Muscle activity, time to fatigue, and maximum task duration at different levels of production standard time

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Abstract. [Purpose] This study investigated the variations in muscle fatigue, time to fatigue, and maximum task duration at different levels of production standard time. [Methods] Twenty subjects performed repetitive tasks at three different levels of production standard time corresponding to "normal", "hard" and "very hard". Surface electromyography was used to measure the muscle activity. [Results] The results showed that muscle activity was significantly affected by the production standard time level. Muscle activity increased twice in percentage as the production standard time shifted from hard to very hard (6.9% vs. 12.9%). The muscle activity increased over time, indicating muscle fatigue. The muscle fatigue rate increased for the harder production standard time (Hard: 0.105; Very hard: 0.115), which indicated the associated higher risk of work-related musculoskeletal disorders. Muscle fatigue was also found to occur earlier for hard and very hard production standard times. [Conclusion] It is recommended that the maximum task duration should not exceed 5.6, 2.9, and 2.2 hours for normal, hard, and very hard production standard times, respectively, in order to maintain work performance and minimize the risk of work-related musculoskeletal disorders.
Key words: Muscle activity, Muscle fatigue, Task duration

INTRODUCTION

The term "musculoskeletal disorders" (MSDs) refers to conditions that affect muscles, nerves, tendons, and other soft tissues[1]. MSDs are common among the working population. Work-related musculoskeletal disorders (WMSDs) have become a major social concern, which affect a company's bottom line[2, 3]. Problems related to WMSDs pose a significant threat to employees' health and well-being across a wide range of industries and occupations[4–6]. Workers involved in static low loads or repetitive work frequently have complaints associated with WMSD[7–9]. In France, it is estimated that upper limb MSDs account for approximately two-thirds of the reported work-related disorders[10]. In Malaysia, the upper limb is the most commonly affected region in work-related injuries, with 22,978 cases constituting 39.5% of the total in the year 2010[11]. Therefore, there is a critical need to prevent WMSDs among workers with the use of ergonomic interventions[12] and by integrating ergonomic measures for upper extremities in the assembly line design[13].

Most tasks in the manufacturing industry, particularly assembly tasks, are repetitive and performed manually[14, 15]. The tasks become more repetitive with harder production standard times and may predispose workers to a higher risk for WMSDs. The muscle fatigue rate may also vary according to the levels of the production standard time. Hence, the ability to assign maximum task duration according to the levels of the production standard time may reduce the risk of WMSDs. However, there is a lack of established references concerning variations in muscle fatigue, time to fatigue, and maximum task duration at different levels of production standard time. Therefore, this is a timely investigation of the variations in muscle fatigue at different levels of production standard time to predict the time to fatigue and maximum task duration, which are important factors in task design for minimizing the risk of WMSDs.

SUBJECTS AND METHODS

Twenty industrial workers (10 females and 10 males) were recruited to participate in this study. The subjects were between the ages of 22 and 45 years (30.9±7.711). None of the recruited participants had a history of any musculoskeletal injuries. The subjects gave their written consent prior to study initiation. The study was approved by the local Ethics Committee. Muscle activity was recorded using Noraxon Surface Electromyography (EMG) and Telemyo 2400 Gen2 Telemetric Real Time 8 Channel SEMG System (Noraxon,

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Table 1. Mean and standard deviation of normalized RMS

Production standard	FCRR		FCRL		ECRR		ECRL	
	Mean	SD	Mean	SD	Mean	SD	Mean	SD
PSN	8.8*	1.8	11.0*	2.8	10.4*	2.3	11.4*	3.4
PSH	9.6*	2.2	11.9*	2.5	11.0*	2.5	11.9*	3.4
PSVH	9.9*	2.4	12.4*	2.9	11.9*	3.1	12.7*	3.5

*Production standard time has a significant effect on the mean RMS for all muscles, $p < 0.05$.

INC, USA) with disposable Ag/AgCl pregelled electrodes. The subjects' skin was cleaned thoroughly and prepared before electrode placement. The surface electrodes were attached to the belly of the forearm muscles bilaterally. The subjects were then instructed to adopt a comfortable sitting posture, and the sitting height was adjusted individually so that the subjects' knees were flexed to 90°. The working height was standardized by placing the table surface 5 cm below the position of the wrist, with the elbow flexed to 90°[16].

The subjects were instructed to perform a maximum voluntary contraction (MVC) task as soon as the signals from all sensors were stable. The subjects performed the MVC task three times in the seated position; the duration of each task was approximately 10 seconds, with 30 seconds of rest provided in between contractions. The 30 seconds of rest served as recovery time after each task. A stable forearm support was arranged, and manual resistance was used. The MVC measurement procedure used in this study was based on Konrad's guidelines[17]. MVC refers to the highest EMG amplitude obtained from the three recordings and is expressed as the percentage of MVC (%MVC). The MVC was used to normalize the surface EMG signals that were recorded during the series of experimental tasks.

The subjects were required to perform the experimental tasks after familiarizing themselves with the tasks for 30 minutes. They performed the tasks according to assigned production standard times over a one-hour period for each production standard time. Muscle activity was recorded using surface EMG. The tasks involved repetitive assembly actions, similar to the actual industrial assembly task. The subjects were given two types of components: plastic clips and plastic foam rings. These components were placed into a polybox and plastic container, respectively. The subjects were instructed to assemble the ring foam onto the plastic clip using a jig, which pushes the foam onto the clip. The subjects performed the tasks according to the production standard times assigned to them. The production standard times used in the experimental tasks were 100% normal standard time (normal, PSN), 126% normal standard time (hard, PSH) and 140% normal standard time (Very hard, PSVH). The normal standard time was determined to be 5 s from the Methods-Time-Measurement (MTM) analysis, and the task was categorized as a highly repetitive light task[18].

EMG signals were recorded from four forearm muscles: the flexor carpi radialis (FCR) and extensor carpi radialis (ECR) on the right and left arms. Raw EMG signals were sampled during the test contraction with a sample frequency of 1,500 Hz and were band-pass filtered (20–400 Hz). Data
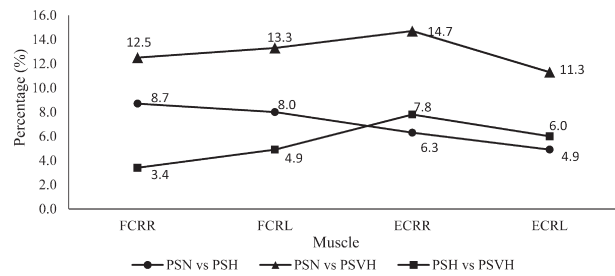

Fig. 1. Percentage of increment in muscle activity for different levels of production standard time

were continuously recorded with the Telemyo 2400T G2 Telemetry EMG System. The EMG data were normalized with MVC to obtain the root-mean-square (RMS, %MVC). The RMS value corresponds to the square root of the average power of the raw EMG signal over a given period of time[19]. The normalized RMS (%MVC) was averaged for every 5 minutes. In this study, the mean value of the normalized RMS represents the muscle activity, while the rate of muscle fatigue is represented by the linear regression slope of the normalized RMS.

RESULTS

The mean value and standard deviation of the normalized RMS for all muscles are summarized in Table 1.

Muscle activity increased with harder production times. PSVH had the highest RMS value for all muscles. The highest RMS value was obtained for ECR-left (ECRL) followed by FCR-left (FCRL), ECR-right (ECRR), and FCR-right (FCRR). Repeated measures ANOVA was conducted to investigate the effect of production standard time on muscle activity, and the results revealed that the production standard time has a significant effect on the mean RMS (muscle activity) for all muscles (Table 1).

Figure 1 presents the percentage of increment in muscle activity at different levels of production standard times. The increment in muscle activity for a hard production standard time was in the 4.9–8.7% range. The provision of an assigned very hard production standard time showed that the muscle activity was higher than that for an assigned normal production standard time and hard production standard time, with an increment in the 11.3–14.7% and 3.4–7.8% ranges, respectively, depending on the type of muscles. On average, the muscle activity increased 6.9% for the hard production standard times and 12.9% for the very hard production stan-

Table 2. Muscle fatigue rate

Production standard	Muscle fatigue rate			
	FCRR	FCRL	ECRR	ECRL
PSN	0.045	0.061	0.088	0.059
PSH	0.046	0.086	0.092	0.105
PSVH	0.050	0.088	0.103	0.115

dard times.

The muscle fatigue rate was determined from the normalized RMS versus time, and the values are summarized in Table 2. It can be seen that the muscle fatigue rate is higher for harder production standard times.

Based on the prediction of time to fatigue at 15%MVC, it was found that muscle fatigue occurs earlier for hard and very hard production standard times compared to the normal production standard time. The time to fatigue at 15%MVC is predicted to be 5.6 hours. 2.9 hours, and 2.2 hours for continuous work at normal, hard, and very hard production standard times, respectively.

DISCUSSION

Muscle activity, expressed as the RMS value (%MVC), was observed to increase significantly with harder production standard times. The results of this study reveal that the average muscle activity increases by 6.9% and 12.9% for hard and very hard production standard times, respectively, whereby the values are determined relative to the normal production standard time. This indicates that the muscle activity is twice its initial value as the production standard time shifts from hard to very hard. This result is consistent with the findings of previous studies, which reported that an increase in work pace leads to an increase in muscle activity[20, 21].

The maximum muscle activity occurred at the ECRL, with a value of 12.7%MVC at 140% of the normal standard time. The ECRL muscle exhibited the highest muscle activity, followed by the FCRL, ECRR, and FCRR. The results are also consistent with the findings of previous studies, which were focused on repetitive hand tasks, during which the forearm extensor muscle activity increases with respect to time[20, 21].

It was found that the RMS value increases with respect to time for all muscles, which signifies the development of muscle fatigue. The highest indication of muscle fatigue was detected in the ECRL. The left-sided muscles were found to be more active compared to the right-sided muscles, which was possibly due to all subjects being right-handed. Moreover, the left-sided muscles are used to grip and hold the components while carrying out a task, and thus they have a greater number of active motor units[22]. The greater the motor unit recruitment and firing rate, the greater is the generated force[23]. The force generated shows a rapid decline when the muscles are stimulated continuously at a frequency close to the maximal force and leads to muscle fatigue[24]. Therefore, these findings explained the highest indication of muscle fatigue detected in the left extensor muscle.

Muscle activity was also found to increase over time for different production standard times. The result indicates muscle fatigue at different levels of production standard time. This result is in agreement with that of previous studies, which found that increment of muscle activity over time indicated a sign of muscle fatigue[25]. In addition, muscle fatigue rates were found to be higher as the production standard time became harder. The result showed that higher muscle activity corresponds to a higher muscle fatigue rate[26]. Manifestation of muscle fatigue was detected during the one-hour task duration, and the result was in agreement with previous studies, which reported muscle fatigue and reduction in worker performance due to WMSDs associated with tasks that were one hour[27] or less[28] in duration. Previous studies also found that muscle fatigue develops over time[29], and the accumulation of muscle fatigue caused functional disability resulting in musculoskeletal disorders[30]. Therefore, long-term effects and longitudinal studies are required to further investigate WMSDs. However, the ability to control muscle fatigue, which is an indicator of WMSDs, will help to minimize the risk of developing WMSDs and maintain worker performance.

In general, it can be deduced that the muscle fatigue rate is higher for harder production standard times due to the shorter task time and higher frequency of movement. The muscle fatigue rate increases with a corresponding increase in muscle activity. An increase in muscle activity indicates the development of muscle fatigue. These results are in agreement with the results of previous studies in which an increase in muscle activity resulted in an increase in muscle fatigue and WMSD risks[25, 30].

The maximum muscle activity is found to be below 15% of the MVC. Rohmert[31] suggested that muscle fatigue occurs when the muscular activity exceeds 15%MVC. However, recent studies reported that muscle fatigue and fatigue-related changes occur at lower force levels[32]. To date, there is no consensus regarding the acceptable levels of muscle fatigue at the workplace, and fatigue risks are still debated[33]. The time to fatigue in this study was predicted at 15%MVC, and it was found that time to fatigue occurs earlier for harder production standard times compared to the normal production standard time. The time to fatigue at 15%MVC is predicted after 5.6, 2.9, and 2.2 hours for normal, hard, and very hard production standard times, respectively, assuming that the workers perform the repetitive tasks continuously.

In the manufacturing industry, workers are usually given rest breaks after a certain task duration. Previous studies suggested that recovery from muscle fatigue can be achieved with appropriate rest breaks, such as a one-hour break[34, 35]. Shin and Kim[36] suggested that an appropriate rest break can be used as an early intervention to prevent muscle fatigue at the workplace. Meanwhile, other studies have shown that setting a limit for the task duration is more useful than improving break allowance[37]. Based on these findings, we suggest that the maximum task duration for normal, hard, and very hard production standard times should be limited before time to fatigue. Hence, the maximum task duration should not exceed 5.6, 2.9, and 2.2 hours for normal, hard, and very hard production standard times, respectively. The maximum task duration for different levels of production

standard time is an important factor in the work design for sustaining the desired work performance and for minimizing the risk of developing WMSDs.

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