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The Relation Between Upper Limb Muscle and Brain Activity in Two Precision Levels of Repetitive Light Tasks

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A study was conducted to investigate the effects of repetitive light tasks of low and high precision on upper limb muscles and brain activities. Surface electromyography (EMG) and electroencephalography (EEG) were used to measure the muscle and brain activity of 10 subjects. The results show that the root-mean-square (RMS) and mean power frquency (MPF) of the muscle activity and the mean power of the EEG alpha bands were higher on the high-precision task than on the low-precision one. There was also a high and significant correlation between upper limb muscle and brain activity during the tasks. The longer the time and the more precise the task, the more the subjects become fatigued both physically and mentally. Thus, these results could be potentially useful in managing fatigue, especially fatique related to muscle and mental workload.

upper limb muscle   brain activity   precision   repetitive light task

1. INTRODUCTION

Fatigue can occur because of either mental or muscular activity. The concept of mental fatigue, introduced by Grandjean, clearly differentiated mental fatigue from muscle fatigue. Grandjean defined muscle fatigue as concerned with reduced muscular system performance, while mental fatigue dealt with reduced mental performance and the sense of weariness. Muscular fatigue contributes to impaired co-ordination and increased chances of errors and accidents [1].

When people become fatigued, in addition to muscle fatigue, they usually report difficulties in concentrating and focusing their attention on the tasks they are required to perform [2]. This 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, as cited in Zadry, Dawal and Taha [3]). 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 is still hard to draw a generalized conclusion as to the method of selecting the most appropriate test battery for a given workload [4].

An empirical review showed there were many studies on muscle fatigue. Some 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 characterized jobs associated with a high risk for muscular problems. In contrast to muscle fatigue, relatively few studies have investigated both muscle and mental fatigue.

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Most studies observed the impact of mental activities on muscle and mental fatigue [5].

Repetitive movements, which are involved in most light-assembly work, seem to be among the most common hazard factors in certain types of work situations [6]. A repetitive light task is also a clear example of low intensity work with elevated risks of neck and shoulder disorders [7]. Although many studies investigated muscle fatigue in repetitive tasks, few research studies investigated the correlation between upper limb muscle and brain activities during repetitive light tasks with different levels of precision. Previous research on the effects of precision of a repetitive light task only measured muscle activity [6, 8, 9, 10]. It did not measure brain activity during the tasks. Wartenberg, Dukic, Falck, et al. investigated the aspect of precision and speed in an assembly task (i.e., tape application) [11]. Their findings showed that higher precision resulted in longer completion times per cycle, lower product quality and less postural movement (less variation) of the hand and head. Their study, however, did not include any measurements of muscle activation.

Many studies investigating muscle and brain activities involved laboratory experiments, and only a few surveys. Electromyography (EMG) is the most popular tool for measuring muscle activation and fatigue, whereas blood pressure, blink rate and heart rate are rarely used. Changes in the EMG activity (a decrease in the mean power frequency, MPF, and/or an increase in the EMG amplitude) during standardized voluntary contractions were frequently used as indicators of muscle fatigue [12, 13]. On the other hand, there were also a few studies that measured brain activity in light repetitive tasks using electroencephalography (EEG) [14]. Most studies used EEG to measure drowsiness or fatigue on drivers [15, 16] and night work [17, 18].

Therefore, this study aims to investigate the effects of precision levels on upper limb muscles (brachioradialis and upper trapezius) and brain activities (Fz, Pz, O1 and O2 channels[1]) and the relationship between upper limb muscle and brain activities during repetitive light tasks at different precision levels. In addition, subjective measurements were carried out simultaneously.

2. METHODOLOGY

2.1. Subjects

Ten subjects, 5 males and 5 females from the university population, were recruited to participate in the experiment. The subjects were 18–30 years old (22.80 ± 1.48). Potential participants were excluded if they had a history of any neurological, muscular or skeletal disease or disorder. Subjects were also excluded if they had taken any medication or substance that could affect motor and neurological performance.

2.2. Apparatus and Materials

Noraxon Surface Electromyography and Telemyo 2400 Gen2 Telemetric Real Time 8 channel SEMG System (Noraxon USA, USA) completed with disposable surface electrodes Ag/AgCl solid adhesive pregelled were used to record the electrical activity of muscles. EEG BIOPAC MP150 System with AcqKnowledge 4.0 software and Electrode Cap (CAP100C) (BIOPAC Systems, USA) were used to record brain activity. Vertical electrooculograms (EOG) were also recorded and later used to identify blink artifacts from the recorded EEG data. The EEG and EOG data were sampled at 1000 Hz.

2.3. Procedures

The subjects had to perform a repetitive light task at two levels of precision (low precision, LP, and high precision, HP). This task was based on Nakata, Hagner and Jonsson's study [6]. The subjects were supplied with wooden trays, 14 × 11 cm. One set of trays had 35 holes with a diameter of 6 mm (for LP). The other trays had 56 holes with a diameter of 1.5 mm (for HP). The subjects were asked to insert nails into the holes

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[1] An electrode placement on Fz was chosen because this location represents the intentional and motivational centres. On the other hand, Pz represents the activity of perception and differentiation [19]. The channels of O1 and O2 are where the primary visual area is located.

of the LP tray and colored needles into the holes of the HP tray. Both hands were used alternately. These work tasks were repeated for 2 h with 3-s cycle times without any pauses, on two days. The cycle time was based on the study of methods-time measurement (MTM) and Li and Buckle [20].

The two tasks were performed in a random order on two consecutive days between 9:00 and 13:00. To become familiar with the experimental equipment and procedures, a training session preceded the experiment. All sessions were performed in a laboratory at a normal temperature of 25 °C. The subjects sat in an ergonomically designed 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 a 90° angle when the hand was positioned in the middle of the desk and the upper arm was vertical.

At the start of each experimental day, maximal voluntary contractions (MVCs) of the right and left brachioradialis muscles and the right and left upper trapezius muscles were performed. For the brachioradialis muscles, the subjects were seated in the kneeling position (in front of a bench) with a stable forearm support. The MVCs were done against resistance from manual resistance (a belt with a load) with both hands. For the upper trapezius MVC, static resistance came from the investigator with manually fixating the arm to press down the shoulder [21].

Each MVC was performed three times; each lasted 5 s with a 30-s rest between contractions to allow for recovery. Force was not measured during these contractions and MVC will refer to the highest EMG amplitudes from the three MVC recordings. Normalizing EMG data was the main objective of performing these contractions.

The subjects also filled out subjective measurements of fatigue (Borg's CR-10 scale and mental fatigue scale, see section 2.4.3.) before and after the experiment. EMG and EEG measurements were recorded concurrently while the subjects were performing the tasks.

2.4. Data Collection

2.4.1. Surface EMG

EMG signals were recorded from four muscles: the brachioradialis and the descending part of the upper trapezius on the right and left arms. Bipolar Ag/AgCl surface electrodes were placed with an interelectrode distance of 20 mm at the belly of the muscles. The electrodes were located according to Hermens, Freriks, Disselhorst-Klug, et al. [22]. A reference electrode was placed on the piciform bone. The electrode positions were marked with a waterproof pencil to place the electrodes at the exact same positions for both conditions.

Before the electrodes were applied, the skin was cleaned with alcohol. The recording started

Figure 1. Subject doing the task.

when the interelectrode resistance was under 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 were continuously recorded with Telemyo 2400T G2 Telemetry EMG System.

From the three MVC tests per subject the one with the highest force output was used for further processing. The EMG data was normalized with MVC to obtain EMG RMS (root-main-square) (%MVC). The MPF was analyzed with a fast Fourier transformation with a sliding window of 1000 samples. The MPF values were normalized to the measurement at the beginning of the working day. The MPF values were calculated per window and averaged over one trial, resulting in one MPF value for each trial. Consequently, 24 MPF values were obtained during the tasks. A simultaneous decrease in the MPF is generally considered to be indicative of fatigue [23].

2.4.2. EEG

EEG was used to record the brain activity simultaneously with the surface EMG during the experiments. It was recorded using an AgCl electrode cap, with electrodes placed at Fz, Pz, O1, and O2 of the International 10-20 electrodes placement system [24] and with an electronic earlobe reference. Data were continuously recorded for 2 h with an MP150 system and analyzed with AcqKnowledge 4.0 software (BIOPAC Systems, USA).

Electrodes were checked before each testing session to ensure that the impedances were 5 kΩ or less. The bipolar recording technique was used to record the signals. The signals were band-pass filtered between 1 and 100 Hz and recorded digitally (1000 Hz sample frequency). The EEG was checked offline for artefacts. The EEG alpha band was defined as the frequency between 8 and 13 Hz. For this measurement, average power values over 5-min (24 epochs) periods were computed.

Eye movements were recorded with an electrooculogram (EOG). A right-eye EOG was obtained with electrodes positioned above and below the eye with a ground on the masseter. The EOG signal was used to identify blink artefacts in the EEG data as well as changes in blink types, such as the small and slow blinks that characterize fatigue.

2.4.3. Subjective measurement of fatigue

Subjective measurements of fatigue have been used to capture participant perceptions of fatigue during task performance [25]. It is important to understand the relationship between objective and subjective measures of muscle and mental fatigue, because humans react to the environment as they perceive it rather than as as it “really is” [26]. The advantage of using subjective measurements such as rating scales is that they are easy to administer and do not require any instrumentation or calibration. The process is generally noninvasive (although it may interrupt the task), and the data are easy to interpret. In this study, the measurement used was a modified Borg-CR10 and a mental fatigue scale. The surveys were administered before and after the experimental task.

The Borg-CR10 is a category scale with ratio properties that can yield ratios and levels and allow comparisons [26]. The scale ranges from 0 to 10, where 0 represents *no fatigue* and 10 represents *maximum fatigue*. The mental fatigue scale followed the measurements from a study by Huston [27]. The scale used is a 5-point bipolar scale consisting of four categories with descriptors. The categories are the subjects’ feelings of being *fresh/weary*, *awake/sleepy*, *physically strong/physically weak* and their level of *interest/boredom*.

2.5. Data Analysis

The EMG MPF and the EEG alpha band power were analyzed with SPSS version 16.0. For processing and filtering the signal, the software available together with the hardware was used. The Shapiro-Wilk test was used to analyze the normality of the data. The data were normally distributed.

The independent-samples t test was used to investigate the differences in the EMG MPF and EEG alpha band power between genders. The paired-samples t test was used to investigate the differences in EMG MPF and EEG alpha band power between LP and HP levels and to analyze the subjective measurements. Significance was accepted at $p < .05$. Correlation analysis was carried out to examine the relationship between EMG MPF and EEG alpha band power.

3. RESULTS

3.1. EMG RMS and MPF

Table 1 shows the mean of EMG RMS and EMG MPF data for all subjects in the 2-h experiment. The table demonstrates that EMG RMS and EMG MPF are higher on the HP task than on the LP task for all muscles. Moreover, the EMG RMS of the the muscles tends to increase while EMG MPF tends to decrease with time for both the LP and HP tasks. The significant increases in the EMG RMS were only found on the right brachioradialis for the HP task ($p = .026$) and on the left upper tapezius muscle for the LP task ($p = .010$). However, the significant decrease in the EMG MPF was found on almost all muscles, except for the left brachioradialis muscles for both the LP and HP tasks.

3.2. EEG Alpha Band Power

Table 2 demontrats that the EEG alpha band power for the Fz-Pz channels were higher on the LP task than the HP task. It is contrary with the O1-O2 channels, the EEG alpha band power was higher on the HP task than the LP task. The EEG alpha band power on all channels also tends to increase as the time increases.

3.3. Comparison Between Genders

The differences in muscle contractions between male and female subjects were investigated using the independent-samples t test. The analysis showed that the EMG RMS and EMG MPF of male and female subjects were not significantly different for either the LP or the HP task. Gender differences were also not found in the EEG alpha band power for either of the tasks.

TABLE 1. Mean (*SD*) of EMG MPF, EMG RMS and Slope for Low- (LP) and High-Precision (HP) Tasks

	Right Brachioradialis				Left Brachioradialis			
Fatigue Measure	**LP**		**HP**		**LP**		**HP**	
EMG RMS (%MVC)	6.09	(0.23)	8.68	(0.70)	4.81	(0.16)	8.97	(0.38)
EMG MPF (Hz)	76.03	(1.09)	80.21	(1.64)	78.03	(1.09)	80.18	(1.34)
EMG RMS slope	0.03	(0.04)	0.10*	(0.12)	0.01	(0.04)	0.05	(0.08)
EMG MPF slope	–0.09*	(0.34)	–0.20*	(0.33)	–0.04	(0.28)	–0.13	(0.38)
	Right Trapezius				**Left Trapezius**			
Fatigue Measure	**LP**		**HP**		**LP**		**HP**	
EMG RMS (%MVC)	8.39	(1.18)	10.76	(0.90)	7.39	(1.15)	8.21	(1.20)
EMG MPF (Hz)	58.09	(2.14)	59.39	(1.56)	51.07	(1.38)	52.49	(0.75)
EMG RMS slope	0.16	(0.24)	0.11	(0.20)	0.15**	(0.15)	0.14	(0.23)
EMG MPF slope	–0.19*	(0.34)	–0.18**	(0.24)	–0.15**	(0.29)	–0.04**	(0.20)

Notes. **—changes (increase/decrease) significant at .01; *—changes (increase/decrease) significant at .05; EMG—electromyography, MPF—mean power frequency, RMS—root-mean-square, MVC—maximal voluntary contractions.

TABLE 2. Mean (*SD*) of EEG Alpha Band Power and Slope for Low- (LP) and High-Precision (HP) Tasks

Fatigue Measure	**Alpha Power of Fz-Pz Channel**		**Alpha Power of O1-O2 Channel**	
	LP	**HP**	**LP**	**HP**
EEG alpha power (V^2/Hz)	6.80E-07 (6.77E-08)	6.07E-07 (3.88E-08)	9.56E-07 (1.91E-07)	1.06E-06 (1.69E-07)
EEG alpha power slope	6.18E-09 (5.34E-09)	4.69E-09 (2.10E-09)	2.23E-08 (3.82E-08)	2.02E-08 (2.71E-08)

Notes. EEG—electroencephalography.

3.4. Comparison Between LP and HP Tasks

Analysis using paired-samples *t* test showed there was no significant difference in the EMG RMS between LP and HP tasks. A significant difference was only found in the EMG MPF between LP and HP tasks for the left upper trapezius muscle. However, the differences between the LP and HP tasks were not significant for the other muscles. The EEG alpha band power levels for all channels were also not significantly different between LP and HP tasks (Table 3).

3.5. Correlation Analysis Between Muscle and Brain Activities

Tables 4–5 summarize the correlation analysis between muscle and brain activities on the LP and HP tasks. Significant high correlations between muscle and brain activities were found on the LP task between the MPF of the right brachioradialis muscle and the O1-O2 channel ($r = -.644$, $p < .001$), and the MPF of the left brachioradialis muscle and the O1-O2 channel ($r = -.605$, $p < 0.001$). Significant correlations were also found between the MPF of the left brachioradialis muscle and the Fz-Pz channel, the MPF of the MPF of the right upper trapezius muscle and the

TABLE 3. Paired-Samples *t*-Test Results for Comparison of EMG RMS, EMG MPF and EEG Alpha Band Power Between Low- and High-Precision Tasks

Muscles	Mean Difference	*SD*	Sig. (2-tailed)
RMS of right brachioradialis	–2.589	6.738	.255
RMS of left brachioradialis	–4.152	8.102	.140
RMS of right upper trapezius	–2.369	4.419	.124
RMS of left upper trapezius	–0.828	3.717	.499
MPF of right brachioradialis	–10.151	15.127	.126
MPF of left brachioradialis	–3.827	6.932	.194
MPF of right upper trapezius	–5.504	8.988	.156
MPF of left upper trapezius	–23.395	9.410	.001**
Fz-Pz	4.E-08	2.E-07	.640
O1-O2	5.E-08	7.E-07	.865

Notes. ***p* < .01; sig.—significance; EMG—electromyography, RMS—root-mean-square, MPF—mean power frequency, EEG—electroencephalography, Fz-Pz—alpha power of Fz-Pz channel, O1-O2—alpha power of O1-O2 channel.

TABLE 4. Pearson Correlation Analysis Between EMG RMS, EMG MPF and EEG Alpha Band Power for a Low-Precision Task

	MPF RT_Br	MPF LT_Br	MPF RT_Tr	MPF LT_Tr	RMS RT_Br	RMS LT_Br	RMS RT_Tr	RMS LT_Tr	Fz-Pz	O1-O2
MPF RT_Br	1	.733**	−.158	.244	−.424*	−.270	−.653**	−.623**	−.404	−.664**
MPF LT_Br	.733**	1	−.378	.261	−.408*	−.327	−.701**	−.570**	−.412*	−.605**
MPF RT_Tr	−.158	−.378	1	.238	.115	.134	.353	.259**	.278	.453*
MPF LT_Tr	.244	.261	.238	1	−.310	−.323	−.279	−.428*	−.421*	−.117
RMS RT_Br	−.424*	−.408*	.115	−.310	1	.748**	.791**	.859**	.484*	.675**
RMS LT_Br	−.270	−.327	.134	−.323	.748**	1	.597**	.540**	.187	.345
RMS RT_Tr	−.653**	−.701**	.353	−.279	.791**	.597**	1	.883**	.538**	.846**
RMS LT_Tr	−.623**	−.570**	.259	−.428*	.859**	.540**	.883**	1	.730**	.848**
Fz-Pz	−.404	−.412*	.278	−.421*	.484*	.187	.538**	.730**	1	.631**
O1-O2	−.664**	−.605**	.453*	−.117	.675**	.345	.846**	.848**	.631**	1

Notes. **—significant at .01 (2-tailed), *—significant at .05 (2-tailed); EMG—electromyography, RMS—root-mean-square, MPF—mean power frequency, EEG—electroencephalography; RT—right, LT—left, Br—brachioradialis, Tr—trapezius, Fz-Pz—alpha power of Fz-Pz channel, O1-O2—alpha power of O1-O2 channel.

TABLE 5. Pearson Correlation Analysis Between EMG RMS, EMG MPF and EEG Alpha Band Power for a High-Precision Task

	MPF RT_Br	MPF LT_Br	MPF RT_Tr	MPF LT_Tr	RMS RT_Br	RMS LT_Br	RMS RT_Tr	RMS LT_Tr	Fz-Pz	O1-O2
MPF RT_Br	1	.754**	.625**	.253	−.720**	−.719**	−.630**	−.741**	−.613**	−.585**
MPF LT_Br	.754**	1	.525**	.244	−.504*	−.450*	−.336	−.492*	−.477*	−.519**
MPF RT_Tr	.625**	.525**	1	.418*	−.737**	−.722**	−.462*	−.661**	−.700**	−.732**
MPF LT_Tr	.253	.244	.418*	1	−.599**	−.497*	−.358	−.507*	−.537**	−.573**
RMS RT_Br	−.720**	−.504*	−.737**	−.599**	1	.927**	.847**	.822**	.856**	.855**
RMS LT_Br	−.719**	−.450*	−.722**	−.497*	.927**	1	.776**	.813**	.824**	.803**
RMS RT_Tr	−.630**	−.336	−.462*	−.358	.847**	.776**	1	.606**	.743**	.714**
RMS LT_Tr	−.741**	−.492*	−.661**	−.507*	.822**	.813**	.606**	1	.619**	.747**
Fz-Pz	−.613**	−.477*	−.700**	−.537**	.856**	.824**	.743**	.619**	1	.827**
O1-O2	−.585**	−.519**	−.732**	−.573**	.855**	.803**	.714**	.747**	.827**	1

Notes. **—significant at .01 (2-tailed), *—significant at .05 (2-tailed); EMG—electromyography, RMS—root-mean-square, MPF—mean power frequency, EEG—electroencephalography, Fz-Pz—alpha power of Fz-Pz channel, O1-O2—alpha power of O1-O2 channel.

O1-O2 channel, and between the MPF of the left upper trapezius muscle and the Fz-Pz channel. However, the correlations were not high ($r < .5$).

For the HP task, significant high correlations between muscle and brain activities were found between all of the muscles and the EEG channels. The highest correlation was between the RMS of the right brachioradialis muscle with the Fz-Pz and O1-O2 channel ($r = .856$ and $r = .855$, respectively, $p < .001$). The other correlations have $r > .5$, except that the correlation between the MPF of the left brachioradialis muscle and the Fz-Pz channel has $r < .5$.

3.6. Subjective Measurements

3.6.1. Perceived muscle fatigue

The perceived muscle fatigue ratings with the Borg CR-10 scale [26] increased during the task at both levels of precision. During the LP task, the perceived muscle fatigue of the subjects for the whole body increased significantly from 0.038 (*no fatigue*) before the experiment to 1.438 (*weak*) after the experiment ($p = .007$). Significant increases in perceived muscle fatigue ratings were also found on the right and left shoulder and lower arm muscles (Table 6).

During the HP task, perceived muscle fatigue ratings increased significantly for the whole body from 0.027 (*no fatigue*) to 1.500 (*weak*) ($p = .001$). A similar result was found on the right and left shoulder and lower arm. However, the increases in the perceived muscle fatigue ratings were not significant between the LP and HP tasks.

TABLE 6. Perceived Muscle Fatigue Analysis (Mean Ratings)

	LP		HP	
Body Part	**Before**	**After**	**Before**	**After**
Whole body	0.038	1.438**	0.027	1.500**
Right shoulder	0.038	1.864**	0.027	2.438**
Left shoulder	0.038	1.509**	0.000	2.188**
Right lower arm	0.038	1.775**	0.000	1.818**
Left lower arm	0.038	1.600**	0.027	1.718**

Notes. ** $p < .01$; LP—low-precision task, HP—high-precision task.

3.6.2. Perceived mental fatigue

The results of the subjective ratings for mental fatigue were statistically analyzed with the paired-samples *t* test. This statistical technique tested the significance of the time and the condition factors. The first subjective measurement analyzed was the *fresh/weary* measurement. The results in Table 7 show that there is an obvious increase in the mental fatigue ratings after the experiment for each task. The results indicated the subjects would feel wearier in the later parts of experiment, while feeling fresher in the earlier stages of experiment.

TABLE 7. Perceived Mental Fatigue Analysis (Mean Ratings)

Mental Fatigue Scale	LP		HP	
	Before	After	Before	After
Fresh–weary	1.125	2.636**	1.091	2.750**
Awake–sleepy	1.375	2.545**	1.182	3.000**
Strong–weak	1.222	2.778**	1.273	2.818**
Interested–bored	1.625	3.091**	1.455	3.250**

Notes. $^{**}p < .01$; LP—low-precision task, HP—high-precision task.

The next category pertained to the subjects' drowsiness. This category is the *awake/sleepy* measurement. Once more, there was an obvious rise in the mean rating after the experiment. The differences in the mean rating were significant between before and after the experiment for both levels. The subjects felt sleepier toward the end of the experiment as opposed to the beginning.

The *strong/weak* measurement analysis shows that the mean values of the rating were significantly higher after the experiment for both levels. The final subjective category is the level of boredom. The ratings also increased after the experiment compared to before the experiment for both levels. However, the *t* test showed that the precision levels (LP and HP) did not cause significant differences on all the mental fatigue scales.

4. DISCUSSION

In the current study, muscle and brain activity was investigated in the laboratory on subjects while they were performing a repetitive light task at two levels of precision. Muscle activity was recorded with surface EMG, while brain activity was recorded with EEG.

Muscle fatigue in the upper extremity muscles has been studied extensively during low force isometric contractions [28, 29]. However, muscle fatigue during dynamic and light assembly tasks has been examined in only a few studies [7, 30, 31]. Moreover, there were relatively few studies on both muscle and mental fatigue. More studies observed the impact of brain activity on muscle and mental fatigue. Those studies indicated that there was a relation between muscle and mental fatigue, which could lead to mental stress and muscle tension. In addition, slow and fast conditions, which can be defined as time pressure, can also lead to muscle fatigue. However, there are no studies on the effect of the precision of a repetitive light task on muscle and mental fatigue, and their correlations.

Muscle fatigue can be characterized by a feeling of tightening in the muscle, a sustained cramp with deep and intermittent pain, and continuous pain with a desire to cease the work or activity. Indications of muscle fatigue using EMG include an increase in the EMG amplitude and a decrease in the MPF [12, 13, 32]. EEG is sensitive to a variety of states ranging from stress and alertness to rest and sleep. During a normal state of wakefulness with open eyes, beta waves are dominant. In relaxation or drowsiness, alpha activity rises, and with the onset of sleep, the power of lower frequency bands increases [33].

Our results show that the EMG MPF is lower on the LP task than on the HP task for all muscles. This indicates that the HP task requires more muscle activity than the LP task. Those results were in line with Sporrong, Palmerud, Kadefors, et al.'s [8], who found that light manual precision work increased shoulder muscle activity as revealed by EMG. However, the differences between the precision factors (LP and HP) were only significant for the left upper trapezius muscle (p = .001). This is thought to reflect a decreased conduction velocity of muscle fibers, which is related to fatigue development (De Luca, 1984, as cited in Kingma, Bosch, De Looze, et al. [34]).

Some possible explanations for the small significant differences in EMG RMS and MPF between LP and HP tasks can be given. Firstly, methodological limitations might explain the lack of an effect in our study. The differences between the weights of the objects used in both tasks were almost the same and very light; therefore, they were too small to be reflected by EMG. Secondly, the effect of the speed in the task might be an explanation. Laursen, Jensen and Sjùgaard showed that speed and precision demands were often related and affected the EMG [9]. They found that the greatest effect of precision demand was in combination with a high speed. At a low speed precision had little or no influence on EMG. In this study, the speed for the LP and HP tasks was similar and it was determined by MTM. Therefore, precision had little influence on EMG.

Table 1 also shows that the EMG RMS of the muscles tends to increase with time while the EMG MPF of the muscles tends to decrease with time for both the LP and HP tasks. This can be a sign of muscle fatigue [7, 31]. Oberg et al. (1990), as cited in Nakata et al. [6], suggested that only a decrease in MPF during a test contraction exceeding 8% of its initial value should be considered a significant sign of muscle fatigue. In this study, no muscle showed a decrease in MPF as great as this suggested value; the mean decrease was only ~3.56%. However, in this study, the EMG MPF was sensitive to an increase in time and the symptoms of muscle fatigue. The changes in the EMG MPF were mostly significant on all muscles compared to the EMG RMS, indicating that the EMG MPF was more useful in evaluating muscle fatigue. These results suggest that such measures can be reliably used to evaluate muscle fatigue. This supports Murata, Uetake, Matsumoto, et al.'s results [35].

The present study showed the activity of the brachioradialis muscles was not as high as the activity of the upper trapezius muscles. The brachioradialis muscles did not really influence the MPF results compared to the upper trapezius muscles. Previous studies had the same results. The slight or lack of EMG activity was seen throughout the movement of the brachioradialis muscles without the load and with a small torque of the load [36]. The differences in RMS were not significant in the isometric test for the brachioradialis muscle, which indicated the lower activation of the brachioradialis [32]. Bonnefoy, Louis and Gorce also found that the brachioradialis muscle activation was not influenced by the distance [37]. This can be explained by difficulties in recording the EMG signal of this muscle site, which is not as large and developed as the other muscles recorded.

Like the results of the surface EMG, the results from the EEG showed that the EEG alpha bands power were higher during the HP task than during the LP task on the O1-O2 channels. The opposite was true for the Fz-Pz channels, where the power of the EEG alpha bands on the LP task was higher than on the HP task. However, these differences were not statistically significant. In contrast to the EMG MPF, the graphs showed that the mean power of the EEG alpha bands on all channels tended to increase as the time increased. The increased EEG alpha band power indicates that the subjects experienced drowsiness. These results were in step with several EEG studies related to driving. Pal, Chuang, Ko, et al. [38] and Kee, Tamrin, Goh, et al. [39] observed that the EEG power of the alpha and theta bands increased as the alertness level of the driver decreased. Alpha activity reflects a relaxed wakefulness state, and decreases with concentration, stimulation or visual fixation. According to Thorsvall and Akerstedt (1984), as cited in Jap, Lal, Fischer, et al. [40], alpha activity was the most sensitive measure that could be used in detecting fatigue, followed by theta and delta activity.

The results of the independent *t* test (SPSS version 16.0) showed there was no significant difference in the EMG RMS, EMG MPF and EEG alpha band power between male and female subjects on both levels of tasks. This may require additional clarification because of the small number of subjects. The results might have been significantly different if the study included more subjects.

Correlation analysis results showed there was a significant and high correlation between EMG muscles and EEG channels. The positive correlations between EMG RMS and EEG alpha band power indicated that as the EMG RMS increased, so did the EEG alpha band power. This indicates that if the muscles begin to fatigue, the brain also begins to fatigue. For the LP task, significant and high correlations were found between EMG MPF of the right and left brachioradialis muscles with alpha band power of the O1-O2 channel ($r = -.644$ and $r = -.605$, respectively). High and significant correlation were also found between EMG RMS of the right and left trapezius muscles with alpha band power of the O1-O2 channel (r = .846 and r = .848, respectively).

For the HP task, high and significant correlations were found between EMG RMS of the right and left brachioradialis muscles with alpha band power of the Fz-Pz (r = .856 and r = .824) and O1-O2 (r = .855 and r = .803) channels. It was followed by the correlation between EMG RMS of the right and left upper trapezius muscles with Fz-Pz (r = .743 and r = .619) and O1-O2 (r = .714 and r = .747) channels. All of the r values were over .700, except for the correlation between the right trapezius and the Fz-Pz channel.

In this study, higher correlations were mostly found between muscles and O1-O2 channels. The O1 and O2 points in EEG channels are near the primary visual area [33]. Therefore, the explanation for these correlations might be that as the muscle activity increases, the subjects become drowsy. Drowsiness is one indication of mental fatigue. Hence, the study showed that there was a correlation between upper limb muscles and brain activity during the repetitive light task. Over time, the tasks increases the activity of both the muscles and the brain [41].

The perceived muscle fatigue ratings after the experiment were higher than those before it. Lower rates of perceived muscle fatigue on all body parts after the experiment were found at the LP level compared to the HP level. These results are supported by studies that found that the more stressful the task, the higher the rating of perceived exertion for the workload selected by the subjects [42].

Similar results are found for the perceived mental fatigue analysis. This finding indicates that the HP task is considered more fatiguing. This means that the subjects felt *wearier*, *sleepier*, *weaker*, and *more bored* in the HP task compared to the LP task. Furthermore, the results show that subjects felt *wearier*, *sleepier*, *weaker*, and *more bored* after the experiment than before. In other words, the subjects perceived more fatigue towards the end of the experiment.

The subjective measurement results support the objective measurement (EMG and EEG) results. They show that the upper limb muscle and brain activity increased over the course of the experiment. The longer the time and the greater the precision of the task, the more the subjects are physically and mentally fatigued.

5. CONCLUSION

Muscle and mental fatigue were successfully induced through the precision task; it was found to occur in agreement with perceived fatigue changes during the task period. Muscle and brain activity are greater in the HP task than in the LP one. Thus, the level of precision affects muscular and brain activity. However, the differences in muscle and mental activity between the precision factors were not significant, since they were also influenced by the load and the speed of the task. The relationship between muscle and brain activity was found when repetitive light tasks were done without rest or break times. Therefore, the longer the time and the more precise the task, the more the subjects become fatigued both physically and mentally. Thus, in the future, a quantitative model for predicting time to muscle and mental fatigue should be developed; it would be potentially applicable in managing fatigue in industry.

REFERENCES

1. Kroemer KHE, Grandjean E. Fitting the task to the human—a text book of occupational ergonomics. 5th ed. New York, NY, USA: Taylor & Francis; 2001.
2. Boksem M, Meijman TF, Lorist MM. Effects of mental fatigue on attention: An ERP study. Cogn Brain Res. 2005;25:107–16.
3. Zadry HR, Dawal SZ, Taha Z. Effect of load on upper limb muscle and brain activity in light assembly task. In: Proceedings of the International MultiConference of Engineers and Computer Scientists 2010, vol. III. 2010. Retrieved September 20, 2011, from: http://www.iaeng.org/publication/IMECS2010/IMECS2010_pp1971-1976.pdf
4. Saito K. Measurement of fatigue in industries. Ind Health. 1999;37:134–42.
5. Zadry HR, Dawal SZ, Taha Z. Muscle and mental fatigue on repetitive tasks in

industry: a mini review. In: International Conference on Ergonomics (ICE). Kuala Lumpur, Malaysia: University of Malaya; 2007. p. 52.

6. Nakata M, Hagner IM, Jonsson B. Perceived musculoskeletal discomfort and electromyography during repetitive light work. J Electromyogr Kinesiol. 1992; 2(2):103–11.
7. Mathiassen SE, Winkel J. Physiological comparison of three interventions in light assembly work: reduced work pace, increased break allowance and shortened working days. Int Arch Occup Environ Health. 1996;68:94–108.
8. Sporrong H, Palmerud G, Kadefors R, Herberts P. The effect of light manual precision work on shoulder muscles—an EMG analysis. J Electromyogr Kinesiol. 1998;8:177–84.
9. Laursen B, Jensen BR, Sjùgaard G. Effect of speed and precision demands on human shoulder muscle electromyography during a repetitive task. Eur J Appl Physiol. 1998; 78:544–8.
10. Nordander C, Balogh I, Mathiassen SE, Ohlsson K, Unge J, Skerfving S, et al. Precision of measurements of physical workload during standardised manual handling. Part I: surface electromyography of m. trapezius, m. infraspinatus and the forearm extensors. J Electromyogr Kinesiol. 2004;14:443–54.
11. Wartenberg C, Dukic T, Falck AC, Hallbeck S. The effect of assembly tolerance on performance of a tape application task: a pilot study. Int J Ind Ergon. 2004;33(4): 369–79.
12. Madeleine P, Jørgensen LV, Søgaard K, Arendt-Nielsen L, Sjøgaard G. Development of muscle fatigue as assessed by electromyography and mechanomyography during continuous and intermittent low-force contractions: effects of the feedback mode. Eur J Appl Physiol. 2002;87(1):28–37.
13. Dimitrova NA, Dimitrov GV. Interpretation of EMG changes with fatigue: facts, pitfalls, and fallacies. J Electromyogr Kinesiol. 2003;13(1):13–36.
14. Zadry HR, Dawal SZ. Future research on muscle and mental fatigue in industry: a mini review. In: Abu Osman NA, Ibrahim F, Wan Abas WAB, Abd Rahman HS, Ting HN, editors. 4th Kuala Lumpur International Conference on Biomedical Engineering. IFMBE Proceedings, Vol. 21, Part 3, Part 13. Berlin, Germany: Springer; 2008. p. 794–7.
15. Lal SKL, Craig A. Review: a critical review of the psychophysiology of driver fatigue. Biol Psychol. 2001;55:173–94.
16. Eoh HJ, Chung MK, Kim SH. Electroencephalographic study of drowsiness in simulated driving with sleep deprivation. Int J Ind Ergon. 2005;35:307–20.
17. Gillberg M, Kecklund G, Goransson B, Akerstedt T. Operator performance and signs of sleepiness during day and night working a simulated thermal power plant. Int J Ind Ergon. 2003;31:101–09.
18. Åkerstedt T, Kecklund G, Gillberg M. Sleep and sleepiness in relation to stress and displaced work hours. Physiol Behav. 2007;92:250–5.
19. Teplan M. Fundamentals of EEG measurement. Measurement Science Review. 2002; 2(2):1–11.
20. Li G, Buckle P. A practical method for the assessment of work-related musculoskeletal risks—quick exposure checks (QEC). In: Proceedings of the Human Factors and Ergonomics Society 42nd Annual Meeting. Santa Monica, CA, USA: Human Factors Society; 1998. p. 1351–5.
21. Konrad P. The ABC of EMG, a practical introduction to kinesiological electromyography. Scottsdale, AZ, USA: Noraxon; 2005.
22. Hermens HJ, Freriks B, Disselhorst-Klug C, Rau G. Development of recommendations for SEMG sensors and sensor placement procedures. J Electromyogr Kinesiol**.** 2000; 10:361–74.
23. Yamada H, Okada M, Oda T, Nemoto S, Shiozaki T, Kizuka T, et al. Effects of aging on EMG variables during fatiguing isometric contractions. J Hum Ergology. 2000;29(1–2):7–14.
24. Andreassi JL. Psychophysiology: human behavior and physiological response. 4th ed. Mahvah, NJ: Erlbaum; 2000.
25. Quiñones-Vientós S. Quantifying localized muscle fatigue of the forearm during

simulations of high pressure cleaning lance tasks [master's thesis]. Blacksburg, USA: Virginia Polytechnic Institute and State University; 2005.

26. Borg G. Borg's perceived exertion and pain scales. Stockholm, Sweden: Human Kinetics; 1998.
27. Huston TR. An investigation into knowledge worker mental fatigue and restbreak duration [doctoral dissertation]. Cincinnati, OH, USA: University of Cincinnati; 1985.
28. Blangsted AK, Vedsted P, Sjøgaard G, Søgaard K. Intramuscular pressure and tissue oxygenation during low-force static contraction do not underlie muscle fatigue. Acta Physiol Scand. 2005;183(4):379–88.
29. Madeleine P, Farina D, Merletti R, Arendt-Nielsen L. Upper trapezius muscle mechanomyographic and electromyographic activity in humans during low force fatiguing and non-fatiguing contractions. Eur J Appl Physiol. 2002;87:327–36.
30. Bosch T, De Looze MP, Van Dieen JH. Development of fatigue and discomfort in the upper trapezius muscle during light manual work. Ergonomics. 2007;50(2): 161–77.
31. Bosch T, De Looze MP, Kingma I, Visser B, Van Dieen JH. Electromyographical manifestations of muscle fatigue during different levels of simulated light manual assembly work. J Electromyogr Kinesiol. 2009;19: 246–56.
32. Hostens I, Segher J, Spaepen A, Ramon H. Validation of the wavelet spectral estimation technique in biceps brachii and brachioradialis fatigue assessment during prolonged low-level static and dynamic contractions. J Electromyogr Kinesiol. 2004;14:205–15.
33. Kingma I, Bosch T, De Looze MP, Visser B, Van Dieën JH. Development of fatigue in the trapezius muscle in two levels of light manual assembly work. J Biomech. 2007;40 Suppl 2:S71 (DOI:10.1016/S0021-9290(07)70068-4).
34. Murata A, Uetake A, Matsumoto S, Takasawa Y. Evaluation of shoulder muscular fatigue induced during VDT tasks. Int J Hum Comput Interact. 2003;15(3):407–17.
35. Naito A, Sun YJ, Yajima M, Fukamichi H, Ushikoshi K. Electromyographic study of the elbow flexors and extensors in a motion of forearm pronation/supination while maintaining elbow flexion in humans. Tohoku J Exp Med. 1998;186:267–77.
36. Bonnefoy A, Louis N, Gorce P. Muscle activation during a reach-to-grasp movement in sitting position: influence of distance. J Electromyogr Kinesiol. 2009; 19:269–75.
37. Pal NR, Chuang CY, Ko LW, Chao CF, Jung TP, Liang SF, et al. EEG-based subject- and session-independent drowsiness detection: an unsupervised approach. EURASIP J Adv Signal Process. 2008; 2008:1–11 (DOI:10.1155/2008/519480). Retrieved September 20, 2011, from: http://www.hindawi.com/journals/asp/2008/519480/
38. Kee SS, Tamrin SBM, Goh, YM. Driving fatigue and performance among occupational drivers in simulated prolonged driving. Glob J Health Sci. 2010; 2(1):167–77.
39. Jap BT, Lal S, Fischer P, Bekiaris E. Using EEG spectral components to assess algorithms for detecting fatigue. Expert Syst Appl. 2009;36:2352–9.
40. Zadry HR, Dawal SZ, Taha Z. Investigation of upper limb muscle and brain activities on light assembly tasks: a pilot study. In: Proceedings of the International Conference of Technical Postgraduates (TECHPOS). Kuala Lumpur, Malaysia: University of Malaya; 2009. p. 1–4.
41. Adams KJ, DeBeliso M, Sevene-Adams PG, Berning JM, Miller T, Tollerud DJ. Physiological and psychophysical comparison between a lifting task with identical weight but different coupling factors. J Strength Cond Res. 2010;24(2):307–12.