Experimental Studies of Gastrocnemius Muscle Force and Fatigue Induced by Electrical Stimulation

Chaoyang Chen, MD¹, Xin Tao, PhD², Bo Cheng, PhD², John M. Cavanaugh, MD¹.
¹Wayne State University, Detroit, MI, USA, ²Tsinghua University, Beijing, China.

Disclosures:
C. Chen: None. X. Tao: None. B. Cheng: None. J.M. Cavanaugh: None.

Introduction: It has been reported that 40%-65% of all truck drivers suffer from chronic back problems. Among many physical exposures encountered in working conditions, whole-body vibration (WBV) has repeatedly been identified as a risk factor for low back pain. Mechanical vibration (namely 5 Hz or 20 Hz) directly applied to a muscle belly or tendon elicits the tonic vibration reflex (TVR). TVR is a neuromuscular response caused by excitation of muscle spindles leading to enhanced muscle activity. The increased muscle activity that is necessary to dampen the mechanical vibration could lead to muscle fatigue, which affects neuromuscular coordination and proprioception. Back muscle fatigue leaves the spine at increased risk of injury. The time course of muscle fatigue under different loading conditions is still unknown. The correlation between electromyogram (EMG) and contraction force is also not completely understood. The purpose of this study was to characterize the correlation between EMG measures and muscle contraction force, as well as the time course of muscle fatigue under various loads.

Methods: Thirty-six SD rats were used with 71 legs been tested (n=71). The rats were anesthetized with an intraperitoneal injection of xylazine and ketamine. All procedures were approved by the Wayne State University Animal Investigation Committee. The sciatic nerve was exposed and the proximal end was cut to avoid the stimulus pulses entering the spinal cord which would cause trunk muscle contraction. The gastrocnemius muscle and Achilles' tendon were exposed by cutting the skin above the muscle. The Achilles tendon and a small piece of the calcaneus were clamped by an alligator clamps attached to a load cell transducer to record forces from gastrocnemius muscle (Fig.1). A miniature stimulating electrode was placed under the proximal sciatic nerve to evoke gastrocnemius muscle contraction. A pair of intramuscular EMG recording electrodes was inserted into the gastrocnemius to record the EMG. The recording electrodes were coated platinum wire, with a diameter of 0.005 inch at the bare tip. Data was recorded in the Biopac data acquisition system (MP-36, Biopac Inc, Goleta, CA). An 0.03 to 1 volt stimulus pulse with 10, 20, 30, 60, or 90 Hz stimulus pulse were used to evoke muscle contraction. The force and EMG were recorded simultaneously. The following correlations were studied: (1) Force and stimulus voltage, in which 0.05 V gradually increased to 1V with a fixed 90 Hz stimulus, (2) Force and frequency, in which stimulus voltage changed from 10Hz to 90Hz with a fixed 1V square waves stimulus, (3) Contraction force and time course of muscle fatigue, in which 0.2V with 90 Hz stimulus pulse was
Results: In this study, under 1V stimulus, increase of stimulus frequency caused increase of muscle contraction force (Fig. 2). The correlation between frequency and force appeared to be logarithmic ($R^2=0.99$, p<0.01) (Fig. 3A). The contraction force appeared to be saturated at 50-70 Hz electrical stimulation. With a 90 Hz stimulus frequency, increase of stimulus voltage also caused increase of force. The correlation between voltage and force appeared to be exponential ($R^2=0.79$, p<0.05) (Fig. 3B). Muscle contraction force decreased 6 minutes after trial onset with 0.2V at 90 Hz stimuli, in which 8.3% of MVC contraction was evoked (Fig. 4). Muscle fatigue occurred more quickly at higher stimulus voltage in higher stimulating frequency groups.

Figure 1. Experimental setting for muscle fatigue studies. The sciatic nerve was stimulated to evoke controlled gastrocnemius contraction. The contraction force was monitored by a load cell transducer, and the intramuscular EMG was monitored simultaneously.
Figure 2 demonstrates the effects of 1 V electrical stimulation frequency on muscle contraction force. Muscle force was normalized to the maximum force (%MVC).

Figure 3: A shows a logarithmic correlation between muscle contraction force and stimulus frequency. Fr=frequency, Tc=contraction time obtained from EMG. B shows the correlation between force and stimulus voltage using 90 Hz electrical stimulus.
Discussion: This study established an experimental methodology for the study of muscle activity under the low-level loading conditions. Data was obtained from a single muscle, the gastrocnemius in which the correlations between EMG and force was identified. The muscle fatigue life data obtained in this study can be used to construct computational models to predict human fatigue time-course under various driving conditions.

Significance: This work established an in vivo animal model for determining total active muscle force during isometric contractions at various frequencies and voltages. This animal model can also be used to determine muscle fatigue life under different conditions of contraction intensity normalized to the maximum voluntary contraction. The experimental set-up developed for fixing the animal to the test fixture ensured the accuracy of the force data collected and is suitable for future studies of fatigue loading.

Acknowledgments: This study was funded by State Key Laboratory of Automotive Safety and Energy Funding (#KF11011).


ORS 2014 Annual Meeting
Poster No: 0532