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Using electrical stimulation to measure physiological changes in the human extensor carpi ulnaris muscle after prolonged low-level repetitive ulnar deviation

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ABSTRACT

The objective of this study was to determine whether muscle fatigue would result from repetitive voluntary contractions performed consecutively over four, 8-h workdays. Using a repeated measures design, ten healthy females participated in three conditions: a control and two repetitive work conditions involving 8 h of repeated ulnar deviation of the wrist, at self-selected workloads at 20 and 25 repetitions per minute (RPM). The 2, 20 and 50 Hz force response of the Extensor Carpi Ulnaris muscle was measured before, during work, and in three hours of recovery. Twitch contraction times (CT), one-half relaxation times (½ RT) and 20:50 Hz ratios (low frequency fatigue ratios) were also compared. The average workloads for the 20 and 25 RPM conditions were 20.3% (±11.6%) and 16.3% (±10.8%) MVC respectively. In the exposure conditions there was a decrease in the 20:50 Hz ratios indicating low frequency fatigue (LFF), a significant increase in the muscle's force response across all stimulation frequencies (potentiation), and a corresponding decrease (quickening) in the twitch CTs and ½ RTs. During recovery, the 20:50 Hz ratios, muscle forces and twitch CTs and ½ RTs returned to pre-exposure/baseline levels. There were no carryover effects or significant differences between the two consecutive workdays. For the low-level dynamic workloads tested in this study, LFF coexisted with muscle potentiation and the results indicated that both LFF ratios and the individual force responses at each frequency needs to be evaluated in order to understand the underlying state of the muscle.

1. Introduction

The muscle's force response to electrical stimulation measured before, during and after exercise can be used to measure changes in the physiological state of the muscle and may provide a biomarker for cumulative exposure to sustained static or prolonged repetitive work. When the muscle's force response to electrical stimulation drops and the contraction slows after exposure to exercise, this is muscle fatigue in its purest form. Muscle fatigue and pain are common in the workplace and may precede more serious musculoskeletal disorders (Rempel etal., 1992; Takala, 2002; Valencia, 1986). For example, using electromyographic (EMG) zero-crossing techniques in the trapezius muscle, a relationship between muscle tissue damage and increased fatigability during occupational work has been reported (Hägg and Suurkula, 1991; Hägg, 2000). Given the low-force exertions, the long hours of repetitive work and the fact that motor units are recruited and used at low frequencies in everyday life (Dideriksen et al., 2010; Enoka and Stuart, 1992; Hägg, 1991; Westgaard and De Luca, 2001), Low Frequency Fatigue (LFF) is likely to be the most common type of muscle fatigue in the modern workplace (Westerblad et al., 2000).

The classic condition of LFF is where the muscle's force response is suppressed in response to low frequency (1–20 Hz) of stimulation, but remains intact when subjected to higher frequencies (50–100 Hz) of stimulation (Edwards et al., 1977; Jones, 1996; MacIntosh and Rassier, 2002). However, there are different physiological states the muscle goes though as it progresses to a state of LFF (Alway et al., 1987; Garner et al., 1989; Rassier and MacIntosh, 2000). The first state is muscle potentiation, where the muscle's force output increases and the muscle contracts at a faster rate as muscle attempts to fight the fatigue (Alway et al., 1987; Behm and St-Pierre, 1997; Hamada et al., 2000; Oskouei and Herzog, 2005; Paasuke et al., 2000). Then, the muscle starts to give way and enters a combined state of potentiation and fatigue; here, the force

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response of the muscle is still elevated but the muscle starts to contract at a slower rate (Rassier and MacIntosh, 2000). Finally, if the exposure is high and/or long enough, the muscle will enter the classic state of muscle fatigue, where both the muscle's force output and contraction rate are suppressed relative to its fresh, unfatigued state. These alternative states of LFF may be particularly relevant to low-force occupational work activities.

Most previous studies have documented changes in the force response of the muscle to short-term moderate to high-level force exposures (Adamo et al., 2002; Bentley and Lehman, 2005; Chang et al., 2008; De Ruiter et al., 1999; Edwards et al., 1977; Jones et al., 1989; Mellor and Stokes, 1992; Stokes et al., 1989). All of these studies have measured the muscle's force response to electrical stimulation before work, after work and in a period of recovery to measure and track the fatigue response of the muscle. None of these studies, however, have examined the effects of exposure to prolonged low-force repetitive tasks exerted for a whole workday or over multiple workdays.

Previously we have reported that LFF, as measured from isometric forces produced by electrical stimulation of the extensor carpi ulnaris muscle, was present when subjects performed a repetitive, low-force, wrist-based task for 8 h (Dennerlein et al., 2003). The self-selected force exposure levels for these repetitive wrist-based tasks were performed using a psychophysical protocol deemed acceptable by the subjects themselves (Ciriello et al., 2002a,2002b; Snook et al., 1995). In addition to the LFF measures, we simultaneously measured the EMG response of the extensor carpi ulnaris muscle before, during and after exposure to repetitive work (Bennie et al., 2002). However, unlike traditional EMG behavior where the EMG amplitude increases with fatigue, during the exposure to exercise the mean EMG amplitude of the extensor carpi ulnaris muscle decreased and was lower compared to the pre-exposure and recovery periods. Bennie et al. (2002) hypothesized that the lower mean EMG amplitude may have been the result of muscle potentiation. Potentiation and fatigue may coexist further complicating the interpretation of the chain of events leading to muscle fatigue and recovery (Alway et al., 1987; Garner et al., 1989; MacIntosh and Rassier, 2002).

Based on our previous work (Bennie et al., 2002; Dennerlein et al., 2003), when the ECU muscle is exposed to an 8-h repetitive wrist-based task there is evidence that the muscle may be in a state of both potentiation and fatigue, similar to the co-existence hypotheses of Rassier and MacIntosh (2000). If, when exposed to low-force occupational work, the muscle first potentiates, then goes into a combined state where potentiation and fatigue coexist, these physiological events may be precursors to classical muscle fatigue. Therefore the goal of this study was to investigate whether there were systematic changes in the physiologic state of the ECU muscle when exposed to full-day, low-force, repetitive wrist-based work.

2. Methods

2.1. Subjects

Thirteen females between the ages of 19 and 53 (mean 37 years) were recruited from the general public using newspaper advertisements to participate in this study. Since the majority of the manufacturing workforce preforming low-force, high-repetition jobs are women, we chose to only test women in our study. The study protocol was approved by the Harvard School of Public Health Human Subjects Committee and the Liberty Mutual Research Institute for Safety Internal Review Committee. After giving informed consent, subjects were examined by a nurse practitioner for musculoskeletal disorders of the upper extremity. All subjects were free of musculoskeletal disorders of the upper extremity and three of the subjects were left-hand dominant.

2.2. Maximum voluntary contractions

On the orientation day prior to the experiments, maximum voluntary contractions (MVCs) were collected from the subject's extensor carpi ulnaris (ECU) muscle. Subjects sat upright in an adjustable chair with their feet flat on the floor, knees positioned at 90° and shoulders relaxed. Subjects placed their right forearm in an apparatus especially designed to measure isometric force in the direction of ulnar deviation (Fig. 1), and pushed down with the wrist onto a force sensor as hard as possible for 3 s, using a 1-s ramp. A minimum of three MVC-recordings were taken with a 2-min rest in between until the two highest measures differed by less than 10%. The highest attempt was taken as the subject's MVC.

2.3. Electrical stimulation

The ECU muscle was stimulated using a Grass Instruments S48 Stimulator, SIU5 Stimulus Isolation Unit, and CCU1 Constant Current Unit (Grass Instruments; Quincy, MA). As shown in Fig. 1, the subject's right forearm was stimulated using disposable 10 mm Ag/AgCl electrodes (Model 125RWCR, Taylor Industries; Jefferson City, MO) placed over the ECU muscle on the dorsal side of the forearm distal to the lateral epicondyle at roughly ¼ of the length of the forearm and the other electrode was located over the ulnar mid-way between the elbow and wrist. Before electrode attachment, the subject's forearm was prepared by cleansing the skin's surface with 70% alcohol and 5% pumice pads (Model 1508; Dynarex; Brewster, NY).

On an orientation day prior to the actual experiment, each subject's optimal site for ECU electrical stimulation was determined by probing the dorsal aspect of the forearm with a 4 mm diameter surface electrode probe (Model E208, InVivo Metric Systems; Healdsberg, CA) at 2 Hz. Once the site which gave the greatest muscle response was identified, electrodes were attached to the forearm. For each stimulation frequency (2, 20 and 50 Hz) the stimulus current was increased to determine each subject's maximum tolerable current level for each frequency. These maximal tolerable current levels were recorded and used in the subsequent procedures. The stimulation was a constant current pulse between 10 and 30 mA with a 100 μs duration. To ensure consistent electrode placement each day, henna tattoos, which last

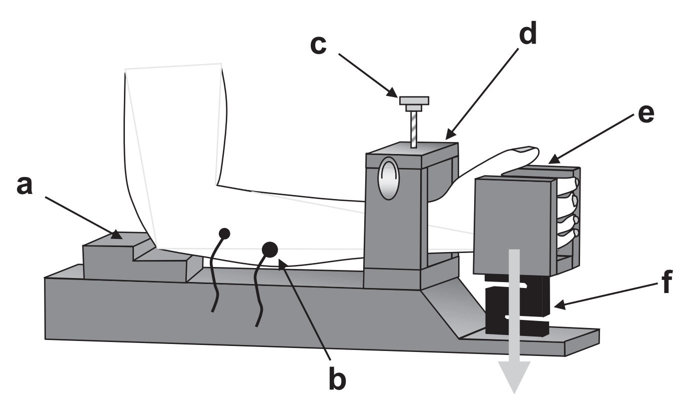

Fig. 1. Apparatus used to measure muscle forces during maximum voluntary contractions and electrical stimulation of the muscle. a – adjustable elbow support to ensure proper positioning, b – stimulating electrodes, c –wrist support adjustment knob to apply pressure ensure proper positioning of the wrist, d – wrist support apparatus, e – hand support apparatus, f – load cell to measure forces.