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A Review on Muscle and Mental Fatigue in Industry

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Abstract

Human fatigue is a complex phenomenon resulting from various factors in modern industries. At present, very few studies discuss on the relation of muscle and mental fatigue particularly in industries. This paper investigates and discusses on the relation between muscle and mental fatigue based on empirical past studies. The findings indicated that there is a relation between muscle and mental activity which direct to fatigue. What is lacking at present is the methodology to assess quantitatively on the relation of muscle and mental fatigue in the industry. Therefore, for future research, development of a quantitative model in predicting time to muscle and mental fatigue is proposed.

Keywords: *muscle, mental, fatigue, workers, industry.*

1. Introduction

Ergonomics plays an important role in designing systems and tasks that are capable of meeting the manufacturing goals-to meet or exceed quality standards while decreasing costs through optimizing manufacturing productivity, efficiency, and safety. Design of successful work methods requires the use of ergonomic principals that best match human capabilities with job demands. A mismatch of this interface can increase expenses, thus affecting the net profit by causing human operators to make mental mistakes, work inefficiently, or work beyond their physical capabilities to the point of injury (Sherman, 2003).

Worker's fatigue is one of the most prevalent root causes of earth-moving equipment accidents in the industry (Edwards et al., 2007). In light of growing public awareness of the impact of fatigue on both employee health and on public safety in general, shift-work industries including mining, utility providers, medical services, transportation, on-highway transport, rail, aviation, etc. are looking to technology to provide a solution to the fatigue problem. Fatigue can occur because of either mental or physical activity. Therefore, based on the review of this paper, the accurate methodology to evaluate muscle and mental fatigue can be determined, and then, propose a framework in developing a quantitative model for predicting time to muscle and mental fatigue in industry.

2. Review

2.1. Muscle Fatigue

Jensen et al. (2000) defined muscle fatigue as failure to maintain the required or expected force or power. Muscle fatigue is associated with physically monotonous or repetitive work but more recent studies also report an association between psychosocial factors at the work place and musculoskeletal disorders (John et al., 1999). 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 (Lundberg et al., 2002).

Muscle fatigue develops gradually over time during a constant task using low to moderate force levels typical of those tasks found in modern assembly plants. The muscle is considered to have reached its failure point when it is no longer capable of maintaining a desired force. This failure point is well defined for static muscle loads, but considerably less is known about the development of muscle fatigue during low force intermittent and dynamic tasks. Fatigue of this type, however, is common in occupational settings and is characterized by long recovery times.

Valencia (1986) as quoted by Sherman (2003) suggested that one method of preventing muscle fatigue is to provide guidelines in terms of work and rest cycles. If activities causing fatigue are continued without proper time to recover, chronic pain can develop. The body is generally able to recover from changes due to fatigue if given sufficient rest, but the amount of rest needed depends on the level of fatigue accumulated, task demands, and individual factors like fitness and motivation. Fatigued workers or workers who are recovering from injury may be at a higher risk for developing a Work-related Musculoskeletal Disorders (WMSD) than well-rested healthy workers. This fact contributes to the theory that muscle fatigue is an indicator of likelihood of developing a WMSD, and that minimizing fatigue will decrease the risk of developing a WMSD (Putz-Anderson, 1992).

In measuring muscle fatigue, however, most of the studies used subjective measurement methods, or very limited number of subjects was measured with objective methods (Bao et al., 2001). Electromyography (EMG) is the most popular objective-measurement tool used in experiments. EMG is suitable in ergonomic field and laboratory studies for the determination of muscle strain during work and for the derivation of recommendations for work design. It can determine the strain and fatigue of individual muscles or muscle groups and offer a valuable tool for the indication of muscular fatigue in occupational field studies (Luttmann et al., 2000). Study by Cook, et al. (1999) also found that EMG collection methods used at the work site were feasible for analysis of changes in muscle effort and hold promise for use in other investigations.

Muscle tension can be measured by the electromyography (EMG) signal reflecting motor activity. Under static conditions, there is a monotonous relation between muscle contraction level and the amount of EMG produced by the muscle. The root mean square (RMS) value of the signal reflects the momentary degree of involvement of the muscle, whereas the spectral composition reflects localized muscle fatigue

(Chaffin, 1973). Under prolonged static contraction, there is a general increase in EMG amplitude and a shift in the frequency spectrum from high to low frequencies, due to a decrease in the propagation velocity of the depolarization wave along the muscle fiber as fatigue sets in. In fact, the decrease in mean frequency of the spectrum can be plotted as a function of time and the slope of the regression line provides a measure of the rate of fatigue. The mean frequency measure may thus serve as an objective indicator of muscle fatigue.

In field studies, for example, at the work place, recording by means of surface electrodes is often the only choice for practical and ethical reasons. Due to variations in skin resistance, the distance from the surface to the underlying muscles etc., an absolute EMG measure is not a meaningful value. The bipolar surface EMG electrodes reflect a relatively large volume of the superficial muscle and the recording has to be standardized against a reference level, such as the maximal voluntary contraction (MVC) or a sub maximal reference contraction (RC) comparable between subjects. Thus, a common way to express EMG activity is in terms of percent of MVC or RC. In order to determine MVC, it is important to motivate all subjects to perform a maximum contraction.

2.2. Mental Fatigue

The present industrial climate is characterized by the continued increase in the efficacy of technology in manufacturing and service organizations. One of the major implications of this increase in sophistication and automation of human-machine systems is the change in the nature of human work. This change in function and nature has high-lighted the importance of task performance of certain mental functions such as information assimilation and decision making. Current technological breakthroughs in the areas of digital computers and electronics and the increase in the use of automated work systems mean increased mental demands and attendant mental fatigue (Okogbaa and Geoffrey, 1983).

The concept of mental fatigue earlier introduced by Grandjean (Kroemer and Grandjean, 2001) was clearly differentiated mental fatigue from muscle fatigue. He defined that muscle fatigue was concerned on the reduced muscular system performance while mental fatigue deals with much reduced mental performance and the sense of weariness. Okogbaa and Geoffrey (1983) have conducted a five hour laboratory experiment to simulate mental work output. The experiment was run under two work conditions (Rest/no rest) and involved the reading of standardized texts, finding solutions to arithmetic-logical problems and a combination of both. The duration of the rest period for the first group was ten minutes on the hour while the second group worked continuously and did not break for rest. Three primary performance measures were obtained namely work output, heart rate and brain waves. For the task output, the raw data and two types of data transformations were examined in order to determine the best way to express mental work output.

The results supported the hypothesis of performance deterioration due to mental fatigue. In addition the results showed that there was a significant difference between output for the rest versus no rest task conditions. In general, total mental output for tasks with rest breaks was six percent greater than tasks performed without rest breaks. Differences between arithmetic and reading tasks were also significant.

There were some methods in measuring mental fatigue. Some studies (Boksem et al., 2005; Murata et al., 2005; and Trejo et al., 2007) used Electroenchepalography (EEG) and Event-related Brain Potentials (ERP) to detect and evaluate mental fatigue. It is because the simultaneous measurement of EEGs and ERPs can detect the effects of mental fatigue on ongoing brain processes and about the brain's responses to particular events. Eoh, et al. (2005) also used EEG to detect fatigued subjects while performing a simulated driving task. The changes in the EEG theta band and the alpha band reflect cognitive and memory performance. EEG beta band is related to alertness level, and as the activity of beta band increases, performance of a vigilance task also increases.

Other studies did not use objective measurement in diagnosing mental fatigue. For example, Ahsberg, et al. (2000) used Swedish Occupational Fatigue Inventory (SOFI) to study the effects of shift work on different dimensions of perceived fatigue, as well as to study if fatigue changes over an entire shift cycle. On the other hand, Saeki, et al. (2004) carried out a short-time memory task, then used questionnaire in identifying mental fatigue.

2.3. Research on Muscle and Mental Activities

Empirical researches (Wærsted et al., 1991; Lundberg et al., 1994; Larsson et al., 1995; Wærsted et al., 1996; Iwanaga et al., 2000; Lundberg et al., 2002; Blangsted et al., 2004; Visser et al., 2004; Bloemsaat et al., 2005; Hughes et al., 2007) showed that not only physical demands but also cognitive factors and mental stress might induce muscle tension. The findings indicated that ongoing psychological stress might keep low-threshold motor units active more or less continuously. Studies on the correlation between muscle and mental activities by some researchers are summarized in Table 1 below:

Table 1: Some Studies on Muscle and Mental Activities

AUTHOR	OBJECTIVES	METHODOLOGY	SUBJECT	RESULTS
Larsson et al. (1995)	To investigate the effects of psycho physiological stress on trapezius muscle blood flow and EMG during a standardized series of fatiguing static contractions.	Mental stress was induced by the stroop colour word task (CW task). The effects on the microcirculation and EMG in the upper portion of the trapezius muscle were studied during a series of fatiguing, standardized static contractions.	20 females	The blood flow in the neck-shoulder muscles during isometric work normally increased upon exposure to mental stress, as did the muscle tension.

AUTHOR	OBJECTIVES	METHODOLOGY	SUBJECT	RESULTS
Iwanaga et al. (2000)	1. To investigate whether the increase in muscle activities could occur due to mental tasks without any reaction movement. 2. To determine the effects of types of mental task on changes in physiological parameters including muscle activity.	1. Surface Electromyogram (EMG), blood pressure (BP), blink rate (BR) and heart rate (HR) were recorded before and during four types of mental task. 2. Four types of mental tasks: a. Memory (M) b. Visual Search (VS) c. Color-Word (CW) d. Control Task (CT)	8 males	Muscle activities were enhanced when mental work was loaded, especially in the M task where significant increase in EMG were observed at the respective points monitored during performance compared with the pretrial reference value.
Lundberg et al. (2002)	To investigate if the same motor units are activated by mental stress as by physical demands.	Participants were exposed to mental stress tests (mental arithmetic, stroop color word) and physical demands (standardized reference contraction, force ramp contraction) in the laboratory. EMG activity was measured in the trapezius muscle.	17 subjects	Mentally induced stress may contribute to keeping low threshold motor units active, even in the absence of physical demands. Lack of mental rest is an important risk factor for the development of muscular pain.
Visser et al. (2004)	1. To know the effects of precision demands and mental pressure to perform accurately and to perform at highest speed on the load of the upper extremity. 2. To simulate work situations with different levels of	Two computer mouse tasks: 1. An aiming Subjects made the cursor follow a dot moving anti-clockwise in a circle at a fixed speed on the computer screen. 2. A Tracking task Subjects were asked to click on a dot, which appeared at	4 males and 6 females.	1. Precision demands and mental pressure increase upper extremity load, with mental pressure effects being larger than precision effects. 2. Precision demands and

	mental pressure and precision demand.	random locations on the computer screen. Muscular activity was measured by means of EMG on trapezius, extensor, and flexor.		mental pressure were found to have effects on performance.
Bloemsaat et al. (2005)	To investigate whether the activation patterns of proximal and distal arm muscle types are differentially affected by an additional mental load during the performance of a repetitive tapping task.	Participants tapped various keying patterns with their dominant index finger at two prescribed tempi. Mental load was manipulated by means of an auditory short-term memory task. The EMG activities of two neck/shoulder muscles, two upper arm muscles, and four forearm muscles were recorded and the kinematics and impact forces of the index Finger were analyzed.	5 males and 9 females	Activity of the executive distal musculature was increased during tapping at the higher pace, while the activity of the postural upper limb musculature was elevated due to the memory task.
Hughes et al. (2007)	To quantify the effects of mental workload and time pressure on perceived workload and physiological responses of the distal upper extremity during typing.	Subjects completed nine 5-min typing sessions representing 3 levels of time pressure and mental workload. Levels were manipulated by adjusting typing speed and by requiring participants to perform arithmetic tasks while typing. Outcomes were measured in muscle activation levels by using EMG, wrist postures and movements, key strike force and subjective assessments of workload.	18 typists	Increased time pressure increased muscle activation, key strike force and wrist deviations. Increased mental workload increased key strike force. Mental workload and time pressure mediated physical risk factors during typing to increase WMSD risk for the distal upper extremity.

2.4. The Comparison of Methodologies

Table 1 illustrated the relationship between muscle and mental activities. All studies were done experimentally and most of them used Visual Display Unit (VDU). Larsson et al. (1995) designed stroop colour word task (CW task) to induce mental stress. The task was also used in Iwanaga et al. (2000) studies, but they added memory task, visual-search task, and control task. While Lundberg et al. (2002) added mental arithmetic and physical demands test in their study.

On the contrary, the study by Visser et al. (2004) used computer mouse tasks in all of their experiment. An aiming task and a tracking task were utilized to identify the effects of precession demands and mental pressure to perform accurately at high speed on the load of upper extremity. Experiment by Bloemsaat et al. (2005) on mental load manipulated an auditory short-time memory task. Here participants were asked to tap various keying patterns with their dominant index finger at two prescribed tempi. The latest experiment by Hughes et al. (2007), involved 18 typists to perform arithmetic tasks while typing. The experiment was designed with different time pressure and mental workload, to quantify their effects on perceived workload and physiological responses.

All of the above studies measured the outcomes using Electromyography (EMG). However Iwanaga et al. (2000) added the measurement of blood pressure (BP), blink rate (BR), and heart rate (HR) to determine the effects of types of mental task on changes in physiological parameters including muscle activity. For EMG measurement, upper extremity body, such as trapezius muscle, were mostly chosen by the researcher as the location of the measurement. This is because the upper part of the body were much involved in the experiment.

The highest number of the participants involved in the experiments is 20, and the study was carried out by Larsson et al. (1995). However, they only involved female participants. Experiments by some researchers (Lundberg et al. 2002; Visser et al., 2004; and Bloemsaat et al., 2005) involved fewer participants, but involved both male and female participants. The fewest participant involved in the study was carried out by Iwanaga et al. (2000) with only eight male participants.

2.5. The Comparison of Research Findings

The results from the above studies showed that muscle and mental task influenced the effects on muscle activation. Muscle activities were enhanced when mental work and time pressure was loaded (Iwanaga et al., 2000; Visser et al., 2004; Bloemsaat et al., 2005; and Hughes et al., 2007). It happened even in the absence of physical demands (Lundberg et al., 2002). Based on Larsson et al. (1995) study, this is because of the blood flow in the neck-shoulder muscles during isometric work normally increased upon exposure to mental stress, as did the muscle tension. The finding supported the theory proposed by Schleifer et al. (1994). They found that stress-induced hyperventilation decreases peak CO_2 levels and increases the blood pH-level (beyond 7.45=alkalosis). This contributes to elevated muscular tension and a suppression of parasympathetic activity. Johansson and Sojka (1991) have suggested that vicious circles may start in muscle spindles during stress and repetitive work, which may contribute to elevated muscle stiffness, dysfunctional coordination and a high concentration of inflammatory substances and increased pain sensitivity.

Another significant factors found in the study are break and rest time that influenced muscle fatigue. Lack of mental rest can develop the muscular pain[5)]. The finding is supported by Ye et al. (2007) study that used questionnaire survey to 3380 administrative officers. They found that duration of daily Visual Display Terminal (VDT) used and lack of breaks and rest during VDT work were significantly associated with eyestrain, upper extremity pain, back pain, and psychological distress. Therefore, in order to protect users from the adverse effects associated with VDT work, reducing daily VDT exposure, taking breaks and rest are important factors to emphasis during the activity.

3. Future Research on Muscle and Mental Fatigue

Based on the 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. However, most studies observed the impact of mental activities that direct to muscle and mental fatigue (Larsson et al., 1995; Iwanaga et al., 2000; Lundberg et al., 2002; Blangsted et al., 2004; Visser et al., 2004; Bloemsaat et al., 2005; Hughes et al., 2007). The studies above indicated that there is a relation between muscle and mental fatigue that lead to mental stress and muscle tension. In addition, the slow and fast condition, which defined as time pressure, may lead also to muscle fatigue.

Most studies in the review were carried out using laboratory experimental method, and only a few were 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. On the other hand, there is still a few studies that using a specific tool to measure mental fatigue, such as Electroencephalography (EEG). In addition, measurements of workers performance were also carried out in the same experiment, for example precision and time performance.

Although there is consistent pattern indicating a correlation between muscle and mental activities, there is still gap to find the best method in evaluating muscle and mental fatigue. Most of the studies emphasis on the correlation, but neglected on the development of quantitative model to predict the time to fatigue.

4. Conclusions

In conclusions, fatigue is inevitable for workers and in life in general. Fatigue is usually related to a loss of efficiency and disinclination to effort. It is important to manage fatigue, so that the workers do not damage their health. It is also possible that cumulative fatigue leads to decrease productivity in the workplace and induces critical errors in the worst cases. Therefore, the management of muscle and mental fatigue is important from the viewpoint of occupational risk management, productivity, and occupational health. Since there is still few studies investigated on muscle and mental fatigue in industry, so it is proposed that for future directions, it will be developed a quantitative model for predicting time to muscle and mental fatigue in industry, which would be potentially applicable to the management of fatigue.

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