Investigation on Time to Fatigue for Upper Limb Muscle during a Repetitive Light Assembly Task

Santy and S. Z. Dawal

***Abstract*— Repetitive tasks are known as one of the prevalent root causes of muscle fatigue. Light assembly tasks, which are common in electronic and electrical industries, are a class of repetitive tasks with involving light weight (< 1 kg). The upper limb region was reported as most complained of strain by the workers doing this type of job. This study aims to investigate the time to fatigue for upper limb muscles in a light assembly task. Twenty subjects (10 males and 10 females) with mean (SD) age of 24.05 (1.76) years performed a light assembly task continuously for two hours. The time to fatigue was defined by significant changes in RMS of electromyography as well as grip strength. Results from RMS EMG show that upper trapezius muscle (right and left) was the muscle fastest being fatigued the fasted (90 minute), followed the right and the left anterior deltoid (95 minutes), the right and the left brachioradialis (100 minutes) and right and the left bicep brachii muscle (110 minutes). On the other hand, a significant change in grip and pinch strength occurred after 100 minutes and 120 minutes work, respectively.**

***Index terms*—Electromyography, fatigue time, light assembly task, upper limb muscles**

I. Introduction

Repetitiveness (the extent of use of similar motions at work) has been identified as a major risk factor for work-related upper-extremity musculoskeletal disorders (UEMSDs). Latko [1] showed that repetitiveness is associated with the clinical symptoms (such as pain, weakness, clumsiness, numbness) of the tendon and nerve disorders at the hand and wrist. Report from European Agency of Safety and Health at Work shows that in 2001, repetitiveness is reach to 71% as causal factor of upper extremities [2]. Bureau of Labor Statistic [3] also reported that in 2007, injuries from repetitive motion continue to be the event with the highest median away days from work for all private industry.

Light assembly task is an example of repetitive task that common in electrical and electronic industries. Assembly task means fitting two or more discrete parts together to form a product [4]. The assembly operation involves considerable amount of handling, positioning and orienting of parts and applying controlled force to mate them together properly. Upper extremities of human body are proved to be mostly used to perform this kind of task [5].

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In today's competition, assembly industries are under a great deal of pressure. In one hand, there is a forced to increase the number of product but on the other hand there is a pressure to reduce the cost price, whilst retaining the quality. The pressure on companies is likely to reflect the pressure for all workers, and more on each operator. A successful approach combines the expertise of both ergonomics and industrial engineer solves this problem. The ergonomist are focus on human involvement in the production process, while industrial engineer is more on the improvement of the assembly process in term of lead time and cost reduction and improvement of product quality.

Review on literature shows only a few papers studied on light assembly task related to MSDs in the literature. Bosch et. al [6] studied the effect of intensity level (at 8 % MVC and 12 % MVC) on upper trapezius muscle in simulated light assembly task. Subject performed simulated light assembly (constructing a small tower of eight blocks) for three hours. The study found that there is a significant decrease in the mean power frequency (MPF) of EMG, at both intensity levels while the amplitude remained constant.

One of the most often applied methods of assessing local muscular load is an analysis of the Electromyography (EMG) signals [6]. Electromyography used more often to evaluate lighter, repetitive work where the activity of specific muscle interest [7]. The EMG signal is the electrical manifestation of neuromuscular activation associated with a contracting muscle. The signal represents the current generated by the ionic flow across the membrane of the muscle fibers that propagates through the intervening tissue to reach the detection surface of an electrode located in the environment [8].

Nordander [9] evaluated gender effect on EMG signals in mechanical assembly plant. Muscle rest and percent of maximum EMG was measure in upper trapezius muscle and forearm extensor. Registered amplitudes were expressed as percentages of values registered during maximal voluntary contractions (%MVE). Hence, the muscular activity was normalized to the capacity of the individual. For each muscle, the EMG amplitude during work was expressed as the 10th, 50th, and 90th percentiles of the amplitude probability distribution function (APDF). The study shows that females had higher muscular activity (50% higher for trapezius and 44% higher for the right forearm extensors at the 90th percentile).

Therefore, the objective of the study is to investigate the time to fatigue for upper limb muscle during a repetitive light assembly task.

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II. METHODS

A. Subjects

Twenty subjects (ten males and ten females) with mean (SD) age of 24.05(1.76) years old were participated. All participants are right handed, have no history of any upper limb in the last year. They were allowed to practice the task until they become familiar with it.

B. Task and Experimental Design

Subjects were asked to perform a light assembly task using BlockSet^{TM}. The blocks were placed on the right and left side of the subjects in normal and maximum reach area in horizontal plane. Normal and maximum reach area are defined by a sweep of the forearm and arm. It is suggested by some guides, that tools, part, and fixture located in this range area [10]. Subjects were comfortably seated in ergonomics chairs and ergonomics appropriate posture. The ambient temperature (25^{o}-27^{o}) in the laboratory was kept constants during the study. The task consists of taking blocks to assemble and construct a tower of twenty blocks. This task was done by the subjects in cycle time of 30 seconds. Both hands were used in alternating orders and one block was picked up at a time. After completing the task, subjects were asked to put the output it in front of them. This task was repeated over two hours and paused every 20 minutes to allow measuring of grip and pinch strength.

C. Muscles Monitored

The research investigated on the activity of upper limb muscle while performing a light assembly task. The selected muscles investigated in the study are brachioradialis, biceps brachii, anterior deltoid, upper trapezius, and Table I summaries the muscles involved in the study.

TABLE I
SIGNIFICANT MUSCLES INVOLVED IN THE STUDY

Muscle	Function
Brachioradialis	Flexion of the forearm Extension of the forearm
Biceps Brachii	Flexion of the forearm Extenstion of forearm
Anterior Deltoid	Abduction of humerus Rotation of humerus
Upper Trapezius	Elevation, retraction, and rotation of scapula

D. EMG recording and Analysis

Surface EMG (Noraxon USA Inc.,Basic Edition) was utilized to record signals from eight upper limb muscles (right and left brachioradialis, right and left biceps brachii, right and left anterior deltoid, right and left upper trapezius). EMG signals were picked up by using bipolar Ag/AgCl electrode. Electrodes were placed on the muscles according to Marras [8] to obtain the excellent quality of signals. A sampling rate of 1500 Hz and band pass filter (20-400 Hz) was used to eliminate the movement artifact. Then the signals were cleaned from ECG signal and rectified and smoothing to root mean square. The signals were also normalized to the maximum voluntary contraction (MVC) in order to get the percentage of muscle activity within the work to the maximum that workers can carried out. The MVC was done for each muscle separately. It is because each muscle has a different function as shown in Table 1. Therefore, the specific task/posture is needed to determine the maximum value of muscle strength. The EMG signals were recorded in real time during two hours experiment.

III. RESULT

A. Mean RMS of EMG

Fig. 1 shows that for all muscle, female had higher RMS compare to the male. The results showed that the right and the left upper trapezius had the highest RMS among eight investigate muscles. The right upper trapezius had the higher RMS of EMG than the left upper trapezius. The second highest RMS was different for right and left hand. Second highest RMS for right hand was anterior deltoid (female =8.82, male =5.91), while for left hand was brachioradialis (female =9.29, male =5.55). The result also shows that biceps brachii muscle had the lowest RMS on the right ((female =5.96, male =4.48) and left hand (female =5.43, male =3.35).

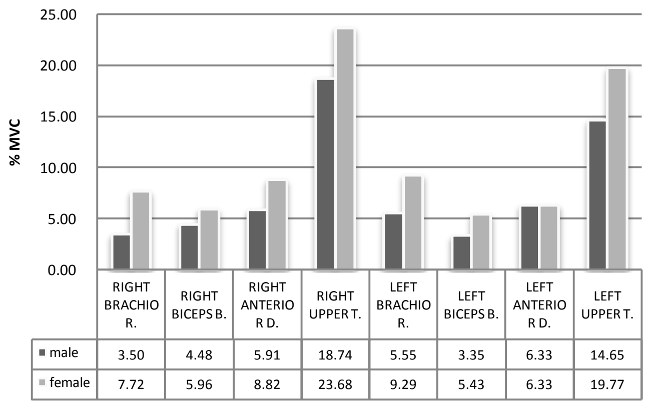

Fig. 1 Mean RMS of EMG of upper limb muscle in light assembly task

B. Significant Differences of RMS of EMG between male and females subjects.

Result from independent sample t-test indicated that there were no significant difference of RMS and MPF of EMG between male and female subjects (df= 18, $p< 0.05$) for all muscles (Table II). The differences of RMS of EMG between male and female was in range of 0.330 (left anterior deltoid) to 6.723 (upper trapezius).

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TABLE II
INDEPENDENT SAMPLE T- TEST OF RMS OF EMG BETWEEN MALES AND FEMALES

Muscle	t-test for Equality of Means						
	t	df	Sig. (2-tailed)	Mean Diff.	Std. Error Diff.	95% Confidence Interval of the Difference	
						Lower	Upper
Brachioradialis (Right)	-1.82	18	0.08	-2.47	1.35	-5.32	0.37
Biceps Brachii (Right)	-1.30	18	0.20	-2.57	1.96	-6.70	1.55
Anterior Deltoid (Right)	-1.69	18	0.10	-4.32	2.54	-9.67	1.02
Upper Trapezius (Right)	-1.33	18	0.19	-6.72	5.03	-17.29	3.84
Brachioradialis (Left)	-1.11	18	0.27	-2.69	2.41	-7.77	2.38
Biceps Brachii (Left)	-0.41	18	0.68	-0.34	0.83	-2.10	1.40
Anterior Deltoid (Left)	-0.13	18	0.89	-0.33	2.40	-5.38	4.72
Upper Trapezius (Left)	-1.05	18	0.30	-4.44	4.21	-13.30	4.42

C. Correlation Analysis between RMS of EMG with time

Fig. 2 show the RMS of EMG change over two hour assembly task. The figures show that over two hours of assembly task, an increase of RMS was occurred, Correlation analysis between RMS of EMG with time was investigated using Pearson Correlation Coefficient. It indicated that there was a correlation between RMS of EMG with time ($p < 0.05$) (Table III). The correlation between RMS and time was varied among eight muscles from 0.335 (left anterior deltoid) to 0.719 (left brachioradialis).The direction of correlation between RMS of EMG and time was positive, which means that there is an increase of RMS of EMG when time increases.

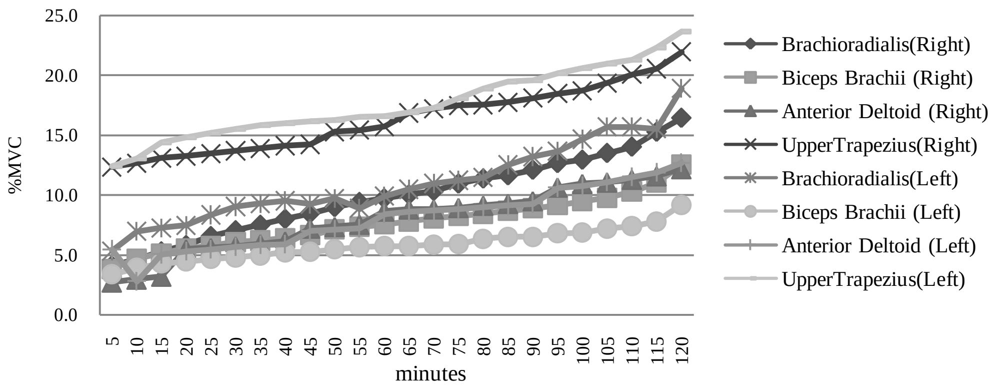

Fig. 2 RMS of EMG change during two hours experiment

TABLE III
CORRELATION BETWEEN RMS OF EMG AND TIME

		RMS EMG with Time
Right brachio radialis	Pearson Correlation	.799*
	Sig. (2-tailed)	0.013
Right biceps brachii	Pearson Correlation	.636*
	Sig. (2-tailed)	0.033
Right anterior deltoid	Pearson Correlation	.669
	Sig. (2-tailed)	0.076
Right upper trapezius	Pearson Correlation	.669**
	Sig. (2-tailed)	0.002
Left brachio radialis	Pearson Correlation	.719**
	Sig. (2-tailed)	0.000
Left biceps brachii	Pearson Correlation	.712*
	Sig. (2-tailed)	0.046
Left anterior deltoid	Pearson Correlation	.635
	Sig. (2-tailed)	0.109
Left upper trapezius	Pearson Correlation	.675**
	Sig. (2-tailed)	0.003

D. Grip and Pinch Strength Measurement

Fig. 3 and Fig. 4 show the grip strength change over time. The results showed that there is a decreased of grip and pinch strength over two hours experiment. The maximum grip in male are higher than female but the decreases was more visible in female (32.7 % from the initial) than male (21.4% from the initial). On the other hand, decreases of pinch strength in male and female are 35.9 % and 27.4 % from the initial, respectively.

Independent sample t-test was carried out to investigate the significant difference of grip and pinch strength between male and female subjects. The result showed that there is a significant difference of grip and pinch strength in male and female ($p<0.01$). The correlation between grip strength and time was high and negative ($p<0.01$) (Table IV).

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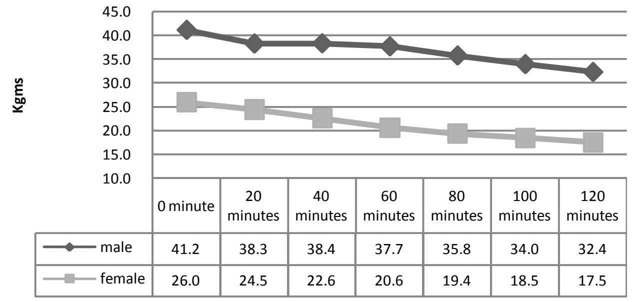

Fig. 3 Grip strength change during two hours experiment

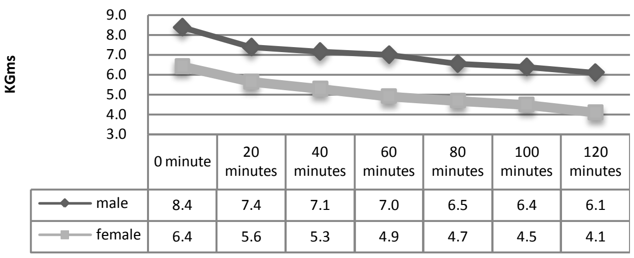

Fig. 4 Pinch strength change during two hours experiment

TABLE IV
CORRELATION BETWEEN PINCH AND GRIP STRENGTH AND TIME

		Time
Grip strength	Pearson Correlation	-.984**
	Sig. (2-tailed)	.000
	N	7
Pinch strength	Pearson Correlation	-.979**
	Sig. (2-tailed)	.000
	N	7

E. Time to Fatigue

Time to fatigue was identified when there is a significant change in performance level for all independent variables [11]. Sherman [11] was investigated the time to fatigue based on EMG and perceived discomfort during an overhead work. In this present study, time to fatigue was interpreted as the time which the change in the fatigue measure (EMG, grip and pinch strength) had become significant [11]. Paired sample t test was used to investigate the significant difference of EMG and grip and pinch strength between first and the second interval, between first and third interval, until the last interval. Each interval is during five minutes experiment. Time to fatigue based on grip and pinch strength and also EMG are show in Fig. 5 – Fig. 6.

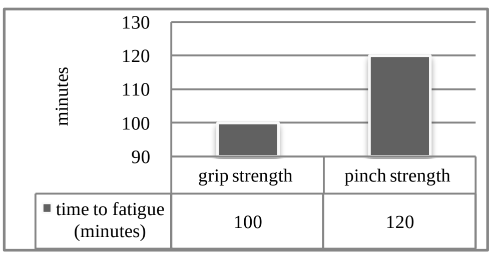

Fig. 5 Time to Fatigue based on Grip and Pinch Strength

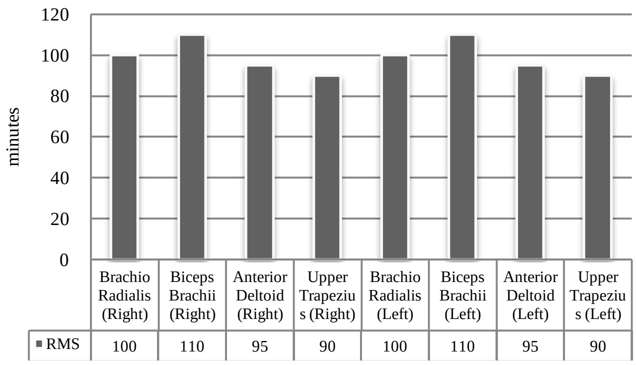

Fig. 6 Time to Fatigue based on RMS of EMG

IV. DISCUSSION

The aim of this study is to investigate time to fatigue for upper limb muscles in a light assembly task. Fatigue can be occurred when people work with high or light effort. Even a causative relationship between fatigue and injury/illness is not scientifically proven to date; almost people agree that a fatigue muscle is more subjects to injury than a fresh one [12]. Moreover, researchers defined the term fatigue differently. Oberg et. al [13] noted that the scientists often use operational definition dependent on measurement method to describe muscle fatigue, such as impaired motor performance, increased EMG activity, shift of EMG power spectrum toward low frequencies, and impaired force generation. In ergonomics context, Luttman [12] defined fatigue as a reduction on force generating capacity of a muscle, which occurs in the course of work. It is believed that fatigue workers may be at higher risk for developing work related musculoskeletal disorders. On other point of view, several studies also shown that there is a relationship between electromyographic sign of muscle fatigue and perceived exertion and discomfort [14].

As describe before, assembly industries are under a great deal of pressure to increase the number of product and to reduce the cost price, whilst retaining the quality. The operators are become more pressure for the responsibility. Combined the two expertise was proved to be the successful approach to achieved the purpose. A review by De Looze and Van Rhijn [15] explained four of time aspect in assembly work which can be used as the choice to focus on design a good assembly line. They were work pace, cycle time, task variation, and work rest pattern. A great deal of research on the effects of work rest schemes has been performed, but not in assembly sectors. Study by Mathiassen and Winkel [17] that investigated the physiological comparison of three intervention on a light assembly work found that limitation on daily duration of assembly work may be more effective in limiting acute fatigue than reduce work pace and break allowance. Limitation on daily duration of assembly work (which can be described as giving a limitation on working time) will allow workers take a rest time to release the muscle fatigue. The time when the workers should take a rest or time to fatigue has been developed by previous researchers [7], [18] but not in a light assembly task.

Several researchers was succeed investigated the development of muscle fatigue in light assembly task [6], [19]-[21] from changes in EMG spectrum, while some others proved that fatigue was also indicated by decrease in maximal grip strength [23]. However, another group of researcher was also trying to investigate if there is a correlation between muscle fatigue with subjective /perceived feeling of discomfort [12][24]. The fact, the investigation on fatigue time prediction in a light assembly task based on EMG, pinch and grip strength is still lacking.

A combination of RMS increased and MPF are believed as manifestation of the development of muscle fatigue [6] and also in the present study. A high and positive correlation between RMS RMG and time was presented in this study. Increase RMS of EMG is represent of an increase of motor unit recruitment, and motor unit firing rate modulation taking place in order to match the required force demand. Result showed that the first muscle to fatigue was upper trapezius muscle. This muscle was fatigue after 90 minutes of working, while the other muscles get fatigue after more than 90 minutes work. This result is actually in line with previous study [26]. The result showed that fatigue for light effort (< 20 % MVC) and high frequency (>15/minute) tasks will perform after 1 to 2 hours of work.

This present study was investigated the maximum grip and pinch strength, because hand and finger are frequently used for the assembly task. The result showed a significant decrease of maximum grip and pinch force after 90 minutes experiment. The decrease of maximum force was about 8% (grip) and 10% (pinch) from the initial. Roman-Liu [23] found that relative hand grip force was decrease as time increase, and it is an indicator of fatigue. They also found that time to fatigue was after 4.5 minutes.

V. CONCLUSIONS

In this study investigation of time to fatigue for upper limb muscle in a light assembly task was based on the EMG, grip and pinch strength. In order to minimize the risk of upper limb muscle fatigue in a light assembly task, it is suggested that workers should allow having rest after 90 minutes work. This result can be used as guideline to management level in scheduling the work rest schedule. Future research should be done to determine the rest time and develop the work rest schedule for a work day. Subjective measurement of fatigue should be taken for consideration to determine time to fatigue.

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