STUDY OF MUSCLE TORQUE SHARING PATTERNS IN ISOMETRIC PLANTAR FLEXION BY AN EMG-DRIVEN BIOMECHANICAL MODEL

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INTRODUCTION

Skeletal muscles are usually simulated with mechanical models for estimating the force produced by individual muscles in different motor tasks [1,2]. Although it is usual to discuss motor control strategies based on EMG recordings, a coherent relationship between neuromuscular activation and its respective biomechanical effect must be sought. The aim of this study was comparing the excitation from EMG and individual muscle force patterns in isometric plantar flexions. A modified version of the classical Zajac contraction dynamics model (Figure 1) was used to find forces from the excitations.

METHODS

A group of 13 male subjects laid prone on a Norm/Cybex^{TM} Dynamometer, with the knee extended and the ankle at neutral (90^o) position. The protocol consisted of two steps of submaximal loads of 20% (low) and 60% (medium/high) MVC, separated by 10 seconds of relaxing time. A feedback display of actual force output was provided to the subject. Torque signal and surface EMG from *gastrocnemius medialis* (**gm**), *gastrocnemius lateralis* (**gl**), *soleus* (**sol**) and *tibialis anterior* (**ta**) muscles were synchronously collected. Raw EMG signal initially band-pass filtered (15 – 350 Hz), rectified and low-pass filtered with a 2th order Butterworth filter (2Hz cut-off frequency). Input excitation signal u(t) for the muscle model (Figure 1) was found by normalizing the processed step EMG with MCV EMG. The torque output was found by the sum of each simulated muscle force multiplied by its respective ankle angle moment arm, using polynomial regression equations [3]. The difference between simulated and dynamometer measured torque was calculated as the mean square error between the two curves and expressed relative to the maximal measured torque (%RMSE). Man-Whitney test was applied to assess significant changes of the muscle individual estimated torque and excitation function between the two intensities levels. Significant difference was set as a p value of 0.05.

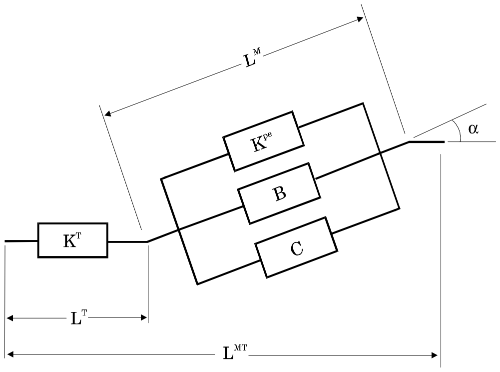

Figure 1: Adimensional Zajac model [5] with added parallel elastic and damping elements .

K^T = stiffness of the tendon
K^{pe} = stiffness of the parallel elastic element
B = damping element
C = contractile element
L^T = length of the tendon
L^M = length of the contractile element
L^{MT} = length of muscle-tendon complex
α = penation angle

RESULTS AND DISCUSSION

The %RMSE was significantly higher for the low intensity level (23.0 ± 10.8%) compared to the medium/high (18.1 ± 11.1 %), showing that the model is less accurate for low contractions. A typical result of the individual muscle torques, total torque and dynamometer-measured torques are shown in Figure 2. From Table 1 the torques generated by each muscle revealed greater contribution of the **sol** muscle followed by the **gm**, similarly for both effort intensities. The **gl** contributed less, although showing a significant increase from the low to the medium/high excitation u(t). Very little co-contraction from **ta** observed. As expected, all muscle activation levels significantly increased to overcome the medium effort, with different rates. However, for the low intensity step, the contribution of **sol** and **gm** were similar, while **gl** contributed significantly less. To attend the torque demands at the medium effort step, **gl** neural contribution increased approximately four times, while the relative participation of both **sol** and **gm** increased approximately twice. Apparently, for this particular task, by increasing the effort level, the SNC keeps a more or less similar torque sharing contribution from each muscle, by changing the relative input contribution from each one.

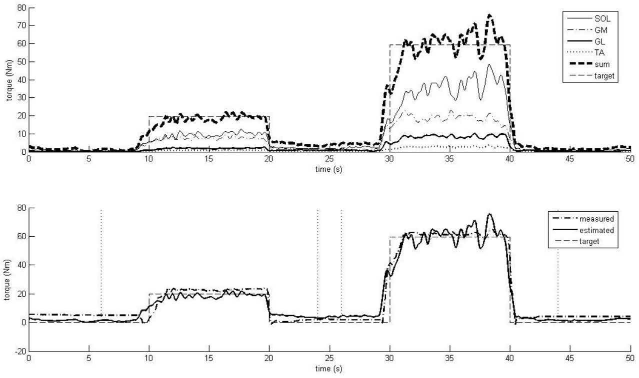

Figure 2: Torque contribution curves from each muscle and total torque, showing also the test protocol (above), for one example subject. Total torque generated by the model and measured by dynamometer (below). The thin dotted vertical lines represents the time limits (before and after the 20% and 60% MVC.

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ACKNOWLEDGEMENTS

The authors are gratefully acknowledged to CAPES Foundation of the Brazilian Education Ministry, and to the Physical Education School of the Brazilian Army, Rio de Janeiro.

Table 1 . Mean ± stand deviation of the normalized excitation function u(t) and relative individual torque contribution to the final torque estimation M(t), for low (20%MVC) and medium/high (60%MVC) contraction intensities. * p<0.05 between contraction intensities.

	Intensity	SOL	GM	GL	TA
u(t)	**low**	8.73 ± 2.98%	11.29 ± 3.53%	5.71 ± 2.93%	1.20 ± 0.62%
	medium	23.37± 6.48% *	27.76 ± 6.77% *	22.73 ± 7.04 % *	3.60 ± 1.40% *
M(t)	**low**	58.17 ± 12.40%	35.43 ± 10.36%	8.63 ± 4.04%	2.24 ± 0.96%
	medium	57.14 ± 7.10%	32.07 ± 5.84%	13.62 ± 2.36 % *	2.83 ± 1.23%