## Triceps surae biomechanical parameters identification using the Markov Chain Monte Carlo Method

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## Abstract

A common application for musculoskeletal models is the estimation of muscle forces, which cannot be directly measured noninvasively. A Hill-type muscle model comprising four ordinary differential equations (1) has been used by our group to estimate muscle forces from EMG signals. The inputs for this model are the neural excitation (u) and the musculotendon actuator velocity ( $v_{MT}$ ), and the dynamic states are the activation (a), the tendon force ( $F_T$ ), the length of the contractile portion of the muscle ( $L_M$ ) and the length of the musculotendon actuator ( $L_{MT}$ ). Such models also depend on many biomechanical parameters to be defined, some of them subject-specific. Some of these parameters are the maximum isometric force ( $F_{0M}$ ), the tendon slack length ( $L_{ST}$ ) and the muscle-fiber pennation angle ( $\alpha$ ).

$$\vec{a} = (u - a)(k_1u + k_2)$$
  

$$\vec{F}_T = \tilde{k}_T (\tilde{v}_{MT} - \tilde{v}_M \cos \alpha)$$
  

$$\vec{L}_M = \tilde{v}_M$$
  

$$\vec{L}_{MT} = \dot{\tilde{v}}_{MT}$$
(1)

The aim of this work is testing a formulation for the subject-specific identification of  $L_{ST}$  and  $\alpha$  for the 3 muscles of the triceps surae, based on experimental tests with an isokinetic dynamometer: the set of parameters which the simulations best match the dynamometer measured joint torque x time curve, for a known input, is, presumably, the *correct* ones. Thus, the identification problem can be interpreted as an inverse problem, considering that the results are known (the joint torque curve), and what is sought are the problem parameters that lead to that result. In this paper, the experimental torque will be simulated through the numerical integration of Equations (1) with known parameters, which will be identified and compared to its known values, as the numerical validation of the approach.

Joint torques measured by the dynamometer present errors and uncertainties. For this reason, to simulate the experimental data, a normal (Gaussian) distribution of the torque has been considered. The mean of the distribution is the deterministic solution of the model calculated with known parameters, and the standard deviation was assumed as 2.5 N.m, based on [1].

The Markov Chain Monte Carlo method (MCMC) was used to solve the inverse problem, by identifying the muscle parameters using the Metropolis-Hastings algorithm [2]. The convergence of the Markov chain was verified by the Gelman-Rubin method [3].

The burn in period of the generated Markov chains was discarded, according to Gelman-Rubin method. New chains were generated, all combined in a single one, from which each desired parameter was calculated. The initial guess of  $\alpha$  values was randomly selected within the range between  $\pm 15\%$  of the nominal and for  $L_{ST} \pm 5\%$ .

Figure 1 shows the Markov chain of the soleus pennation angle. It can be observed that the whole feasible range of the parameter value can be assumed by the estimation. Figure 2 shows the a posteriori frequency histogram, indicating a tendency towards a uniform distribution. The Markov chain of the  $L_{ST}$  estimates shows convergence to a few specific values (Figure 3); the corresponding frequency histogram can be observed in Figure 4. Table 1 shows the known and the identified parameters values, the 95% confidence interval, and the absolute difference between the known and the identified values.

The histogram tendency towards a uniform distribution for the pennation angle is related to the low sensitivity of this parameter. Inversely,  $L_{ST}$  is a high sensitivity parameter [4]. It is interesting to observe that this parameter shows much closer estimation compared to  $\alpha$  (Table 1). This result

suggests that the proposed methodology is a promising approach for finding sensitive individual parameters of muscle models from experimental torque data.



Figure 1: Markov chain of soleus  $\alpha$ , showing that the whole range of the allowed values was occupied by the possible parameter value



showing the convergence to a few specific values  $\frac{1}{2}$ 



Figure 2: A posteriori frequency histogram of soleus α, indicating a tendency towards a uniform distribution



Figure 4: A posteriori frequency histogram of soleus  $L_{ST}$  showing the convergence to a few specific values

Table 1: Biomechanical parameters; (s) soleus, (mg) medial gastrocnemius, (lg) lateral gastr	rocnemius;							
$\alpha$ is measured in radians and L <sub>ST</sub> in meters								

	Biomechanical Parameter					
	α (s)	α(mg)	a(lg)	$L_{ST}(s)$	L <sub>ST</sub> (mg)	$L_{ST}$ (lg)
Known	0.4363	0.2967	0.1396	0.2680	0.4080	0.3850
Identified	0.4225	0.2713	0.1624	0.2665	0.4134	0.3861
CI (95%)				[0.2622;0.2708]	[0.4078;0.4190]	[0.3841;0.3881]
Difference (%)	3.16	8.54	16.36	0.56	1.31	0.28

## References

- J. M. Drouin, T. C. Valovich-mcLeod, S. J. Shultz, B. M. Gansneder, and D. H. Perrin, "Reliability and validity of the Biodex system 3 pro isokinetic dynamometer velocity, torque and position measurements," *Eur. J. Appl. Physiol.*, vol. 91, no. 1, pp. 22–29, Jan. 2004.
- [2] H. R. B. Orlande, M. J. Colaço, C. P. N. Cotta, G. Guimarães, and V. L. Borges, "Problemas Inversos em Transferência de Calor," SBMAC, Notas em Matemática Aplicada, vol. 51, p. 113, 2011.
- [3] A. Gelman and D. B. Rubin, "Inference from Iterative Simulation Using Multiple Sequences," *Stat. Sci.*, vol. 7, no. 4, pp. 457–472, Nov. 1992.
- [4] K. G. Keenan and F. J. Valero-Cuevas, "Experimentally valid predictions of muscle force and EMG in models of motor-unit function are most sensitive to neural properties," *J. Neurophysiol.*, vol. 98, no. 3, pp. 1581–1590, Sep. 2007.

## Acknowledgments

The authors are greatfully acknowledged to CAPES, FAPERJ, CNPq and FINEP for finantial support.