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Effect of mental fatigue on induced tremor in human knee extensors

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ABSTRACT

In this study, the effects of mental fatigue on mechanically induced tremor at both a low (3–6 Hz) and high (8–12 Hz) frequency were investigated. The two distinct tremor frequencies were evoked using two springs of different stiffness, during 20 s sustained contractions of the knee extensor muscles at 30% maximum voluntary contraction (MVC) before and after 100 min of a mental fatigue task, in 12 healthy (29 ± 3.7 years) participants. Mental fatigue resulted in a 6.9% decrease in MVC and in a 9.4% decrease in the amplitude of the agonist muscle EMG during sustained 30% MVC contractions in the induced high frequency only. Following the mental fatigue task, the coefficient of variation and standard deviation of the force signal decreased at 8–12 Hz induced tremor by 31.7% and 35.2% respectively, but not at 3–6 Hz induced tremor. Similarly, the maximum value and area underneath the peak in the power spectrum of the force signal decreased by 55.5% and 53.1% respectively in the 8–12 Hz range only. In conclusion, mental fatigue decreased mechanically induced 8–12 Hz tremor and had no effect on induced 3–6 Hz tremor. We suggest that the reduction could be attributed to the decreased activation of the agonist muscles.

1. Introduction

Mental fatigue is a psychobiological condition that arises due to prolonged periods of cognitive activity (Boksem and Tops, 2008), and can be characterised by feelings of "tiredness" and "reduced propensity for expending energy". These changes can be attributed to alterations in motor cortical activity with little influence on peripheral mechanisms (Boksem et al., 2005; Marcora et al., 2009; Tartaglia et al., 2008). Muscle tremor, either physiological, pathological or mechanically induced, is a complex phenomenon that can be affected by both peripheral mechanisms and activities in several areas of the central nervous system including the motor cortex (central factors) (Deuschl et al., 2001), for this reason it might be affected by mental fatigue (Slack et al., 2009) and, in this regard, we postulate that a form of tremor mainly related to peripheral factors, should be less influenced by mental fatigue than a form of tremor mainly related to central factors.

Various studies have shown that self maintaining force fluctuations (hereafter referred to as instability) can be revealed when contracting against a compliant load, such as a spring, and can be attributed to instability of the stretch reflex pathway (Durbaba et al., 2005; Joyce and Rack, 1974; Lippold, 1970; Matthews and Muir, 1980). Also, modelling and experimental studies have shown that the frequency of oscillation of the instability is linked to whether the short (spinal) or long (transcortical) latency pathway of the stretch reflex is predominantly activated (Brown et al., 1982; De Serres et al., 2002; Durbaba et al., 2005, 2013; Lippold, 1970; Matthews and Muir, 1980; Stein and Oguztoreli, 1976). Predominant activation via the short latency pathway leads to 8–12 Hz tremor, whilst via the long latency pathway tremor occurs at 3–6 Hz. It is reasonable to postulate that these forms of tremor, being generated by instability around different neuronal loops (either central or peripheral), would respond differently to a stimulus such as mental fatigue which is known to affect an area through which only the central component of the stretch reflex is routed (Mrachacz-Kersting et al., 2006; Taylor et al., 1995).

The purpose of the present study, is to explore the effects of a mental fatigue task on both 8–12 Hz and 3–6 Hz tremor, induced mechanically using springs of different stiffnesses during a knee extension task. We hypothesised that mental fatigue would cause greater changes in the instability at 3–6 Hz, generated by the long latency (transcortical) stretch reflex component, than in the instability at 8–12 Hz, generated by the short latency (spinal) stretch reflex component.

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2. Methods

2.1. Participants

Twelve male individuals (29 ± 3.7 years) with no history of neurological disorder participated in the experiment. The study complied with the latest version of the Declaration of Helsinki and received approval from the Human Research Ethics Committee at University College Dublin. All individuals gave written informed consent prior to participation in the study.

2.2. Experimental design

Participants were requested to attend the laboratory for a single experimental session. They performed a maximal voluntary isometric contraction (MVC) of the knee extensor muscles followed by two submaximal sustained (20 s) contractions of the same muscle group at 30% MVC (Fig. 1A), using two linear springs of different stiffness. After each participant completed a mental fatigue task lasting 100 min, the submaximal contractions were repeated at the same force level as pre-fatigue, and the subject's MVC was measured again.

Participants were seated in a rigid chair with their trunk erect, fastened with an abdominal belt, and with a 90° angle at the knee joint. A cuff around the ankle joint was connected through a metal chain to a load cell (Leane International, Parma, Italy) attached to posterior part of the chair frame. The MVC task consisted of three isometric contractions to the maximum exerted by the knee extensors. Contractions were maintained for approximately 3 s with a five-minute rest between attempts. Participants followed their performance on a computer screen and were verbally encouraged to achieve their maximum, in an effort to exceed the previous force value. MVC was calculated as the highest value reached within any single force recording.

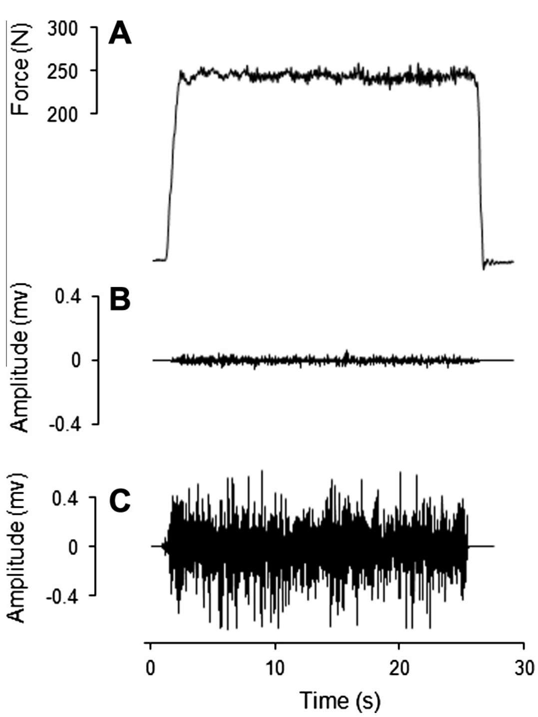

Fig. 1. Sustained anisometric contraction. Representative data from a single subject: (A) Force output at 30% MVC. (B) Surface EMG from the antagonist biceps femoris muscle. (C) Surface EMG from the agonist vastus lateralis muscle.

Once the MVC value was determined, individuals performed a submaximal contraction with each of the two different springs. The spring was connected in series between the load cell and the chain, appropriately shortened to maintain 90° at the knee joint when the spring was stretched. The order of the contractions was randomized (counterbalanced), with a three-minute interval between each contraction. During these tasks, the participants were provided with visual feedback of their performance and were instructed to maintain the force as close as possible to the visual force target represented by a horizontal cursor placed on the computer screen.

Surface EMG was recorded from the Vastus Lateralis (VL, Fig. 1C) and Biceps Femoris (BF, Fig. 1B) muscles. Pre-gelled, self-adhesive Ag/AgCl bipolar disc electrodes (Swaromed Universal, Nessler Medizintechnik GmbH, Innsbruck, Austria) were positioned according to the SENIAM guidelines (Freriks et al., 1999) with an inter-electrode distance of 20 mm on carefully prepared skin (shaved, abraded and cleaned with alcohol).

The force and EMG data were collected using the MP 100 EMG system (Biopac Systems, California; 1000 MΩ input impedance and CMRR of 110 dB). The EMG signals were amplified with a gain of 1000 and band-pass filtered from 1 to 500 Hz. The force signal was amplified with a gain of 200 and low pass filtered at 500 Hz. The force and EMG data were synchronised, sampled at 1 kHz with a 16-bit A/D converter (Biopac Systems, Inc. Goleta, CA, USA) and stored on a PC for later analysis.

2.3. Estimating induced tremor frequency

The choice of the spring's stiffness is important since together with the moment of inertia of the limb, it determines the resonant frequency of oscillation of the mechanical system. This in turn will have a strong influence on the frequency at which oscillations due to instability will be expected to occur.

Under compliant contractions, the frequency of oscillation of the induced tremor can is determined by a spring-mass system coupled to elements contributing to the reflex pathway. Durbaba et al. (2013) recently modeled this for the knee extensors in relation to predominant activation of the short and long latency stretch reflex pathways using the same spring stiffnesses employed in this study: 5.35 N mm^{-1} (hereafter referred to as the 'long' spring) and 11.06 N mm^{-1} (hereafter referred to as the 'short' spring).

2.4. Inducing mental fatigue

The protocol for mental fatigue used in this experiment was based on a switch task paradigm (Lorist et al., 2000). Briefly, the participant sat in front of a computer where a black cross divided the white screen in four squares. The first stimulus appeared in the top left square and disappeared after either 2500 ms had elapsed or the user responded. After random intervals (150, 600 or 1500 ms) a new stimulus appeared in the top right square and so on clockwise continuously for 100 min. Stimuli were letters that could be red or blue and either consonants or vowels. When the stimulus appeared in any of the top squares, the participant was instructed to respond with a right choice (pressing the enter key on the computer keyboard) if it was red and with a left choice (pressing the spacebar on the computer keyboard) if it was blue. When the stimulus appeared in any of the bottom squares, the participant was instructed to respond with a right choice if it was a vowel and with a left choice if it was a consonant. The reaction time, measured as the interval in ms from the stimulus appearance to the individual's response, and the number of errors made by the subject were estimated.