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INVESTIGATION OF UPPER LIMB MUSCLE AND MENTAL ACTIVITIES ON UNIVERSITY STUDENTS AND WORKERS FOR REPETITIVE LOAD-TASKS

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ABSTRACT

A study was conducted to investigate the effect of load on upper limb muscles and mental activities in light repetitive task. The task was conducted at two levels of load (Low and high) on university students and industrial workers. Surface electromyography (EMG) was used to measure upper limb muscle activities of thirty subjects. The results found that the EMG RMS of all muscles increases as time increases that reflect muscle fatigue. Electroencephalography (EEG) was simultaneously recorded with EMG to record mental activities. Mental activities increases as time increase, that indicates mental fatigue was occurred while performing the task. Students and workers have similar muscle activities while doing the tasks, except for the activities of the left brachioradialis muscle on the high load task. It indicates that in this task, the right brachioradialis muscle of the students consumes more energy to perform the task than the students' muscle. The results on mental activities show that there was no difference of mental activities between students and workers (p>0.05), except on the F3-F4 channels for the low load task (p=0.043). The results indicate that the intentional and motivational of workers were higher than students while doing the low load task.

Keywords: *Upper limb muscle; mental activity; load; light repetitive task*

1. INTRODUCTION

The concept of mental fatigue earlier introduced by Grandjean clearly differentiated mental fatigue from muscle fatigue. He defined that muscle fatigue was concerned with reduced muscular system performance while mental fatigue deals with much reduced mental performance and the sense of weariness. Muscular fatigue contributes to impaired co-ordination and increased chances of errors and accidents (Kroemer & Grandjean, 1997).

When people become fatigued, besides muscle fatigue, they usually report difficulties in concentrating and focusing their attention on the tasks they are required to perform (Boksem, Meijman, & Lorist, 2005). It is one indication of mental fatigue. Mental fatigue is believed to be a gradual and cumulative process and is thought to be associated with a disinclination for any effort, reduced efficiency and alertness and impaired mental performance (Grandjean, 1979). Generally, there is no desire for physical or mental effort and there is an associated heavy, drowsy feeling. A number of mental fatigue tests have already been adopted, but it still hard to draw a generalized conclusion as to the method of selecting the most appropriate test battery for a given workload (Saito, 1999).

Based on an empirical review, there are many studies on muscle fatigue. Some of the studies analyzed muscle fatigue during repetitive tasks. They found that time pressure, lack of influence over one's work and constant involvement in repetitive tasks of short duration often characterize jobs associated with a high risk for muscular problems. In contrast to muscle fatigue, relatively few studies investigated on both muscle and mental fatigue. Most studies observed the impact of mental activities on muscle and mental fatigue (H. R. Zadry, Dawal, & Taha, 2007).

Light-assembly work is a clear example of low intensity work with elevated risks of neck and shoulder disorders (S. Mathiassen & Winkel, 1996). Although there were many studies investigating about muscle fatigue in assembly task, few research investigated the correlation between upper limb muscle and mental activities during light assembly task. Many of the studies were carried out using laboratory experiments method, and only a few was carried out by survey. Electromyography (EMG) is the most popular tool for measuring muscle activation and fatigue. While blood pressure, blink rate, and heart rate were rarely used. Changes in the electromyographic activity (a decrease in the mean power frequency and/or an increase in the EMG amplitude) during standardized voluntary contractions have frequently been used as indicators of muscle fatigue (Bigland-Ritchie & Woods, 1984; Merletti, Lo Conte, & Orizio, 1991).

On the other hand, there were still a few studies measuring mental activity in light repetitive task using Electroencephalography (EEG) (H. Zadry & Dawal, 2008). Most studies used EEG to measure drowsiness or fatigue on drivers (Eoh, Chung, & Kim, 2005; Lal & Craig, 2001) and night work (Åkerstedt, Kecklund, & Gillberg, 2007; Gillberg, Kecklund, Göransson, & Åkerstedt, 2003). In addition, subjective measurements were also carried out simultaneously. This study investigates the effect of load on upper limb muscles (brachioradialis, biceps brachii, anterior deltoid and upper trapezius) and mental activities (F3, F4, Fz, Pz, O1 and O2 channels). The study also developes the regression model to describe the relationships between upper limb muscle and mental fatigue over the time.

2. METHODOLOGY

2.1. Subject

Thirty subjects consisted of ten males and ten females from the university population, and five males and five females from industrial workers were recruited to participate in the experiment. The subjects were 18 to 40 year-old. Potential participants were excluded if they had a history of any neurological, muscular or skeletal disease or disorder. Subjects were also excluded if they took any medication or substance that could affect motor and neurological performance. The demographic characteristics of subjects were presented in Table 1.

Table 1. Demographic characteristics of subjects

	Subjects	Age (Years)	Stature (cm)	Weight (kg)
Mean	Students	23.40	160.58	53.50
Std. Deviation		1.70	8.38	8.90
Mean	Workers	31.90	157.00	55.40
Std. Deviation		5.43	10.48	11.79

2.2. Apparatus and Material

Noraxon Surface Electromyography (SEMG) and Telemyo “2400” Gen2 Telemetric Real Time 8 channel SEMG System completed with disposable surface electrodes Ag/AgCl/Solid Adhesive pregelled were used to record electrical activity of muscles. EEG BIOPAC MP150 System with AcqKnowledge 4.0 software and Electrode Cap (CAP100C) were used to record mental activity.

2.3. Procedures

The subjects had to perform a simulated light assembly task at two levels of load (low load, LL and high load, HL). The task was to assemble and disassemble irons with different weight. Low load level includes assembling the iron with the weight of 300 g and high load level includes assembling the iron with the weight of 2 kg. The work task was terminated after two hours for each level. The cycle time was determined based on Methods Time Measurement (MTM).

Each tasks were performed in a random order on two consecutive days between 9.00 am until 1.00 pm. To become familiar with the experimental equipment and procedures, a training session was performed before the experiment. All session were performed in a laboratory at a normal temperature of 25^0C. The subjects were seated in an ergonomically chair with the back vertical and the feet in full contact with the floor or with a footrest. The desk was adjusted to elbow height so that the upper arm and forearm formed 900 angles when the hand was positioned at the middle of the desk and the upper arm was vertical. At the start of each experimental day, three maximal voluntary contractions (MVC) of the right and left of brachoradialis and the right and left of upper trapezius were performed. EMG and EEG were recorded concurrently whilst performing the tasks.

2.4. Data Collection

2.4.1. *Surface Electromyography (EMG)*

EMG signals were recorded from eight muscles: brachioradialis, biceps brachii, anterior deltoid, and descending part of the upper trapezius, on the right and the left hands. These muscles were selected because they are often involved in repetitive movements of upper extremities (Sommerich, Joines, Hermans, & Moon, 2000). They are also the primary muscles used to elevate the arm and upwardly rotate the scapula (Minning, Eliot, Uhl, & Malone, 2007). Moreover, the trapezius muscle is very vital for clinical use because it exhibits high prevalence of pain symptoms due to repetitive work-related tasks. Therefore, it was often selected as a muscle choice to measure electrical activity during repetitive work-related tasks (Forsyth, Hiler, Michels, & Rezin, 2000).

Bipolar Ag/AgCl surface electrodes were placed with an inter electrode distance of 20 mm at the belly of the muscles. The electrode positions were located according to Hermens et al. (Hermens, Freriks, Disselhorst-Klug, & Rau, 2000). A reference electrode was placed on the piciform bone. The electrode positions were marked with a waterproof pencil, in order to place the electrodes at the exact same position in both conditions. Before the electrodes were applied, the skin was cleaned with alcohol. The recording was started after the inter-electrode resistance was less than 10 kΩ. Raw EMG signals were sampled during the test contraction with a sample frequency of 1500 Hz and band-pass filtered (20–400 Hz). Data was continuously recording using Telemyo 2400T G2 Telemetry EMG System.

2.4.2. *Electroencephalography (EEG)*

EEG recorded the mental activity simultaneously with the surface EMG during the experiments. It was recorded using an AgCl electrodes cap with electrodes placed at F3, F4, Fz, Pz, O1, and O2 of the International 10-20 electrodes placement system and with an electronically earlobe reference. The selection of electrode placement on F3, F4 and Fz because the intentional and motivational centers are in these points. On the other hand, Pz points represents the activity of perception and differentiation (Teplan, 2002). Then, the O1 and O2 are the points where the primary visual area is located. Data was continuously recorded for two hours with an MP150 system and analyzed with AcqKnowledge 4.0 software (BIOPAC Systems Inc.).

The bipolar recording technique was used to record the signals. The signals were band-pass filtered between 1.0 Hz and 100 Hz and recorded digitally (1000 Hz sample frequency). The EEG was checked off-line for artefacts. EEG alpha band was defined as the frequency between 8–13 Hz. For this measurement, an average power value over 5 minutes (24 epochs) periods were computed.

2.5. Statistical Analysis

The statistical methods using SPSS 19.0 were used to calculate mean and standard deviation of the EMG RMS, EMG MPF and the EEG alpha power. The Shapiro-Wilk test was used to analysis the normality of the data. The independent-samples t-test was used to investigate the differences in the EMG RMS, EMG MPF and EEG alpha band power between genders.

The paired-samples t-test was used to investigate the differences in EMG RMS, EMG MPF and EEG alpha band power between different levels of the tasks and to analyze the subjective measurements. $P < 0.05$ was taken as the minimum level for a significant difference. Pearson's correlation analysis was carried out to examine the relationship between EMG, EEG data and time. Then, a regression model was developed to describe the relationship between upper limb muscle and mental fatigue over the time. The linear regressions were employed for this purpose.

3. RESULTS

3.1. Muscle Activity

The normalized EMG RMS results for students and workers, and the significant value of their differences are presented in Table 2.

Table 2. Mean normalized EMG RMS (%) on load tasks for students and workers

Muscles	Low Load (LL)			High Load (HL)		
	Students	Workers	Sig. (2-tailed)	Students	Workers	Sig. (2-tailed)
R. Brachioradialis	9.927	14.825	0.095	14.218	16.811	1.000
L. Brachioradialis	9.121	7.717	0.379	13.556	8.566	0.008**
R. Biceps brachii	7.600	11.336	0.253	10.671	12.036	0.895
L. Biceps brachii	7.567	11.354	0.567	10.597	12.176	0.792
R. Anterior Deltoid	5.457	8.191	0.428	8.084	12.067	0.567
L. Anterior Deltoid	4.928	5.340	0.895	7.919	5.843	0.118
R. Upper Trapezius	14.003	20.408	0.271	18.955	24.340	0.124
L. Upper Trapezius	13.060	17.031	0.147	18.126	20.442	0.428

** $p < 0.01$

These results indicate that the muscle activities of workers were majority higher than the muscle activities of the students, both on low and high load tasks. However the differences were not significant ($p>0.05$). The significant difference of muscle activity between students and workers was only found on the left brachioradialis muscle on the high load task ($p=0.008$), where the students' muscle activities were higher than the workers' muscle activities.

The results on the Table 2 show that the right upper trapezius muscle has the highest muscle activity compared to the other muscles, for both low and high load tasks on students (14.003% and 18.955%, respectively), and on workers (20.408% and 24.340%, respectively). On the other hand, the activity of the left anterior deltoid muscle was the lowest compared to other muscles for all tasks and subjects. The muscle activities for students were only 4.928% (LL) and 7.919% (HL), while for workers were 5.340% (LL) and 5.843% (HL). When comparing between load levels, the results on Table 3 show the p-value of the differences. The results indicate that muscle activities were different between low and high load task for all muscles ($p < 0.01$).

Table 3. Mean differences of EMG RMS between low and high load tasks

Muscles	Mean RMS of LL (%)	Mean RMS of HL (%)	% Differences	Sig. (2-tailed)
R. Brachioradialis	14.527	15.963	8.996	0.001**
L. Brachioradialis	7.717	8.566	9.911	0.000**
R. Biceps brachii	11.336	12.036	5.816	0.000**
L. Biceps brachii	11.354	12.176	6.751	0.000**
R. Anterior Deltoid	7.695	11.086	30.588	0.000**
L. Anterior Deltoid	5.34	5.843	8.609	0.000**
R. Upper Trapezius	20.408	24.34	16.154	0.000**
L. Upper Trapezius	17.031	20.442	16.686	0.000**

** $p < 0.01$

3.2. Muscle Fatigue during Load Task

The regression analysis of the EMG RMS versus time for all muscles showed signs of muscle fatigue by positive slopes of the subjects (Table 4).

Table 4. Mean EMG RMS slopes for students and workers

Muscles	Low Load (LL)			High Load (HL)		
	Students	Workers	Sig. (2-tailed)	Students	Workers	Sig. (2-tailed)
R. Brachioradialis	0.095	0.176	0.113	0.085	0.207	0.008**
L. Brachioradialis	0.074	0.092	0.226	0.090	0.102	0.218
R. Biceps brachii	0.070	0.079	0.159	0.119	0.095	0.403
L. Biceps brachii	0.051	0.077	0.058	0.096	0.110	0.725
R. Anterior Deltoid	0.065	0.122	0.056	0.185	0.148	0.758
L. Anterior Deltoid	0.066	0.084	0.416	0.132	0.106	0.930
R. Upper Trapezius	0.187	0.198	0.356	0.194	0.376	0.056
L. Upper Trapezius	0.165	0.190	0.660	0.170	0.234	0.843

** $p < 0.01$

These slopes represent the rate of change of amplitude over time, which reflect the fatigue rate of the muscles. The higher the slopes, the earlier the fatigue will be occurred. The slopes of the EMG RMS were positive for all muscles on both levels. The workers' slopes were relatively higher than the students' slopes. However the differences of the slopes were only significant on the right brachioradialis muscle on the high load task (p=0.008). It indicates that muscle fatigue on the right brachioradialis comes previously on workers than students.

Table 5 illustrates that significant differences were not found in the RMS slopes on different levels of load task for all subjects (p>0.05). However, the slopes of the muscles on the high load task were higher compared to the low load task. It indicates that for longer time of the task, the muscles might be fatigue previously on the high load task than on the low load task. The results on the Table 5 also shows that the right upper trapezius muscle has the highest RMS slope on both of the load tasks (p=0.188, for LL; p=0.254, for HL). It is a sign of fatigue comes previously on this muscle compared to other muscles. Therefore, this muscle can be a reference to identify the initiate of muscle fatigue.

Table 5. Mean differences of EMG RMS slopes between low and high load tasks for all subjects

Muscles	Mean RMS Slopes of LL	Mean RMS Slopes of HL	% Differences	Sig. (2-tailed)
R. Brachioradialis	0.122	0.126	2.802	0.517
L. Brachioradialis	0.080	0.094	14.865	0.530
R. Biceps brachii	0.073	0.111	34.532	0.133
L. Biceps brachii	0.060	0.100	40.530	0.070
R. Anterior Deltoid	0.084	0.173	51.665	0.053
L. Anterior Deltoid	0.072	0.123	41.648	0.058
R. Upper Trapezius	0.188	0.254	26.099	0.382
L. Upper Trapezius	0.176	0.191	8.108	0.629

3.3. Mental Activity

Table 6 presents the mean of EEG alpha band power results for students and workers on low and high load tasks. The results indicate that the mental activities of workers were higher than the muscle activities of the students, both on low and high load tasks. However, the significant value of the differences shows that alpha powers are different significantly only on F3-F4 channels on low load task (p=0.043).

Table 6. Mean EEG alpha power (V2/Hz) on load tasks for students and workers

EEG Channels	Low Load (LL)			High Load (HL)		
	Student	Worker	Sig. (2-tailed)	Student	Worker	Sig. (2-tailed)
F3-F4	2.53E-07	9.44E-07	0.043*	3.53E-07	4.17E-07	0.509
Fz-Pz	7.09E-07	1.28E-06	0.095	8.77E-07	9.82E-07	0.628
O1-O2	2.38E-06	8.96E-06	0.053	1.31E-06	5.39E-06	0.379

* $p < 0.05$

Table 7 presents the differences of EEG alpha power between different levels of load task for all subjects. It indicate that mental activities on F3-F4 and O1-O2 on the low load task were higher 30.361% and 71.447% respectively, compared to the high load task. The difference on the O1-O2 channels was significant with the p-value = 0.001. On the other hand, the mental activities on the Fz-Pz channels were 0.482% higher on the high load task than on the low load task. However, the difference was not statistically significant (p=0.530).

Table 7. Mean differences of EEG alpha power between low and high load tasks

EEG Channels	Mean Alpha Power of LL (V^2/Hz)	Mean Alpha Power of HL (V^2/Hz)	% Differences	Sig. (2-tailed)
F3-F4	4.88E-07	3.74E-07	30.361	0.787
Fz-Pz	9.08E-07	9.12E-07	0.482	0.530
O1-O2	4.57E-06	2.67E-06	71.447	0.001**

** $p < 0.01$

Results on Table 7 also show that the mental activity on O1-O2 channels is the highest amongst the the other channels for both the task levels. It indicates that the tasks affect the activity of visual area in the brain.

3.4. Mental Fatigue during Load Task

Positive slopes of the EEG alpha power regression lines were found on all of EEG channels for both low and high load tasks. The positive slopes signify that mental fatigue was occurred during the tasks. The mean slopes of students and workers for low and high load tasks were presented in Table 8.

Table 8. Mean EEG alpha power slopes for students and workers

EEG Channels	Low Load (LL)			High Load (HL)		
	Students	Workers	Sig. (2-tailed)	Students	Workers	Sig. (2-tailed)
F3-F4	2.87E-09	3.52E-08	0.016*	9.04E-09	1.42E-08	0.006**
Fz-Pz	4.36E-09	5.20E-08	0.016*	1.54E-08	2.49E-08	0.135
O1-O2	5.54E-08	5.13E-07	0.333	2.12E-08	2.17E-07	0.065

* $p < 0.05$
** $p < 0.01$

The results on Table 8 show that mental activities of workers on F3-F4 and Fz-Pz channels on the low load task were significantly higher than students activities (p=0.016). The similar results on the F3-F4 channels on the high load task, the workers' mental activities were significantly higher than the students' mental activities (p=0.006). The higher and positive slopes reflect that mental fatigue was occurred earlier and higher on the workers than on the students.

Table 9. Mean differences of EEG alpha power slopes between low and high load tasks for all subjects

EEG Channels	Mean Alpha Power Slopes of LL	Mean Alpha Power Slopes of HL	% Differences	Sig. (2-tailed)
F3-F4	3.52E-08	1.42E-08	148.741	0.886
Fz-Pz	5.20E-08	2.49E-08	108.836	0.136
O1-O2	5.13E-07	2.17E-07	136.417	0.027*

* $p < 0.05$

Table 9 presents the mean slopes of EEG alpha power on low and high load tasks for all subjects. The results show that the slopes for O1-O2 channels were significantly different between low and high load tasks (p=0.027). The mean slopes were higher on the low load tasks than on the high load task (136.417%). The O1 and O2 are the points where the primary visual area is located. Therefore, the results indicate that the subjects experienced more mental fatigue on the low load task than on the high load task on their visual area. The mean slopes of EEG alpha power on other channels were also higher on the low load task compared to the higher one. However, the differences were not statistically significant (p>0.05).

4. DISCUSSION

In the current study, the muscle and brain activities were investigated in the laboratory on subjects while performing a repetitive task in two load levels. The study measured mean of EMG RMS and EEG alpha power (estimate of muscle and mental activities), and slopes for mean EMG RMS and EEG alpha power (estimate of muscle and mental fatigue). Correlation and regression analysis were also investigated to find out the model of relationship between muscle and mental activities while performing the load tasks.

4.1. Muscle Activity and Muscle Fatigue

The results on muscle activities show that students and workers have similar muscle activities while doing the tasks, except for the activities of the left brachioradialis muscle on the high load task. Muscle activities of the left brachioradialis muscle are higher on students than workers (p=0.008) in this task. It indicates that in this task, the right brachioradialis muscle of the students consumes more energy to perform the task than the students' muscle. However, the activities for other muscles are similar for students and workers even though they have different mean of age and experience in the length of work.

Compared to the other muscles, the right upper trapezius muscle has the highest muscle activity for both low and high load tasks on students (14.003% and 18.955%, respectively), and on workers (20.408% and 24.340%, respectively). These findings may be due to the activation and functional of the muscle. The tasks in this study need the activation of upper arm to carry and move the object while assembling. This activation increases the load on the upper trapezius muscle (Herberts, Kadefors, & Broman, 1980). Then, the upper trapezius muscle is responsible for supporting the upper limb posture (Hagberg, 1981; Herberts, et al., 1980; S. E. Mathiassen & Winkel, 1990). It also has the function to control of head motor control and response to postural sway (Lindman, et al., 1991 as quoted by (Sundelin & Hagberg, 1992)).

Results on the comparison of muscle activities between low and high load task show that on the high load task, muscle activities were significantly higher (5.816% - 30.588%) than on the low load task ($p < 0.01$). It was occurred on all the measured muscles. The results indicate that the high load task needs more muscle activity that the low load task.

In the present study, muscle fatigue was assessed by considering the means of the slopes of the EMG RMS. Muscle fatigue is related to an increase in the RMS (P. Madeleine, Lundager, Voigt, & Arendt-Nielsen, 2003). The results show that the slopes of the EMG RMS were positive for all muscles on both levels. It was a sign of muscle fatigue. The workers' slopes were relatively higher than the students' slopes. However the differences of the slopes between students and workers were only significant on the right brachioradialis muscle on the high load task ($p=0.008$). It indicates that the rate of muscle fatigue on the right brachioradialis was higher on workers than students. For other muscles, the differences of the slopes were not significant between students and workers. It means that students and workers experienced the similar rate of muscle fatigue for both low and high load tasks.

When compared between the levels of the task, the mean slopes of EMG RMS were relatively higher on the high load than the low load task. The differences of the slopes were ranging from 2.802% to 51.665%. However, the differences were not statistically significant because the p-values>0.05. It might be due to some possible reasons. First, methodological limitations might explain the lack of and effect in our study. The weights of the objects used in both task can be categorized as light and medium loads. Therefore, they have been too small to be reflected by EMG. Then, the length of the experiment for two hours stills not enough to see the differences of muscle fatigue between low and high load tasks. However, for longer time of the task, the muscles might be fatigue previously on the high load task than on the low load task.

Among the measured muscles, the mean slopes of the right upper trapezius muscle were higher than other muscles for low and high load the task (0.188 and 0.254, respectively). It indicates that the rate of fatigue on this muscle was higher than other muscles. The development of muscle fatigue in the trapezius muscle has been studied extensively during low force isometric contractions (Jørgensen, Fallentin, Krogh-Lund, & Jensen, 1988; P Madeleine, Farina, Merletti, & Arendt-Nielsen, 2002). However, the development of muscle fatigue during prolonged and more realistic (assembly) tasks have been reported only in a few studies (Bosch, De Looze, & Van Dieen, 2007; S. Mathiassen & Winkel, 1996). These studies also showed indications of muscle fatigue over the working day.

4.2. Mental Activities and Mental Fatigue

The results on mental activities show that there was no difference of mental activities between students and workers ($p>0.05$), except on the F3-F4 channels for the low load task ($p=0.043$). The location of F3-F4 was near the intentional and motivational centers (Teplan, 2002). Therefore, the results indicate that the intentional and motivational of workers were higher than students while doing the low load task. The highest mental activity was occurred on the O1-O2 channels for both levels of the task, followed by the Fz-Pz channels. The explanation for these might be due to the point O1 and O2 in EEG channels are near the primary visual area. Therefore, the eyes were forced to work harder when performed the task for two hours without break, so the mental activity on this area was higher compared to the others.

The significant difference of mental activity was found between low and high load task on O1-O2 channels (p=0.001). It was interesting to find that the mental activity on the low load task was 71.447% higher than the high load task. It might be due to the level of alertness was lower on the low load task than on the high load task. Higher mental activity indicates that the subjects are in experiencing drowsiness (Seen, Mohd Tamrin, & Meng, 2010). Moreover, it can be related to muscle activity, that on the low load task, muscle activities were lower than on the high load task. Therefore, the subjects become drowsier when they were doing the low load task than the high load task.

Positive slopes of the EEG alpha power regression lines were found on all of EEG channels for both low and high load tasks. It means that the EEG alpha power increases as the time increase. The positive slopes signify that mental fatigue was occurred during the tasks. The results were aligned with several EEG studies related to driving (Pal, et al., 2008; Seen, et al., 2010). The study observed that the EEG power of the alpha band was increased as the alertness level of the driver decreased. Alpha activity reflects a relaxed wakefulness state, and decreases with concentration, stimulation or visual fixation. Alpha activity was the most sensitive measure that could be used in detecting fatigue, followed by theta and delta activities (Akerstedt & Thorsvall, 1984).

Significant difference of EEG alpha power slopes was found between students and workers on the F3-F4 and Fz-Pz channels for the low load task (p=0.016 and 0.016, respectively), and on the F3-F4 channels on the high load task (p=0.006). The rate of mental fatigue on these areas was higher on workers than on students. It indicates that intention and motivation of workers decrease previously than students while performing the tasks.

There was no significant difference of mental activity on the O1-O2 channels between students and workers. However, the mental activity on these channels was higher than other channels for all subjects and levels. When compared between task's levels, there was a significant difference of mean EEG alpha power slope on the O1-O2 channels (p=0.027). The mean slope of EEG alpha power for O1-O2 channels was higher 136.417% on the low load task than on the high load task. It indicates that subjects experienced more mental fatigue while performing the low load task than high load task.

5. CONCLUSION

Within the scope of this study, it can be concluded that repetitive load tasks conducted in this study involves both upper limb muscle and mental activities and resulting in upper limb muscle and mental fatigue at the end of the tasks. The muscle fatigue rates were found to be higher than mental fatigue rates, indicating that subjects experienced more muscle fatigue than mental fatigue. It might also be an indication of muscle fatigue appearing earlier than mental fatigue.

Other results from the study also show that the right upper trapezius muscle was found to be the critical muscle of muscle fatigue in all tasks. Muscle activity and muscle fatigue rate in this muscle are higher than in others. The rationales for this issue might be caused by subjects are all right handed. Thus, the results might be different if the subjects are left handed. It is important to design a job task that considers workers' physical and mental capacity and capability in order to prevent muscle and mental fatigue. There are still lacking studies investigating muscle and mental fatigue in industries. Therefore in the future, it is proposed to develop a quantitative model for predicting time to muscle and mental fatigue, which would be potentially applicable to the management of fatigue.

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