INTRODUCTION

Maximum strength and power varies with the velocity of muscular contractions and the length of the muscle fibres. 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].

Maximum torque expressed at the joint level is a complex integration of the muscle fibre contractile properties with the in vivo architecture of multiple muscle fibres, connective tissue and neural input. 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. Using transcutaneous electrical stimulation maximal eccentric torque has been found to be 1.4 times the isometric value and does not drop off at higher eccentric velocities. 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. Fourteen male subjects performed a set protocol on an isovelocity dynamometer consisting 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). Peak isometric torque was compared to the peak eccentric torque (Ecc/Iso) for the different muscle groups and conditions on a per subject basis. Evoked Ecc/Iso ratios in the knee extensors and flexors were significantly different from each other at 1.61 and 1.50, respectively, with the extensor value found here higher than previously measured across a lower velocity range.

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) over three sessions, familiarisation, an extensor session and a flexor session. 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 5 to 100° for quadriceps and 5 to 90° for hamstrings, 0° is straight leg. Isometric torque was also measured at 5 angles equally distributed across the range of motion of the subject. 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. Passive trials for offline gravity correction were also included.

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,
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 angle at the start the range and angular velocities could differ by, ~15°, ~20° and up to, or even over, 50°/s and lead to 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, although it should be noted not all evoked trials were as clean with regard to the measured data point distribution. 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 higher velocities, where torque had not been measured at previously, the drop off became more rapid. This meant that the maximum voluntary eccentric torques were normally recorded at -50 or -100°/s and were more variable than those determined with the fitted method. The effect of this can be seen in the standard deviation values in Table 1.

Evoked extensor torques were set at ~35%, and flexors at ~20% of MVC.

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: we measured torque 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. Group mean and SD for the eccentric/isometric ratio for flexors and extensors, voluntary and evoked. Both raw and surface fitted results are shown. * P<0.05.

<table>
<thead>
<tr>
<th>Muscle Group</th>
<th>Knee extensors</th>
<th>Knee flexors</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Voluntary</td>
<td>Evoked</td>
</tr>
<tr>
<td>Mean raw</td>
<td>0.96</td>
<td>1.84*</td>
</tr>
<tr>
<td>SD raw</td>
<td>0.11</td>
<td>0.38</td>
</tr>
<tr>
<td>Mean fit</td>
<td>1.11</td>
<td>1.61*</td>
</tr>
<tr>
<td>SD fit</td>
<td>0.09</td>
<td>0.08</td>
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</tbody>
</table>

CONCLUSIONS

Electrically evoked Ecc/Iso ratios in the knee extensors and flexors are significantly different from each other at 1.61 and 1.50, respectively, with the extensor value found here higher than previously measured across a lower velocity range [1].

REFERENCES