Residual force enhancement in maximal voluntary contractions of human dorsi flexors

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INTRODUCTION

When an activated muscle is stretched, the force during stretch exceeds the isometric force at the corresponding muscle length. In the steady state phase following the stretch, there is a remnant increase in force called "residual force enhancement" (RFE). RFE has been observed at different structural levels (ranging from myofibrils to human muscles), across activation levels (stimulated, sub- and maximal voluntary contractions), and on the entire force-length relationship (ascending and descending limb, plateau). Several mechanisms have been suggested to explain this phenomenon but no generally accepted explanation has been found (Herzog, 2004). In voluntary activated human muscles, different results have been found. Lee & Herzog (2002) reported RFE in maximal activated m. adductor pollicis, Pinniger & Cresswell (2007) observed RFE during submaximal voluntary contractions in the plantar- and dorsiflexion groups, while Hahn et al. (2007) did not find RFE in human quadriceps femoris. This study was aimed at investigating RFE under different stretch conditions to identify the possible reasons for the discrepancies in results reported in the literature. We hypothesized that RFE might be abolished in human voluntary contractions following great stretch magnitudes or fast stretch speeds.

METHODS AND PROCEDURES

Ten subjects (5 male, 5 female; 29 (9) years, 177 (11) cm, 71 (14) kg) participated in this study which was approved by the local Ethics Committee. Subjects were seated on a dynamometer (Biodex®, System 3) with their test leg horizontally extended. The backrest was set to 155 degrees to allow for a comfortable sitting position. The flexion-extension axis of the ankle was carefully aligned with the axis of the dynamometer and the ankle securely attached to the footplate with inelastic strapping. Knee and hip were fixed to the dynamometer chair with inelastic strapping. Ankle torque, angle and angular velocity as well as EMG from the tibialis anterior (TA) and medial gastrocnemius (MG) were recorded at 1,000 Hz. Fascicle lengths of TA were measured with ultrasound imaging.

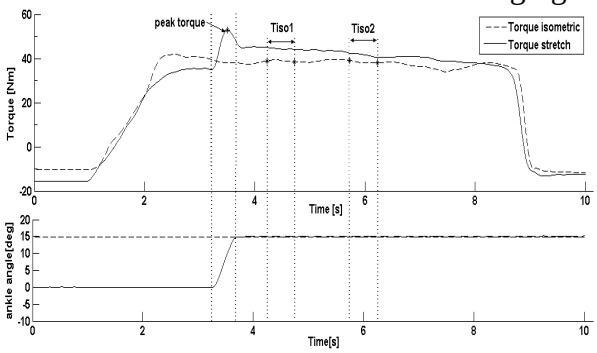

Figure 1. Ankle joint torque and angle as a function of time for an isometric reference contraction and an isometric contraction following stretch.

After a warm up, subjects performed isometric contractions with induced stretches from 0 (sole of the foot perpendicular to tibia) to 15 and from 0 to 30º plantar flexion. The stretches were performed at angular velocities of 10 and 45º/s in random order. Isometric reference contractions at the final stretch position preceded each test contraction. To evaluate possible RFE, we compared the

mean torque values of the isometric reference and the stretch test contractions at 0.5-1.0s ($T_{iso}1$) and 2.0-2.5s ($T_{iso}2$) following stretch (Fig.1). Differences were evaluated at a level of significance of 0.05 using paired t-tests (Bonferroni-Holmes corrected). Normalized mean values were analyzed using repeated measures ANOVA.

RESULTS

Peak torques during stretch did not occur at the end of the stretch and were always greater than the isometric reference torques (Fig. 1). Force following stretch was significantly greater than the isometric reference force at both times of evaluation and for both stretch magnitudes and stretch speeds. Residual force enhancement was greater at 0.5-1.0 than 2.0-2.5s. Stretch amplitude and angular velocity did not significantly influence RFE.

$T_{iso}1$		
Velocity/amplitude	15 deg	30 deg
10 deg/s	112 (10)	114 (10)
45 deg/s	112(10)	115 (10)
$T_{iso}2$		
10 deg/s	110 (10)	109 (14)
45 deg/s	106 (11)	108 (11)

Table 1. $T_{iso}1$ and $T_{iso}2$ torques normalized to isometric reference in %. Data are means (SD). n=10

The mean EMG values (rms 500ms) of TA during stretch exceeded the mean values observed during the isometric reference contractions for all stretch conditions (104-107 % of isometric). For the 0.5-1.0s evaluation period, mean EMG values were greater for all but one (30º and 45º/s) condition (105-107 vs. 97 % of isometric).

DISCUSSION

The aim of this study was to measure RFE for different stretch conditions of human TA activated by maximal voluntary effort. In accordance with Hahn et al. (2007), peak torques did not occur at the end of the stretch. Since we observed a decrease of EMG after peak torques had been achieved, it appears that muscle inhibition may have caused this result. Contrary to Hahn et al. (2007), but in accordance with Lee & Herzog (2002) and Pinniger & Cresswell (2007), we observed significant RFE in voluntary activated human muscles. We must reject the hypothesis that RFE is abolished by long stretch magnitudes or high speeds of muscle stretch during voluntary contractions, and thus cannot explain the discrepancies regarding RFE in the literature with differences in stretch conditions. Possibly, RFE in human muscles depends on muscle size, or might be masked by changes in activation that cannot be observed by surface EMG recordings. Comparisons of RFE at different times following stretch show that the residual force enhancement decreases with time, at least for the short time (2500ms) evaluated here.

SUMMARY

Residual force enhancement was observed for maximal voluntary contractions of the dorsi flexors at 0.5-1.0s and 2.0- 2.5s following stretch. EMG activity was greater during and after stretch compared to isometric. Stretch amplitude and velocity did not significantly affect the amount of RFE. The contradictory results in the literature remain unexplained.

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