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Muscle Fatigue Analysis During Welding Tasks Using sEMG and Recurrence Quantification Analysis

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ABSTRACT

The main goal of this study was to detect muscle fatigue and to identify muscles vulnerable to musculoskeletal disorders by evaluating muscle activation of subjects during welding tasks. In this study, six subjects performed two different welding tasks for a total of three hours. Surface electromyography (sEMG) was used to record the muscle activation of 16 different muscles. Recurrence quantification analysis (RQA) was then used to analyze the EMG data. In addition, a subjective fatigue assessment was conducted to draw comparisons with the RQA results. According to the RQA results, 12 of the tested muscles experienced fatigue by showing significant difference in RQA values (p-value < 0.05) between the first and last 10 minutes of the experiment. Moreover, time-to-fatigue results obtained from RQA and subjective analysis were closely correlated for seven muscle groups. This study showed that RQA can be used in ergonomic studies for evaluating muscle activation during construction tasks.

KEYWORDS

Construction Welding, Muscle Fatigue Analysis, Recurrence Quantification Analysis, Subjective Fatigue Assessment

INTRODUCTION

Work-related musculoskeletal disorders (WMSDs) are common health problems which have tremendous impact on manual workers (Stattin & Järvholm, 2005). In the United States, 37% of all injuries in construction are caused by WMSDs (Schneider, 2001). WMSDs are believed to be caused by prolonged and repetitive work, localized muscle fatigue, tedious and short tasks (Amell & Kumar, 2001; Buckle & Devereux, 2002), as well as repeated awkward postures and handling tasks (Valero et al., 2017). Such musculoskeletal disorders can affect the lower back, shoulder, elbow, forearm, wrist, and hand (Gazzoni, 2010). One construction task which has most of the above mentioned characteristics is welding. Welding is a highly precise and mostly static type of task which requires strength and capability to carry out proficient movements (Kadefors et al., 1976). Research shows that musculoskeletal disorders are common among welders, especially in the shoulder (Jarvholm et al., 1991; Torner et al., 1991), neck, and low back (Torner et al., 1991). Welders also have a prevalence of supraspinatus tendinitis development, even new welders with relatively limited time on the job (Herberts et al., 1981). Torner et al. (1991) found that welders experienced significantly

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more supraspinatus tendinitis than office clerks. They also found that 35 out of 131 surveyed welders experienced shoulder pain during work, and 34 out of 58 surveyed welders experienced dysfunction in the right shoulder, while 15 of them experienced dysfunction in the left shoulder. Moreover, 44 out of 58 surveyed welders faced subjective shoulder and/or neck symptoms during the previous year. In addition, 16 of them encountered symptoms of an earlier hand injury. Investigation of the task and muscle activity related to welding tasks is warranted to identify ways to prevent musculoskeletal disorders related to welding. Therefore, a quantitative measure for evaluating muscle activity and detecting risk factors can be of great importance in preventing WMSDs. Moreover, development of real-time quantitative health and safety-related feedback about worker's activities in construction sites is an emerging area of investigation in construction research (Clasby et al., 2003; Harvey & Peper, 1997; Oldham et al., 2000).

SURFACE ELECTROMYOGRAPHY (SEMG):

The use of sEMG (Surface Electromyography) has been shown to be one of the most effective and quantitative methods to evaluate muscle activity and risk factors (Dennerlein et al., 2003; Farina, 2006; Lowe et al., 2001; Panahi & Cho, 2016; Sporrong et al., 1999). Moreover, sEMG offers a great advantage to be used as a real-time measurement method. There are two major physiological elements of the muscle that affect the EMG signal: reduction in conduction velocity in the muscle fibers and enhanced motor unit synchronization, the state in which motor units fire at the same time. These phenomena cause the frequency of the EMG signal to decrease and the amplitude to increase. These two phenomena, reduction in conduction velocity and increase in motor unit synchronization, are believed to be the myoelectric manifestations of muscle fatigue (Farina et al., 2002; Jensen et al., 2000; Li et al., 2004). Muscle fatigue analysis using sEMG has shown promising results in quantifying muscle activation for ergonomic purposes (Peppoloni et al., 2016).

Antwi-Afari and et al. (2017) used sEMG to evaluate the risk factors for work-related musculoskeletal disorders during repetitive lifting task in construction workers. They studied the effects of lifting weights and postures on muscle activity and muscle fatigue. They were able to show that increased lifting weights significantly increased muscle fatigue of the biceps brachii, brachioradialis, lumber erector spinae, and medial gastrocnemius. Kadefors and et al. (1976) applied quantitative electromyography analysis to the muscles of the shoulder (deltoideus, biceps brachii, rhomboideus major, upper and middle trapezius, and supraspinatus) to find localized muscle fatigue in both experienced and inexperienced welders while performing standard welding tasks, for a total of 10 minutes for each subject. According to their study, inexperienced welders showed signs of muscle fatigue in the deltoid, supraspinatus and upper trapezius muscles, while experienced welders showed signs of muscle fatigue in the supraspinatus muscle only. They concluded that training and enhanced skills may lower the muscle fatigue in welders, but this would not eliminate the load on the supraspinatus muscle.

Lowe and et al. (2001) utilized EMG and discomfort analysis to study muscle fatigue of several muscle groups (upper trapezius, middle deltoid, anterior deltoid, latissimus dorsi, erector spinae, extensor digitorum communis, and flexor digitorum superficialis). The subjects were welders working in a confined space. Their study showed that during SMAW (Shielded Metal Arc Welding), several muscles showed signs of fatigue; however, fewer muscles showed such a symptom during FCAW (Flux-cored Arc Welding), suggesting that this welding method may cause less muscle fatigue in welders.

Ergonomic studies on welding tasks such as these are mainly conducted in laboratories with isometric loads or for relatively short periods of time. It is more applicable to study such tasks during real-world tasks that involve dynamic muscle activity. It is also more pertinent to extend the length of simulated studies to represent the real world situation as close as possible. There is, however, a major challenge when it comes to evaluating dynamic activities from the perspective of data analysis. The mechanism involved with such activities is more intricate and less understood than static activities with

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