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Neuromuscular fatigue differs with biofeedback type when performing a submaximal contraction

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Abstract

The aim of the study was to examine alterations in contractile and neural processes in response to an isometric fatiguing contraction performed with EMG feedback (constant-EMG task) when exerting 40% of maximal voluntary contraction (MVC) torque with the knee extensor muscles. A task with a torque feedback (constant-torque task) set at a similar intensity served as a reference task. Thirteen men (26 ± 5 yr) attended two experimental sessions that were randomized across days. Endurance time was greater for the constant-EMG task compared with the constant-torque task (230 ± 156 s vs. 101 ± 32 s, $P < 0.01$). Average EMG activity for the knee extensor muscles increased from $33.5 \pm 4.5\%$ to $54.7 \pm 21.7\%$ MVC EMG during the constant-torque task ($P < 0.001$), whereas the torque exerted during the constant-EMG task decreased from $42.8 \pm 3.0\%$ to $17.9 \pm 5.6\%$ MVC torque ($P < 0.001$). Comparable reductions in knee extensors MVC ($-15.7 \pm 8.7\%$ for the constant-torque task vs. $-17.5 \pm 9.8\%$ for the constant-EMG task, $P > 0.05$) and voluntary activation level were observed at exhaustion. In contrast, excitation–contraction coupling process, assessed with an electrically evoked twitch and doublet, was altered significantly more at the end of the constant-EMG task despite the absence of M-wave changes for both tasks. Present results suggest that prolonged contractions using EMG biofeedback should be used cautiously in rehabilitation programs.

Keywords: Prolonged submaximal isometric contraction; Torque feedback; EMG biofeedback; Muscular twitch; Central activation

1. Introduction

Electromyographic biofeedback technique has been used for several years in rehabilitation programs, notably after knee injury (Draper, 1990; Levitt et al., 1995). This technique involves the voluntary activation of a muscle group at a submaximal level and the subject is provided with visual and/or auditory feedback of the electromyogram (EMG) recorded by surface electrodes.

The surface interference EMG reflects the sum of the excitatory and inhibitory inputs to the motor neuron pool, as well as any alterations in the intrinsic properties of the motor unit and influences from signal cancellation (Farina et al., 2004). Surface EMG constitutes an indirect indicator of the central drive (Gandevia, 2001), and is directly associated with activity of the motor unit (Suzuki et al., 2002). Consequently, when an individual is required to maintain a constant level of EMG, any alteration at the local muscular level is compensated by a change in voluntary drive (e.g. increased duration of motor unit action potential). The output of the motor unit pool may slightly vary due to peripheral adjustments, but here we focus on the resultant signal provided by surface EMG, a well-used index to characterize muscle fatigue. During such a task (constant-EMG task), there is typically a progressive decrease in force for the knee extensor muscles (Mitchell et al., 1981; Sadamoto et al., 1983; Place et al., 2006) and flexor digitorum superficialis muscle (Cain and Stevens, 1973). The progressive decrease in force indicates that the motor output likely experienced significant peripheral fatigue. In these above studies (Cain and Stevens, 1973; Mitchell et al., 1981; Sadamoto et al., 1983; Place et al., 2006), subjects were required to maintain a constant level of EMG for a given

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period of time. Nevertheless, no study has investigated the time to task failure (i.e., endurance time) for a constant-EMG task. Consequently, neuromuscular mechanisms of fatigue subsequent to a constant-EMG task sustained until the EMG level cannot be maintained have never been examined.

In contrast to constant-EMG tasks, endurance time for a submaximal contraction where the force or torque remains constant (constant-torque task) has already been investigated. During a constant-torque task, the progressive increase in electromyographic (EMG) activity (Hunter et al., 2002, 2003; Loscher et al., 1996; Rochette et al., 2003) is thought to be due to recruitment of motor units with some contribution of changes in firing rate (Adam and De Luca, 2003; Carpentier et al., 2001; de Ruiter et al., 2004; Fallentin et al., 1993; Garland et al., 1997) to compensate for the loss in force output from already active motor units (Adam and De Luca, 2003). For this kind of contraction, muscle fatigue mechanisms are associated with central and/or peripheral alterations of the neuromuscular system (Kooistra et al., 2005; Place et al., 2005). However, the relative contribution of peripheral and central fatigue may depend on various task details including muscle length, fatigue protocol (isometric vs. dynamic, continuous vs. intermittent) and relative intensity of the contraction (Kalmar and Cafarelli, 1999; Klass et al., 2004; Kooistra et al., 2005; Place et al., 2005).

The purpose of this study was to examine the acute changes in peripheral and central processes contributing to fatigue at the termination of a sustained submaximal fatiguing isometric contraction performed at an EMG level corresponding to 40% MVC torque (constant-EMG task) with the knee extensor muscles. As the failure mechanisms of a constant-torque task have already been investigated by several authors, subjects performed a reference constant-torque task at the same relative intensity on a separate session. By performing these two tasks, we aimed to understand the mechanisms of failure for a constant-EMG task in light of what is known for a constant-torque task. Because the muscle torque will decrease during the constant-EMG task, we hypothesized different contributions from central and peripheral sources to fatigue between the two tasks. To assess central fatigue, we measured the level of voluntary activation and the maximal EMG activity normalized to the compound muscle action potential (M-wave) at task failure. Peripheral component of fatigue was assessed by evaluating neuromuscular excitability with M-wave and contractile properties with twitch and doublet responses induced by femoral nerve stimulation. Evaluation of neuromuscular system at the end of the constant-EMG task will allow providing guidelines for muscle rehabilitation using visual biofeedback.

2. Materials and methods

Thirteen physically active male adults (age: 26 ± 5 (SD) yr, body mass: 70 ± 7 kg, height: 177 ± 6 cm) volunteered to participate in the study after they were informed of the experimental procedures and possible risks. None of the subjects had any known neurological disorder. The procedures were conducted according to the Declaration of Helsinki. Prior to the study, each subject gave written consent and the local ethical committee approved the study protocol.

Subjects reported to the laboratory on two occasions (4 ± 2 days apart), to perform a protocol that focused on a fatiguing contraction with the knee extensor muscles of the right (dominant) leg. In one session, the fatiguing contraction involved maintaining a torque equal to 40% of the MVC torque for as long as possible; this is referred to as the *constant-torque task*. In the other session, the fatiguing contraction involved maintaining the summed EMG RMS (root mean square) of vastus lateralis (VL), vastus medialis (VM) and rectus femoris (RF) muscles at an RMS level corresponding to 40% of the MVC torque for as long as possible; this is referred to as the *constant-EMG-task*. The order of these two tasks was randomized for each subject across experimental days. The two sessions occurred at the same time of the day for each subject.

2.1. Data collection

2.1.1. Evoked contraction

Transcutaneous electrically-evoked contractions were induced by using a high-voltage constant-current stimulator (model DS7, Digitimer, Hertfordshire, UK). The femoral nerve was stimulated using a monopolar cathode ball electrode (0.5-cm diameter) pressed into the femoral triangle by the experimenter. The site of stimulation was marked on the skin so that it could be repeated after the sustained contraction and between the two sessions. The anode was a $50\,cm^2$ (10×5 cm) rectangular electrode (Compex SA, Ecublens, Switzerland) located in the gluteal fold opposite of the cathode. The optimal intensity of stimulation (i.e., that which recruited all knee extensor motor units) was considered to be reached when an increase in the stimulation intensity did not induce a further increase in the amplitude of the twitch force and the peak-to-peak amplitude of knee extensors M-wave (see Electrical recordings). The stimulus duration was 1 ms and the interval of the stimuli for the doublet was 10 ms. Once the optimal intensity was found, it was kept constant throughout the session for each subject.

2.1.2. Mechanical recording

Maximal isometric torque and mechanical responses from the electrical stimulation of the right knee extensors were recorded using a Biodex isokinetic dynamometer (Shirley, NY). The axis of the dynamometer was aligned with the knee-extension axis, and the lever arm was attached to the shank with a strap. Extraneous movement of the upper body was limited by two crossover shoulder harnesses and a belt across the abdomen. To allow the recording of the biceps femoris (BF) EMG, a