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Medical Education / Method Paper

Practical to Demonstrate Electromyographic Changes Associated With Phenomena of Fatigue Due to Isometric Exercise

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Abstract

Purpose of the study: Teaching the physiology of motor unit recruitment as a strategy for force generation and changes in the recruitment patterns as a consequence of fatigue.

Methodology: A protocol was designed to study fatigue developed as a consequence of graded isometric exercise and the surface electromyographic (sEMG) features associated with development of fatigue.

Main findings: Fatigue can be quantified by reduction in grip force in isometric hand grip. During maximal exercise, sEMG amplitude declined with time as a consequence of fatigue. The sEMG amplitude was observed to increase in the case of submaximal exercise representing recruitment of additional motor units to compensate for declining force production in fatigued motor units.

Conclusion: The proposed practical exercise fulfils the teaching goal of acquainting the students with the motor unit recruitment patterns as reflected in sEMG associated with fatigue development.

Introduction

Nerve muscle physiology is one of the very first fundamental concepts that the medical undergraduate students in India are introduced to in the very initial phase of their curriculum. The concept of fatigue is an important component of nerve muscle physiology with both lectures and practical classes dedicated to ensure clarity of the physiology behind it (1). The emphasis on this particular concept is justified as it forms the foundation of many important applied aspects of work efficiency as well as sports physiology.

Fatigue is defined as a reversible progressive decline in performance over time developing as a consequence of repetitive or sustained activity (2). Fatigue can be quantified in terms of temporal changes in force and power production, endurance at a level of exercise or perception of conscious effort (3). Fatigue is multifactorial in origin (4) and central fatigue is considered to be rate limiting in nature (5). The practical classes dedicated to this concept usually focus on the quantification of fatigue

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based on time to fatigue, the decrement in work capacity with time and the various factors that may affect these parameters like type of exercise, load, frequency, arterial or venous occlusion etc. The associated changes in electromyogram are not currently a part of the practical training modules in Indian syllabus for medical undergraduate students.

Biochemical and physiological changes in muscles during fatiguing contractions are also reflected in properties of myoelectric signals recorded on the surface of the skin above the muscle(s) concerned (6). Continuous monitoring of local muscle fatigue during performance of work is possible by measuring myoelectric activity of the involved muscles through surface electromyography (sEMG).

The electrical activity which is associated with the phenomena of fatigue is an interesting aspect which integrates the understanding of motor unit recruitment and the changes thereof that are associated with the onset of fatigue (7). Not only this, it also reinforces the student's understanding of both motor units and electromyography which is becoming more relevant as electrophysiological investigations becomes ubiquitous in medical practice.

A simple but integrative practical is the best way to address this lacuna. We are therefore proposing an integrative practical exercise module in which the study of the phenomena of fatigue with isometric exercise performed with a handgrip dynamometer is supplemented with simultaneous surface electromyogram recording from the forearm muscles to provide a more comprehensive education to the students about the different aspects of fatigue including the electromyogram related changes.

Materials and Methods

Learning Objective:

To demonstrate the surface electromyographic changes associated with the phenomena of fatigue during isometric hand grip exercise to study motor unit recruitment patterns in fatigue.

Materials required:

1. Chair and surface for hand support.
2. Hand grip force recording: A handgrip dynamometer is required for this.

   If digital handgrip dynamometer is not available, alternatively, a manual hand grip dynamometer may be used but care should be taken to make a note of the time at which the failure to sustain the target force begins on the sEMG being recorded simultaneously.
3. Digital surface electromyogram: A digital biopotential acquisition system should be used for recording the sEMG. The procedure would require surface electrodes and conducting gel.

The experimental setup is depicted in Fig. 1. The electrodes used are pre-gelled Ag/AgCl surface patch electrodes.

Specific Learning Objective 1

To study fatigue and associated sEMG features during maximal isometric hand grip exercise

Principle

Maximal voluntary exercise of a muscle is associated with maximum voluntary central recruitment of motor units. As the exercise is sustained there is a reduction in maximum voluntary capacity due to central derecruitment leading to a reduction in force production. sEMG features like Average rectified value (ARV), Root mean square (RMS) amplitude and Area under the curve (AUC) serve as markers for the motor unit derecruitment process.

Experiment Protocol:

1) Bipolar sEMG is acquired from the flexor muscles of the forearm (Fig. 1). The positive and negative recording electrodes are placed 2 cm apart over the most prominent point of the forearm flexor muscles. The ground electrode is placed over the olecranon process. sEMG is digitally acquired

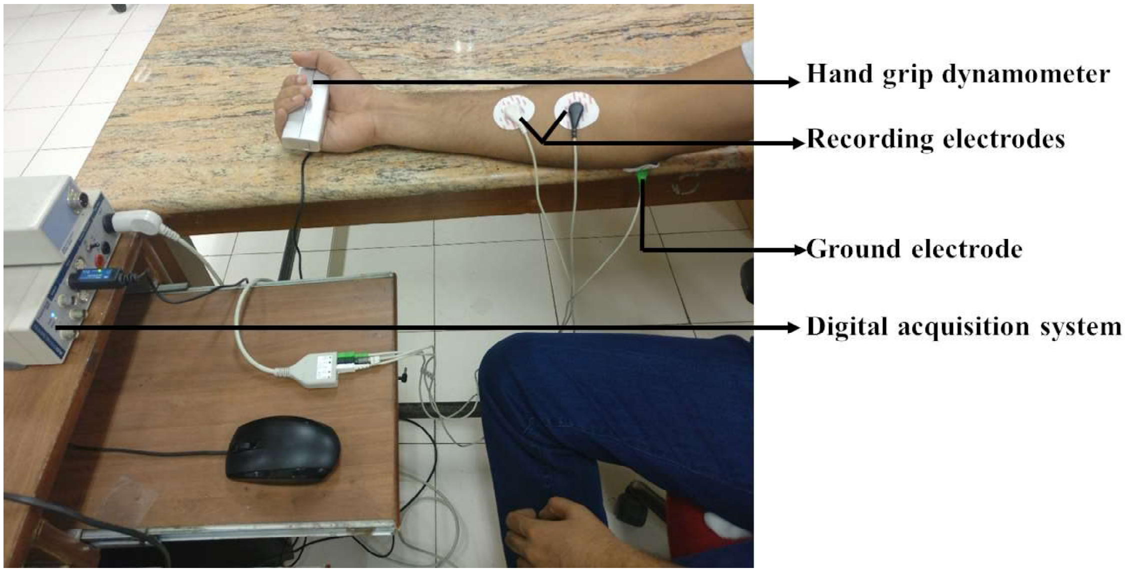

Fig. 1 : Hand grip dynamometer and surface EMG setup.

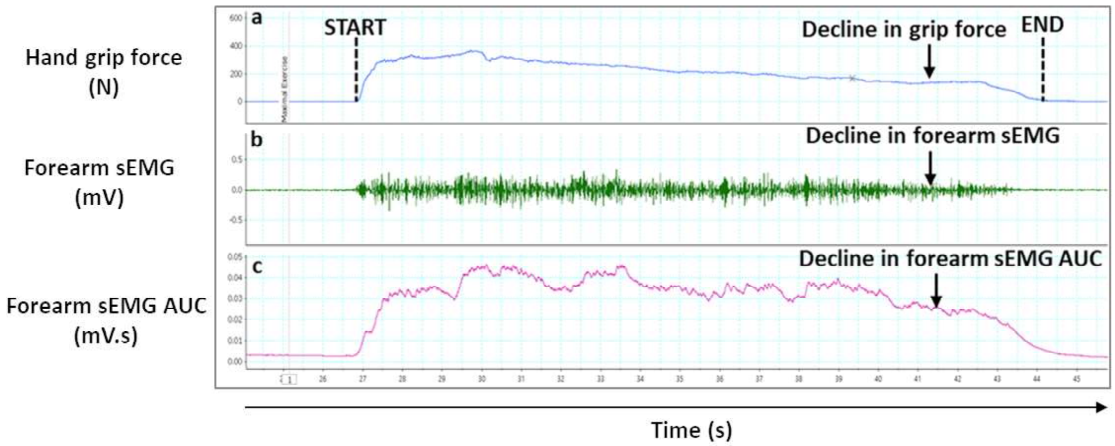

Fig. 2 : Representative record of fatigue during maximal exercise. Trace a shows the hand grip force recorded with digital hand grip dynamometer. The dashed lines mark the start and end of endurance manoeuvre with maximal effort by the subject. Trace b and c show the forearm sEMG and the AUC calculated from the sEMG respectively, both of which show concomitant decline with the reduction in grip force towards the end of experiment. N: Newton, mV: millivolt, mV.s: millivolt second, sEMG: surface electromyogram, AUC: area under the curve.

at a pass band ranging from 10-2000 Hz at a sampling rate >4 kHz with an amplifier range of 5 mV and a mains filter to eliminate line noise.

2) The subject is seated comfortably on the chair with the arm adducted, elbow flexed at 90º and forearm supported on the chair handle. The subject is instructed to perform three trials of brief voluntary maximum hand grip contraction manoeuvres on the grip force transducer with intervening rest periods of 1 minute. The best of 3 trials is considered to be the Maximum Voluntary Contraction (MVC).

3) The subject is then asked to perform an endurance manoeuvre trying to sustain maximal force production for as long as comfortably possible while receiving live feedback about the amount of force produced. The subject is then asked to terminate the procedure once the experimenter observes that the contractile force has decreased below 50% of the target (8).

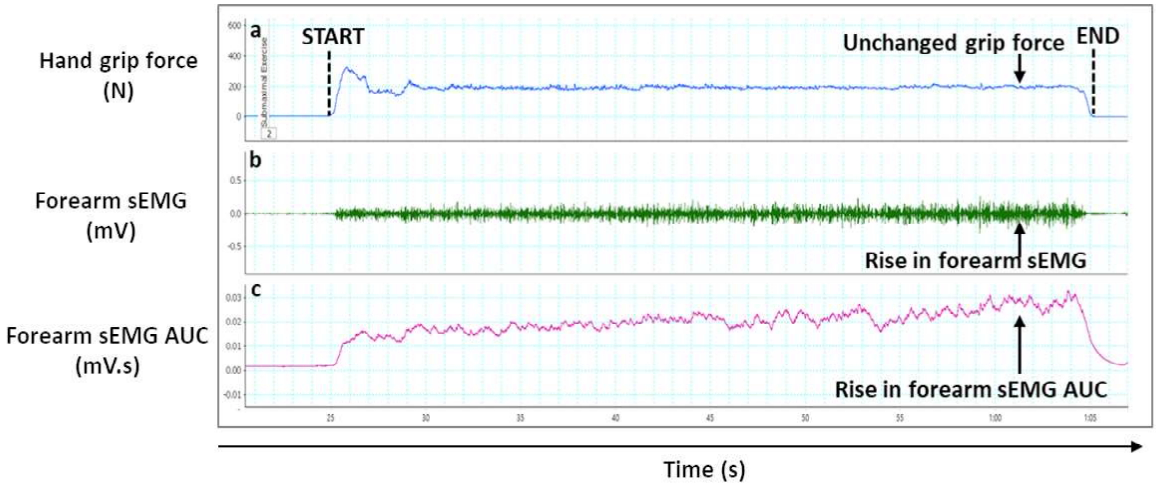

Fig. 3 : Representative record of fatigue during submaximal exercise. Trace a shows the hand grip force recorded with digital hand grip dynamometer. The dashed lines mark the start and end of endurance manoeuvre with submaximal effort by the subject. Trace b and c show the forearm sEMG and the AUC calculated from sEMG respectively, both of which show concomitant rise towards the end of the experiment despite unchanged grip force recorded simultaneously. N: Newton, mV: millivolt, mV.s: millivolt second, sEMG: surface electromyogram, AUC: area under the curve.

4) sEMG processing- sEMG time domain parameters like area under the curve are computed by performing an absolute integral over a moving window to serve as markers of motor unit recruitment (9).

Specific Learning Objective 2

To study fatigue and associated sEMG features during submaximal isometric hand grip exercise

Principle

Submaximal voluntary exercise of a muscle is associated with partial central recruitment of motor units. As the exercise is sustained there is a reduction in force generation capacity and gradual central derecruitment of the initially recruited motor units and eventually additional motor recruitment is required to sustain the same level of submaximal force. sEMG features like Average rectified Value (ARV), Root mean square (RMS) amplitude or Area under the curve (AUC) serve as markers for the motor unit recruitment process.

1) sEMG acquisition is similar to the procedure followed in maximal exercise

2) The subject is then asked to perform an endurance manoeuvre trying to sustain a contractile force at 50% of the maximal force production for as long as comfortably possible while receiving live feedback about the amount of force produced. The subject is then asked to terminate the procedure once the experimenter observes that the contractile force has decreased below 50% of the target (8).

3) sEMG is processed as before.

Results

Force profiles and sEMG changes are plotted throughout the course of endurance exercise. In maximal exercise there is a reduction in contractile force associated with a reduction of sEMG AUC throughout the course of the manoeuvre. In submaximal exercise, force production is sustained but there is an increase in sEMG AUC towards later parts of the exercise. Endurance time in submaximal exercise is more than that of maximal exercise. The experimental setup and data analysis took around 90 minutes from start to completion.

Discussion

This experiment probes into the mechanisms driving reduction of force production as a consequence of fatigue in voluntary activity. Students can study objective assessment of fatigue through direct measurements of contractile force and associated sEMG parameters. The force profiles and sEMG AUC can be correlated to explain motor unit recruitment strategies during the course of voluntary activity and fatigue. Maximal and submaximal exercise exhibit differential responses in the motor unit recruitment pattern. The maximal exercise module can be used to demonstrate reduced activation of muscle fibres over time because of fatigue. The submaximal exercise module demonstrates the reduced force outputs of motor units as a consequence of fatigue and the need for additional motor unit recruitment for the purpose of maintenance of target force.

Assessment targets in this practical would be in the form of Objectively Structured Practical examinations (OSPE) in which students can be asked to interpret force profiles and processed sEMG data and elucidate the underlying mechanisms. This experimental paradigm can be expanded for the purpose of postgraduate academics by performing endurance exercise at different grades, plotting additional time domain parameters like RMS and ARV of the sEMG data and frequency domain parameters like median frequency (9).

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