KNEE EXTENSOR AND FLEXOR TORQUE – ANGLE – ANGULAR VELOCITY PROFILES FROM MAXIMAL VOLUNTARY AND ELECTRICALLY STIMULATED EFFORTS

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INTRODUCTION

The tetanic force – velocity relationship in isolated muscle fibres follows a well established profile characterised by an eccentric force plateau at approximately 1.5 – 1.9 times the isometric value, and a hyperbolic decay in force with increasing shortening velocity [3,4]. In vivo measurements of maximum voluntary (MVC) force – velocity show differences to the in vitro tetanic profile, with eccentric forces not increasing much above isometric and tending to decline with increasing lengthening velocity [1,6]. Using transcutaneous electrical stimulation to supplement maximum voluntary contractions increases eccentric knee extension torque to above MVC, but has no significant effect on concentric torque [1,6]. Constant stimulation levels that produce 40 – 60% of MVC were used by Dudley et al. [1] to reproduce a torque – velocity profile that was similar to the in vitro tetanic profile; the eccentric torque plateaued at 1.4 times the isometric value and did not drop off at higher eccentric velocities. Pain and Forrester [5] used a wider range of knees extension velocities and looked at correcting the torque – velocity profile using normalized, wavelet transformed EMG, and found that the theoretical maximum eccentric was 1.6 times isometric.

The aim of this study was to determine maximal voluntary and electrically evoked torque – angle – angular velocity profiles for the knee extensors and flexors in a group of healthy males.

METHODS

Fourteen male subjects (age 23 ± 2 yrs, body mass 77 ± 7 kg, height 178 ± 6 cm) gave informed consent. A set protocol was completed on an isovelocity dynamometer (Con-Trex, CMV AG, Switzerland). The protocol consisted of maximal voluntary and sub-maximally stimulated eccentric and concentric knee extension and flexion series at constant angular velocities (+ 100, 200, 300, 400 and 50°/s) through a range of motion from 100 to 5° for quadriceps and 5 to 90° for hamstrings. Isometric torque was measured at 5 angles equally distributed across the range of motion. To determine more accurate joint angular velocities, trials at 200 and 400°/s for each subject were videoed at 200 fps to calculate joint-crank angle offsets, and extrapolated to the other velocity trials.

Transcutaneous electrical stimulation of the quadriceps and hamstrings was achieved using a stimulator (DS7AH, Digitimer Ltd., UK) that produced square wave impulse trains of single pulse duration 100 µs at 50 Hz. Two carbon-rubber electrodes (140 mm × 100 mm; Electro-Medical Supplies, Greenham, UK) were taped over the RF, VL and VM or the hamstrings. Stimulation began at a current of 40 mA and increased in steps of between 10 and 30 mA until the desired level of torque was achieved. Dynamometer and stimulator data were recorded simultaneously with Spike2 software. Evoked extensor torques were set at ~35%, and flexors at ~20% of MVC.

Peak isometric torque was compared to the peak eccentric torque (Ecc/Iso) for the different muscle groups and conditions on a per subject basis. Due to the poor quality of the voluntary eccentric data the single highest average eccentric value from a velocity trial, irrespective of whether it was a high or low velocity trial, was used and called the raw method. Due to the inherent noise and reliability issues with dynamometer testing, subject specific data sets for each condition and muscle group were
further analysed in Matlab using the protocol of Forrester et al. [2] to produce torque – angle – angular velocity profiles which better describe the underlying physiological performances and called the fitted method. Group data for Ecc/Iso were compared between conditions, but not across methods, using a paired t-test (P < 0.05) for both the raw data and fitted data.

RESULTS AND DISCUSSION

Adjusting the crank data to joint data was essential as the initial and range of angles and angular velocities could differ by ~15°, ~20° and up to ~50°/s respectively, thus preventing serious errors in determining the torque – angle – angular velocity data points. There were no major fatigue effects (retest values between 0 and 9% drop with the norm being <5%). As can be seen in Figure 1 the raw data for the evoked trials appears to follow the in vitro tetanic pattern much more closely than the voluntary trials. As in earlier studies the voluntary eccentric torques dropped off with increasing velocity, and this occurred for both extensors and flexors. The mean Ecc/Iso values for voluntary activation and electrically evoked trials are presented in Table 1. There was no significant difference between the extensor and flexor Ecc/Iso values for voluntary activation but there was for the evoked condition with flexors less than extensors.

At the highest eccentric velocities, where torque has not previously been measured, the voluntary drop off became increasingly rapid. This meant that the maximum voluntary eccentric torques typically occurred at -50 or -100°/s and were more variable than those determined from the fitted method. The effect of this can be seen in the standard deviation values in Table 1. Given the ranges and variability of the raw data it was considered that the fitted method gave a more consistent and reliable set of results with regard to determining Ecc/Iso. For the evoked extensors an Ecc/Iso of 1.61 was almost identical to the EMG corrected value found in Pain and Forrester [5] for the knee extensors. Both the evoked flexor and extensor values were higher than those reported by Dudley [1]. This may be unsurprising for two reasons: in this case torque was measured at much higher eccentric velocities; and the fitting procedure also gives an extrapolated eccentric maximum value. Our values fall more in line with the in vitro tetanic values in the literature.

Table 1. Ecc/Iso ratios - group mean and SD for flexors and extensors, voluntary and evoked.

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<th>Parameter surfaces, in colour, fitted to evoked (left graph) and voluntary (right graph) raw torque data shown by black circles.</th>
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| Knee extensors | Knee flexors |
|---|---|---|---|
| Voluntary | Evoked | Voluntary | Evoked |
| Raw | Mean 0.96 | 1.84* | 1.01 | 1.48* |
| SD | 0.11 | 0.38 | 0.17 | 0.25 |
| Fitted | Mean 1.11 | 1.61* | 1.06 | 1.50* |
| SD | 0.09 | 0.08 | 0.03 | 0.22 |

CONCLUSIONS

Electrically evoked Ecc/Iso ratios in the knee extensors and flexors were 1.61 and 1.50, respectively, with the extensor value found here higher than previously measured across lower velocity ranges [1].

REFERENCES