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Training induced changes in quadriceps activation during maximal eccentric contractions

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ABSTRACT

Despite full voluntary effort, neuromuscular activation of the quadriceps group of muscles appears inhibited during eccentric contractions. A nerve stimulation protocol during dynamic contractions of the quadriceps was developed that employed triplets of supramaximal pulses to assess suppressed eccentric activation. Subsequently the effects of a short training intervention, performed on a dynamometer, on eccentric strength output and neural inhibition were examined. Torque-angular velocity (T-ω) and experimental voluntary neural drive-angular velocity (%VA-ω; %VA, obtained via the interpolated twitch technique) datasets, were obtained from pre- and post-training testing sessions. Non-linear regression fits of a seven parameter torque function and of a 3rd degree polynomial were performed on the pre- and post-training T-ω and %VA-ω datasets respectively. T-test showed a significant ($p < 0.05$) increase in the overall torque output post-training for the group, with three out of the six subjects demonstrating a significant ($p < 0.05$) increase in the torque output across the range of angular velocities as shown by the extra-sum-of-squares F-test. A significant increase ($p < 0.05$) in the %VA post-training was also observed as well as a reduction in the plateauing of the torque output during fast eccentric contractions.

1. Introduction

The maximal force generating capacity of a muscle is a function of its velocity and length. During *in vitro* studies researchers have repeatedly shown isolated muscle fibres stretched under maximal tetanic conditions produce a force that is 1.5–1.9 times higher than maximal isometric force (Katz, 1939; Délèze, 1961; Edman et al., 1978; Edman, 1988). However, *in vivo* measurements of the torque-velocity profile during maximum voluntary contractions (MVC) show either little difference between isometric and eccentric torque across increasing angular velocities (Westing, 1988), or a tendency to decline with increasing velocity (Westing et al., 1990; Dudley et al., 1990; Pain and Forrester, 2009; Forrester and Pain, 2010). EMG studies have shown a 10–30% decrease in the neural drive of the quadriceps under fast eccentric MVC contractions (Westing et al., 1991; Enoka, 1997; Paillard et al., 2005). It has been proposed that this apparent reduction in neural drive could be due to the existence of a neural tension-limiting mechanism that only becomes active during maximal load contractions of skeletal muscle (Westing et al., 1990; 1991). Pain and Forrester (2009) used normalized wavelet transformed EMG to calculate EMG-corrected maximal voluntary torques (MVT) from a wide range of eccentric and concentric contractions of the knee extensors. They arrived at a peak eccentric to isometric torque ratio (T_{ecc}/T_0) of 1.6.

Dudley et al. (1990) used sub-maximal transcutaneous electrical muscle stimulation (40–60% of MVT) to produce a torque-velocity profile for the knee extensors that was closer to the *in vitro* tetanic profile; T_{ecc}/T_0 of 1.4 and did not drop off at higher lengthening velocities. Westing et al. (1990) also used transcutaneous electrical muscle stimulation, in isolation and superposed on MVC, and although these authors attempted to obtain maximal activation levels using both methods the level of stimulation was subjectively limited between subjects based on their pain thresholds. They found that superposed stimulation increased eccentric MVT by 24% from MVC alone at 360°/s. They obtained a T_{ecc}/T_0 of 1.33 for stimulated only, but 1.23 for superposed stimulation. For the latter the absolute torque values were higher and this was seen as a good indicator of the tension limiting mechanism. Amiridis et al. (1996) also used this superposition method and found similar results to Westing et al. (1990) for untrained subjects (torque with stimulation was 25% higher than MVT alone, and T_{ecc}/T_0 was 1.23

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for MVC plus stimulation), but little eccentric increase for trained athletes when superposed electrical stimulation was used. For the athletes in the study of Amiridis et al. (1996) T_{ecc}/T_0 was 1.22 for superposed stimulation. More recently Pain et al. (2013) used sub-maximal transcutaneous muscle stimulation, but with a wider range of velocities than previously used, to obtain a T_{ecc}/T_0 of 1.7 for both the quadriceps and hamstrings. In these studies lower absolute eccentric torque is associated with higher T_{ecc}/T_0 ratios and is supportive of the tension limiting hypothesis.

The aforementioned studies have all used muscle stimulation which can cause rapid fatigue and discomfort and also reduces concentric torque values compared to MVT values. Transcutaneous stimulation of the femoral nerve is an alternative method for stimulating the quadriceps muscles, and has been used repeatedly in studies utilising the interpolated twitch technique (ITT) during isometric and slow dynamic contractions and in maximal rate of force development studies using octets (Deutekom et al., 2000; de Ruiter et al., 2004; Folland et al., 2014; Beltman et al., 2004). However, there does not appear to be any literature on repeated nerve stimulation during fast eccentric contractions and its effect on neuromuscular activation.

The results of Amiridis et al. (1996) suggest that the MVC and stimulated torque-velocity profiles may depend upon the fitness level of subjects. Therefore, it can be hypothesised that specific strength training could induce a reduction in the inhibitive action and a number of studies tested that hypothesis using various training programmes. These, however, were either performed using free weights (Aagaard et al., 2000), focused on the concentric phase of muscular contraction only (Caiozzo et al., 1981), or the aim was to establish training-induced physiological changes of the contracting muscles (Coyle et al., 1981; Aagaard et al., 2001). Spurway et al. (2000) performed a 6 week knee extension training protocol with one leg concentric and one leg eccentric and surmised from their results that eccentric strength was increased primarily from decreased inhibition. However, no measures of neural activity were taken and morphological changes would also likely have started. Furthermore, attempts to improve the force output during maximal voluntary eccentric contractions by following a strictly isovelocity strength training protocol have given contradictory results (Higbie et al., 1996; Seger and Thorstensson, 2005).

The aims of this study were: (a) to develop a nerve stimulation protocol during dynamic contractions without causing excessive discomfort or injury in order to examine suppressed eccentric activation and (b) to investigate whether performing a high velocity strength training protocol using eccentric-concentric cycles on an isovelocity dynamometer would lead to a decrease in the inhibitive action of the neural factors and an increase in torque output during fast eccentric maximal voluntary contractions. The training protocol was specifically geared to high velocity eccentric/concentric training on an isovelocity dynamometer over a period of 3 weeks to limit adaptations to predominately neural changes (Colliander and Tesch, 1990). It was hypothesized that at the end of the training cycle subjects would exhibit significantly higher torque outputs and a reduction in neural inhibition.

2. Method

Two similar groups of male volunteers, (n = 9 and n = 6), who had not previously engaged in any systematic form of strength training or high level sports practice, were recruited for the study (mean ± standard deviation: age 26.3 ± 2.7 years, body mass 72.9 ± 11.7 kg, height, 172.2 ± 8.4 cm). They all gave written, informed consent and the study was conducted in accordance with the approval given by the Loughborough University Ethical Advisory Committee. The study was divided into two phases to address aims (a) and (b) above.

2.1. Phase 1

The minimum required sample size was determined by performing a power analysis on the MVC and superimposed eccentric torque values reported by Westing et al., (1990). The analysis showed that a minimum sample size of four was required to achieve a power value of 0.8 and $p < 0.05$. To account for drop out a total of nine subjects took part in this phase of the study and data collection finished when six had completed the protocol. As this protocol was painful for some subjects, and pain was associated with an increased risk of injury, the subject numbers were kept minimal for ethical considerations, and two more than the minimum completed testing in case of later issues with data. Testing took place on an isovelocity dynamometer with built-in gravitational torque correction (Con-Trex, CMV AG, Switzerland) over three sessions. In each session subjects were seated on the dynamometer with their dominant leg strapped tightly to the unpadded crank arm directly above the ankle joint using a protective moulded plastic shin guard. The anterior hip angle was set at 100° (seat was set at 80° incline). To minimize differences between the crank and joint kinematics, the rotational axis of the crank arm was aligned with the centre of the knee joint during near-maximal efforts.

Dynamometer and stimulator data were recorded simultaneously at 512 Hz with Spike2 software (Spike 2, CED, Cambridge, UK). The dynamometer data were filtered at 8 Hz using a low-pass fourth order Butterworth filter. Knee joint angles were measured with a mechanical goniometer during four isometric trials and the instantaneous crank arm angle was converted to joint angle using a linear regression equation (Pain and Forrester, 2009). For each dynamic trial the maximum eccentric and concentric isovelocity phases were identified and the isovelocity plateau was defined as the region where the angular velocity was within 5% of the peak value.

Each session was initiated with a standardized warm up protocol. Session 1 was a familiarisation session where subjects performed one maximal MVC at crank angles of 15° through to 75° in 15° steps (with 0° corresponding to full extension) and a number of MVC and electrically stimulated dynamic (eccentric-concentric) contractions at 50, 200 and 350°/s. The optimum angle of peak torque was determined by fitting a quadratic to the torque-angle dataset obtained from the isometric MVCs. During the second session maximum, eccentric-concentric contractions were performed at: 50, 200 and 350°/s, according to the protocol of Yeadon and King, 2006 with two-minute rest intervals between trials. Once MVCs were completed subjects performed one stimulated trial at each isovelocity to further familiarise themselves with the sensation. Subsequently, optimum peak torque angles per isovelocity were determined for each subject as well as the time lapse between onset and effect of stimulation in order for the latter to coincide with the optimum angle. The onset of stimulation varied with angular velocity and acceleration (Fig. 1). However, the changing width of stimulation twitch response with angular velocity (Gandevia et al., 1998) was not accounted for. In the third session subjects performed one MVC and one supramaximal stimulation trial at each isovelocity and each contraction mode and the respective peak torque values were recorded and used in the subsequent analysis.

2.2. Electrical stimulation

Transcutaneous electrical stimulation of the quadriceps was achieved using a stimulator (DS7AH, Digitimer Ltd., UK) controlled by Spike 2 software. Two electrodes, a ball probe cathode of 10 mm in diameter, and a rectangular anode (90 × 50 mm) both coated with a thin layer of conductive gel were placed at the femoral

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