AN EMG-DRIVEN MUSCULOSKELETAL MODEL FOR THE ESTIMATION OF BIOMECHANICAL PARAMETERS OF WRIST FLEXORS (AND EXTENSORS)

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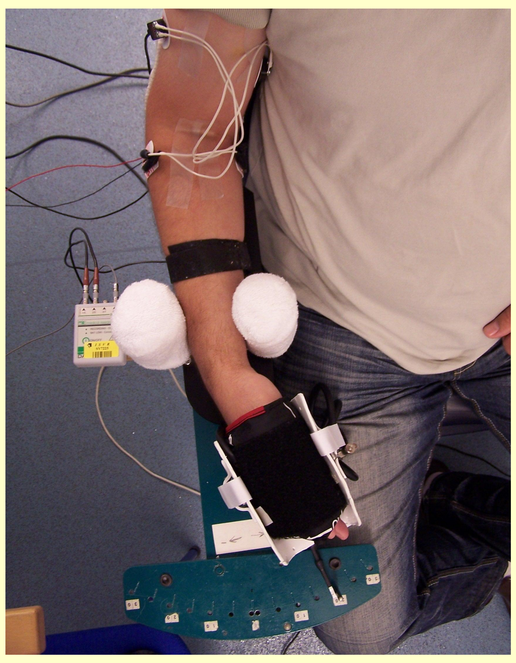
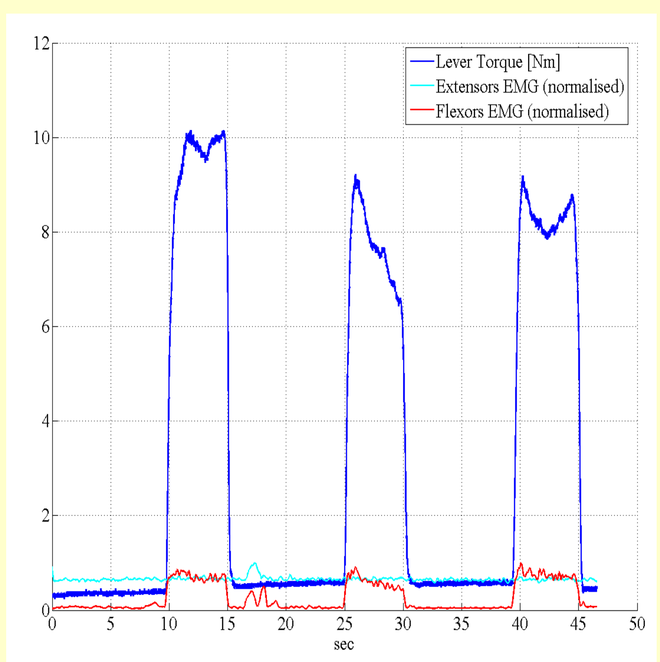
ABSTRACT

A musculoskeletal model of wrist flexors and extensors comprising musculoskeletal dynamics and limb anatomy was experimentally validated with healthy subjects during maximum voluntary contractions. Electromyography signals from flexors and extensors were used as input, while measured torques exerted by the hand were compared to the torques predicted by the model. The root mean square error (RMSE) and the normalized RMSE (NRMSE) calculated during estimation and validation phases were compared. In total, six subject-specific musculoskeletal parameters were estimated, while biomechanical indexes such as the muscle operating range, the stiffness of the musculotendon actuators, and the contribution of the muscle fibers to the joint moment were computed. Results are in agreement with previously published data.

EXPERIMENTAL SETUP

- Instrumented armchair
- 7 positions in the range +30° (flexion) to -30° (extension)
- 12 healthy subjects (mean age 31.1 ± 8.7 years)
- 3 isometric flexion-extension MVCs at each position
- For flexors, surface EMG electrodes equidistant from the motor point of Flexor Carpi Ulnaris (FCU), Flexor Carpi Radialis (FCR) and Flexor Digitorum Superficialis (FDS).
- For extensors, EMG electrodes close to the motor point of Extensor Carpi Radialis Longus (ECRL).
- Torques measured by a calibrated strain gauge load cell.





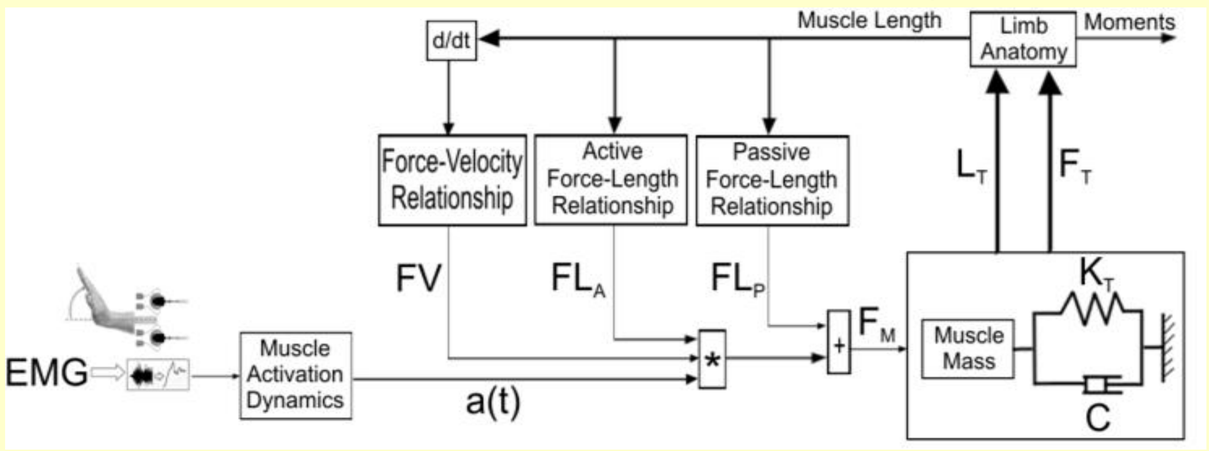
WRIST MODEL

- Hill-type musculotendon model (Zajac ,1989)

$$F_{MT}(\theta,t) = F_M = F_T = \left[\tilde{FL}_a \cdot \tilde{FV} \cdot a + \tilde{FL}_p\right] \cdot F_{oM}$$

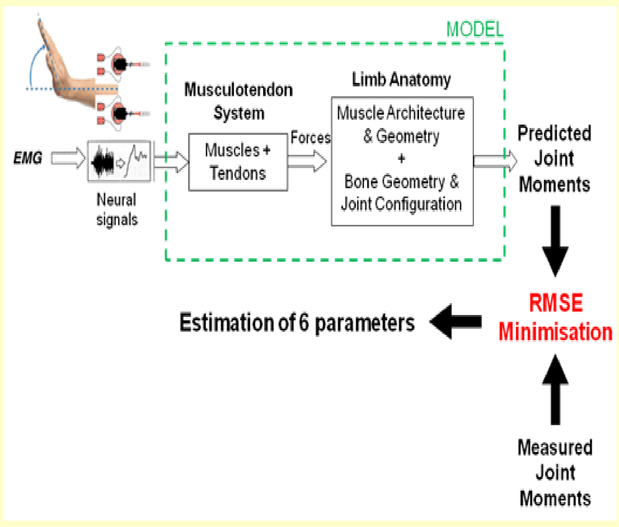
- Muscle length $L_M(\theta)$ given by (Lemay & Crago, 1996)
- Musculotendon dynamics governed by

$$F_M(\theta,t) = M_M \cdot \ddot{L}_T(\theta,t) + C(\theta,t) \cdot \dot{L}_T(\theta,t) + F_{K_T}(\theta,t)$$



PARAMETER ESTIMATION

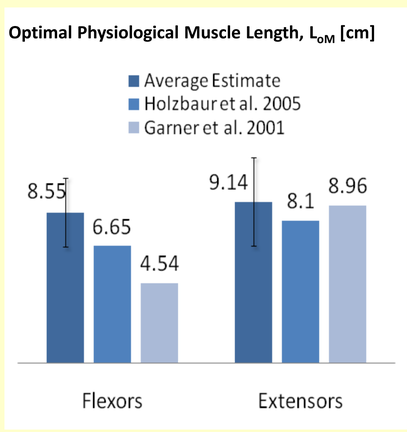
- L_{oM}: Optimal physiological muscle length
- F_{oM}: Maximum isometric muscle force
- L_{TS}: Tendon slack length
- MA: Moment arm
- ΔL_{MT}: Musculotendon length change
- Coefficient (A) related to the activation dynamics

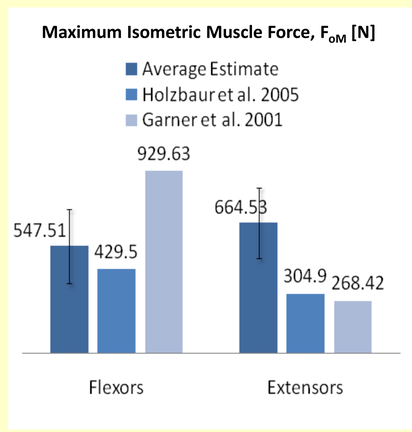


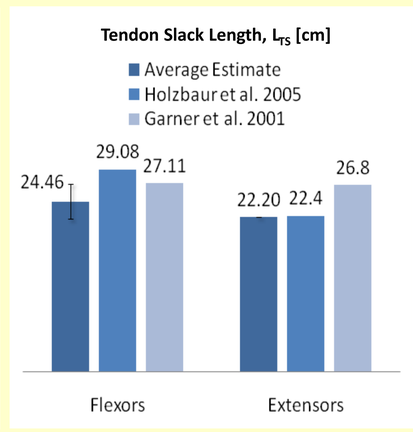
- MA and ΔL_{MT} were allowed a 10% variation with respect to values obtained from (Lemay & Crago, 1996)
- Coefficient A was bounded as in (Buchanan et., 2004)
- 6 out of 7 measurements recorded for each subject and each muscle group were used for estimation
- Measurements at 0° were only used during validation
- The Matlab function *fmincon* was used for the minimization

RESULTS

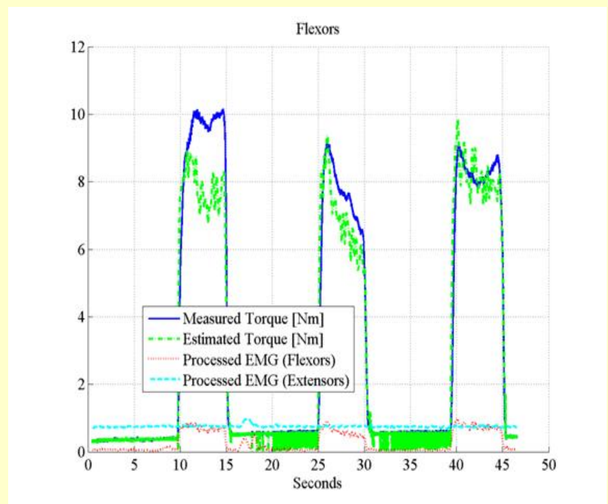
Estimated Parameters

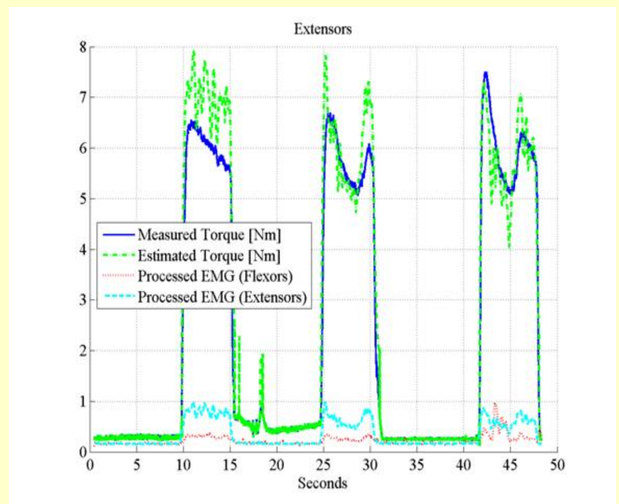


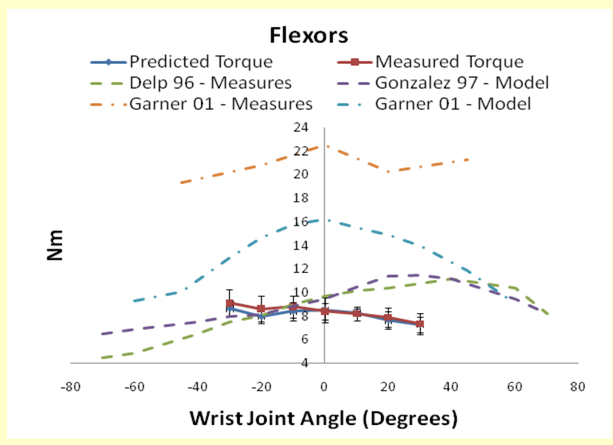


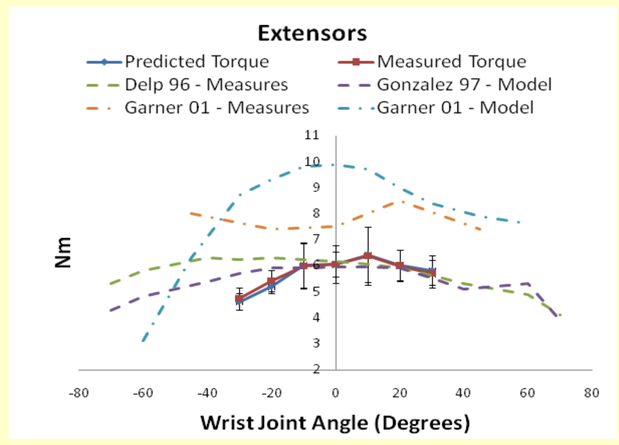


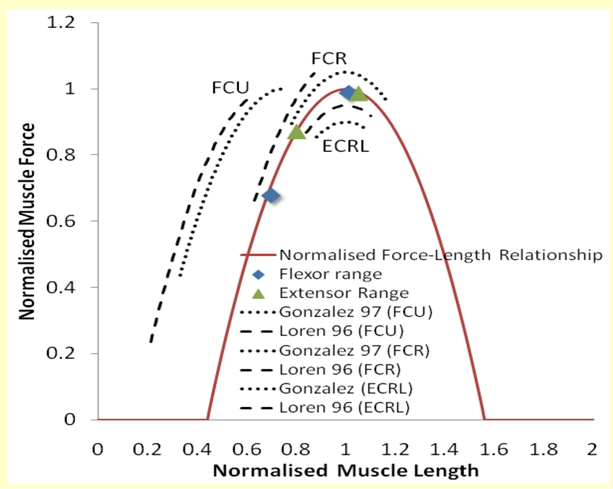
Validation











	Estimation		Validation	
	Flexors	**Extensors**	**Flexors**	**Extensors**
RMSE [N]	0.74	0.39	0.90	0.49
NRMSE [%]	8.76	6.51	10.36	7.80
	Flexors		**Extensors**	
L_{TS}/L_{oM}	2.94 ± 0.53		2.47± 0.32	
L_{oM}/MA_{ave}	4.69 ± 0.79		9.18± 1.23	

- L_{TS}/L_{oM}: stiffness of musculotendon actuators
- L_{oM}/MA_{ave}: contribution of the muscle fibers to the joint moment

CONCLUSIONS

The present model showed its potential as an in vivo method to estimate musculotendon parameters:

- The values of the estimated parameters varied in a physiological range
- The model was able to simulate the measured torques with values of RMSE and NRMSE comparable to those calculated during the estimation phase
- The range of motion of the muscle fibers and the values of L_{TS}/L_{oM} and L_{oM}/MA_{ave} were consistent with findings in (Zajac, 1989; Loren et al., 1996; Gonzalez et al., 1997)

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