictive model to determine the severity of mental fatigue of the workers based on the contributing factors such as age, body mass index, heart rate, and activity metabolic rate.

3. Results and Discussion

3.1. Summary of Factors

The table below shows the statistical descriptions of the factors gathered from the 25 respondents of the study grouped on 5 different construction trades. Using the Deary Lieward RT software, data for SRT and CRT were obtained from the respondents. Activity metabolic rate and heart rate were also obtained using fitness tracker device, and demographic data such as age and BMI were gathered using survey questionnaires. These data will be further analyzed using for statistical tools such as analysis of variance, correlation and regression analysis.

<table>
<thead>
<tr>
<th>Table 1. Descriptive statistics of factors considered in the study</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Descriptive Statistics</strong></td>
</tr>
<tr>
<td>-----------------------------</td>
</tr>
<tr>
<td><strong>CARPENTER</strong></td>
</tr>
<tr>
<td>Mean</td>
</tr>
<tr>
<td>Median</td>
</tr>
<tr>
<td>Standard Deviation</td>
</tr>
<tr>
<td>Sample Variance</td>
</tr>
<tr>
<td>Kurtosis</td>
</tr>
<tr>
<td>Skewness</td>
</tr>
<tr>
<td>Range</td>
</tr>
<tr>
<td><strong>LABORER</strong></td>
</tr>
<tr>
<td>Mean</td>
</tr>
<tr>
<td>Median</td>
</tr>
<tr>
<td>Standard Deviation</td>
</tr>
<tr>
<td>Sample Variance</td>
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<tr>
<td>Kurtosis</td>
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<tr>
<td>Skewness</td>
</tr>
<tr>
<td>Range</td>
</tr>
</tbody>
</table>
3.2. Result of ANOVA

ANOVA was performed in order to determine if there is significant difference between the factors (AMR, heart rate, age, BMI) among the 5 construction trades identified in the study using significance level of 0.05. The results are shown in the figures below.

The results of ANOVA indicate that there is no significant difference in the AMR, heart rate, age and BMI among the 5 construction trades such as carpenter, laborer, mason, plumber and steel man. So, it can be assumed that the results and conclusions that will be derived from this study would be applicable to all types of construction trades.

3.3. Result of Correlation Analysis

To determine the strength of relationship of the factors (AMR, heart rate, age, BMI) to the mental fatigue experienced by the workers, correlation analysis was used. There were two correlation analyses conducted as two measurements.
for mental fatigue were considered: the simple reaction time and choice reaction time. CRT is more complicated than the SRT and can be more related with the decision making of the construction workers. The summary of the results is shown in the table below.

<table>
<thead>
<tr>
<th></th>
<th>SRT</th>
<th>CRT</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>AMR</strong></td>
<td>0.649</td>
<td>0.677</td>
</tr>
<tr>
<td>p-value</td>
<td>0.000</td>
<td>0.000</td>
</tr>
<tr>
<td><strong>Heart Rate</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Pearson correlation</td>
<td>0.832</td>
<td>0.805</td>
</tr>
<tr>
<td>p-value</td>
<td>0.000</td>
<td>0.000</td>
</tr>
<tr>
<td><strong>Age</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Pearson correlation</td>
<td>0.736</td>
<td>0.797</td>
</tr>
<tr>
<td>p-value</td>
<td>0.000</td>
<td>0.000</td>
</tr>
<tr>
<td><strong>BMI</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Pearson correlation</td>
<td>0.885</td>
<td>0.874</td>
</tr>
<tr>
<td>p-value</td>
<td>0.000</td>
<td>0.000</td>
</tr>
</tbody>
</table>

The results of the correlation analysis for simple reaction time and choice reaction time indicate that all factors (AMR, heart rate, age, BMI) have strong positive correlation to the reaction time of the respondents that represents the severity of the mental fatigue experienced by the construction workers. All factors have Pearson correlation value of greater than 0.6 and p-value of less than 0.05. This explains that as each factor increases, the reaction time or mental fatigue of the worker also increases, as the factor and mental fatigue are directly proportional with each other.

As previously mentioned in a study by Aryal, A. (2017), the variations in the heart rate reflect the physical activity performed by the participants. It was observed that an increase in the heart rate happens when the participant performs physical work, and a drop in heart rate when the participant pauses, as the heart rate is correlated with the intensity of the physical activity. And as the intensity of physical activity increases, the risk of physical fatigue increases. Thus, the correlation analysis of this study by the researchers further proves this claim. Meanwhile, the AMR of an individual results to higher level of fatigue experienced by the workers as the physical activity requires exertion of more energy. As intensity of work increases, as proven by the statistical analysis, the AMR of the construction worker also increases. As BMI and age are related with the AMR of an individual, as the BMI increases and as the individual becomes older, the construction worker also experiences the higher level of fatigue.

### 3.3. Result of Multiple Regression Analysis

To further illustrate the relationship of the factors to the mental fatigue of workers, the researchers performed the multiple regression analysis. There are two regression models that were developed in the study. For the first model, response variables considered is the simple reaction time (SRT) and for the second model, response variable is the choice reaction time (CRT) that were obtained using Deary Lieward RT Software. The predictors considered for the both models are the physiological measures for energy expenditure such as AMR, heart rate, age and BMI. The results are shown in the equations 1 and 2 below.

\[
\text{Simple Reaction Time} = -608 + 23.2 \text{ Activity Metabolic Rate} + 5.24 \text{ Heart Rate} + 1.666 \text{ Age} + 9.47 \text{ Body Mass Index}
\]

\[
\text{Choice Reaction Time} = -721 + 35.9 \text{ Activity Metabolic Rate} + 6.06 \text{ Heart Rate} + 3.087 \text{ Age} + 10.10 \text{ Body Mass Index}
\]
The results of the regression models prove that all factors (AMR, HR, age and BMI) significantly affect the SRT and CRT of the respondents (having p-values of less than 0.05 and model accuracy of adjusted R² values 88.48% and 90.48% respectively. Since it was proven in the models that reaction times of the respondents significantly decrease with respect to the factors considered in the study, thus, we can conclude that mental fatigue of the respondent increases as the AMR, HR, age and BMI of the respondent also increases.

### 3.4. Development of Work-Rest Schedule

In order to lessen the mental fatigue experienced by the workers, the researchers designed a suitable work-rest schedule for the specific scope of work that was covered in the study. Previous study has presented a theoretical model that could be the basis for work-rest schedule that considers physiological factors in determining the work capacity of the workers (Hsie, M., 2009). However, it only focuses on the specific activities done by the workers, which could be very diverse for construction workers. Given that, data gathering would be time consuming and the results could vary from workplace to workplace. Another study conducted in Hong Kong presented a work-rest schedule for rebar workers (Garg, A., 2009). The study focused on heat tolerance and environmental exposure of the workers as well as a specific construction trade, which makes the study limited to its scope. The researchers chose to incorporate these
two studies to come up with a simulation model that would allow diverse construction projects—or even other practices—in coming up with their own work-rest schedule.

3.4.1. Calculation of Maximum Allowable Work Duration

In calculating the maximum allowable work duration, an equation derived from a study of Wu, H.C. (2001) was considered to determine the maximum allowable work duration to be imposed on workers doing high-intensity works similar to the tasks of construction workers.

\[
MAWD \text{ (min)} = -2.09 + e^{6.59-5.60 \cdot RV02}
\]

\[
RV02 = \frac{VO_{2work} - VO_{2rest}}{VO_{2max} - VO_{2rest}}
\]

Where \( VO_{2work} \) (l/min) is the oxygen consumption during work, \( VO_{2rest} \) is the oxygen uptake during rest—which is typically at 0.341 l/min and 0.31 l/min for men and women, respectively—and \( VO_{2max} \) is the estimated work capacity of an individual. \( VO_{2max} \) equation is presented below:

\[
VO_{2max} = [5.363 + (1.951 \cdot SRE) - (0.754 \cdot BMI) - (0.381 \cdot AGE) + (10.987 \cdot Gender)] \cdot \frac{W}{1000}
\]

Where SRE is Self-Reported Exercise, BMI (kg/m\(^2\)) is Body Mass Index, Gender is indicated as 0 and 1 for female and male respectively, and \( W \) (kg) is weight. Self-reported exercise is a widely used metrics to determine the level of physical effort exerted by an individual beyond the daily-required tasks. It has been used in various studies to be able to determine the oxygen uptake capacity of certain individuals (Hsie, M., 2009; Jackson, A., 1996).

3.4.2. Monte Carlo Simulation Model

Monte Carlo Simulation method is a technique that produces different randomized situations that will help in determining solutions for a given problem. Thus, for this study, the researchers chose to simulate more situations to acquire more data and attain more accurate results. The model used was derived from a study conducted by Yi, W. & Chan, A. (2013), which has a similar objective with this study—to be able to create an optimal work-rest schedule for workers in the construction industry.

To develop the simulation model, three factors were randomly selected for 9,125 runs to generate approximately a year worth of data for all 25 workers. Factors for the simulation model includes SRE, BMI, Age, Gender, and weight. The estimated work capacity for the worker will be then computed and assigned as \( VO_{2max} \). The next randomly generated number would determine the assigned activity metabolic rate. The activity metabolic rate values were based on the obtained AMR values from the observation. The researchers created a probability distribution table to list down the possible assigned values and its corresponding frequency percentage. The AMR is then converted to oxygen consumption (l/min) by dividing the AMR (kcal) by 4.83—which is said to be the conversion factor as mentioned in a previous study (Chang, F. et al., 2008). After having all the oxygen consumption values needed, the \( RV02 \) can be obtained then the maximum allowable work duration (MAWD). The simulation will then subtract the MAWD to 240 minutes to determine if time left is greater than 240 minutes. The last randomly generated number will let the model know which rest period should be chosen. The rest period will also determine the percent replenishment of MAWD, which was derived from a previous study as well (Garg, A., 2009). The simulation will then proceed to run continuously until there is no time left within 240 minutes. The result of the simulation model is shown in the table below.
3.4.3. Optimal Work-Rest Schedule

In order to determine the optimal work-rest schedule, the researchers first determined the average maximum allowable work duration (MAWD). The average is obtained by adding all the MAWD per run then dividing it by the total number of runs, which are 9,125. Results show that the average MAWD for the workers is 159.92 minutes. The researchers rounded it off to 160 minutes or 1 hour and 40 minutes. Thus, the optimal duration for construction workers before a rest period is mentioned. After that, the optimal rest duration was considered. Two factors were used in determining which rest duration is the most suitable for the model, the average productive time and the average number of rest periods. The summary is shown in the table below.

<table>
<thead>
<tr>
<th>Number of rest</th>
<th>Average Number of rest periods needed</th>
</tr>
</thead>
<tbody>
<tr>
<td>5</td>
<td>2</td>
</tr>
<tr>
<td>10</td>
<td>1</td>
</tr>
<tr>
<td>15</td>
<td>1</td>
</tr>
<tr>
<td>20</td>
<td>1</td>
</tr>
<tr>
<td>25</td>
<td>1</td>
</tr>
<tr>
<td>30</td>
<td>1</td>
</tr>
<tr>
<td>35</td>
<td>1</td>
</tr>
<tr>
<td>40</td>
<td>1</td>
</tr>
</tbody>
</table>

The best choice for average productive time is 5 minutes given that it has an average of 232.00 productive minutes based from the simulation runs. However, the MAWD forecast can only cater up to one (1) rest period in between of morning shift and afternoon shift respectively.

The researchers chose the optimal rest period not only in terms of productive time, but also considering the best in different age brackets. The researchers observed that the optimal rest period and MAWD was affected by the difference in age groups. Therefore, the averaging method was less accurate given that there are still a lot of older working generations. Therefore, the researchers opted to obtain the MAWD and optimal rest period per age bracket to determine the lowest MAWD and highest rest period to cater to all of the workers’ needs.

<table>
<thead>
<tr>
<th>Age bracket</th>
<th>20s</th>
<th>30s</th>
<th>40s</th>
<th>50s</th>
</tr>
</thead>
<tbody>
<tr>
<td>MAWD</td>
<td>179.69</td>
<td>159.02</td>
<td>143.12</td>
<td>123.25</td>
</tr>
</tbody>
</table>
Therefore, in order to consider all age groups in the industry—especially that there are still a lot of construction workers whom are in the eldest age group—the researchers chose 20 minutes for the rest period for both morning and afternoon and the MAW used will be 120 minutes.

![Figure 7. Optimal Work-Rest Schedule](image)

The figure above illustrates the Work-Rest duration in between the lunch break. The work duration runs for 120 minutes. The worker is then given the chance to replenish for 20 minutes and regain his optimal MAWD by 84%. The worker then proceeds to finish the first shift of his task then rest for 60 minutes during lunch break. The worker repeats the same work-rest schedule for the afternoon.

4. Conclusion

The findings of the study have revealed that workers in the construction site routinely exceed generally accepted physiological thresholds for manual work leading to fatigue. This was evident on the factors gathered from the respondents such as their activity metabolic rate, heart rate, age and body mass index. Results of statistical analyses such as correlation and regression model proved that the factors considered in the study have significant effect to the mental fatigue of the workers as measured in the reaction time of the respondents using the SRT and CRT tests. Considering results of this study, the researchers were able to design an optimal work-rest schedule for the construction workers using Monte Carlo simulation. Through this method, the researchers were able to determine the maximum allowable work duration for the workers and compute the optimal rest period to lessen the mental fatigue experienced by workers in different construction trades.

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