

OPTIMIZATION-BASED AND EMG-ASSISTED ESTIMATION OF MUSCLE FORCES AND JOINT MOMENTS UNDER ISOMETRIC AND DYNAMIC CONTRACTIONS

D. Amarantini

Laboratoire Adaptation Perceptivo-Motrice et Apprentissage - EA 3691, Université Toulouse III
118 route de Narbonne, 31062 Toulouse Cedex 9, France
david.amarantini@cict.fr and <http://www.lapma.ups-tlse.fr/>

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Abstract: The quantification of muscular efforts remains a major challenge in biomechanics for numerous applications. The direct measurement of muscle tensions being almost impossible in humans, this presentation focuses on original *EMG-assisted and optimization-based* methods developed to estimate net, agonist and antagonist muscle groups moments as well as individual muscle forces (IMFs) in both static and dynamic conditions. Despite the limitations inherent with the use of EMG, our aim is to combine its use with numerical optimization to obtain reliable estimate of muscular efforts and overcome the limits placed on solutions from classical optimization [1]. First, we propose a EMG-to-moment approach to obtain realistic estimates of agonist and antagonist muscle group moments [2,3], even in fatigued conditions [4]. Second, we propose a novel EMG-assisted minimax optimization method to obtain accurate IMFs in dynamic conditions.

These models were tested on participants who performed dynamic squat exercise. Firstly, the kinematics of body segments were recorded at 120Hz with Vicon equipment; ground reaction was sampled at 240Hz from a AMTI force-plate; surface EMG from the right *Gastrocnemius Medialis*, *Biceps Femoris*, *Rectus Femoris*, and *Vastus Medialis* muscles were recorded at 1000Hz with Mega ME 3000 P8. Secondly, the knee net joint moment (M_K) was computed by solving the inverse dynamics problem using static optimization of joint accelerations [5], and the flexor and extensor knee muscle group moments (M_{Kflex} and M_{Kext} , respectively) were obtained from a generalized version of the EMG-to-moment optimization process proposed by [2]. Finally, the tension developed by nine muscles acting around the knee was obtained by solving the minimax optimization problem expressed at each time instant by:

$$\text{find } t_i \text{ minimizing : } f(t_i) = \max \left(\frac{t_i}{PCSA_i} \right) \quad \text{with: } \begin{cases} 0 < t_i < \sigma_{\max} \cdot PCSA_i \\ \sum r_x \cdot t_x = M_{flex} \quad \text{and} \quad r_y \cdot t_y = M_{ext} \end{cases}$$

where t_i and $PCSA_i$ are the tension and the cross sectional area of muscle i , σ_{\max} is the maximum muscle stress set to 40N/cm², r_x and r_y are respectively the lever arms of flexor muscle x and extensor muscle y .

In general, the combined use of numerical optimization with the introduction of EMG

data as inputs produces suitable estimates of agonist and antagonist moments, as well as IMFs (Figure 1). Particularly, all muscles are predicted to be active and the agonist and antagonist moments are in accordance with the physiological constraints under isometric and dynamic conditions. The proposed methods also provide physiologically realistic IMFs more consistent with both EMG and mechanical laws when compared with “Classical” minimax optimization. Moreover, by appropriately accounting for co-contraction at the level of opposite muscle groups, we obtain reliable IMFs for muscles from which EMG was not recorded.

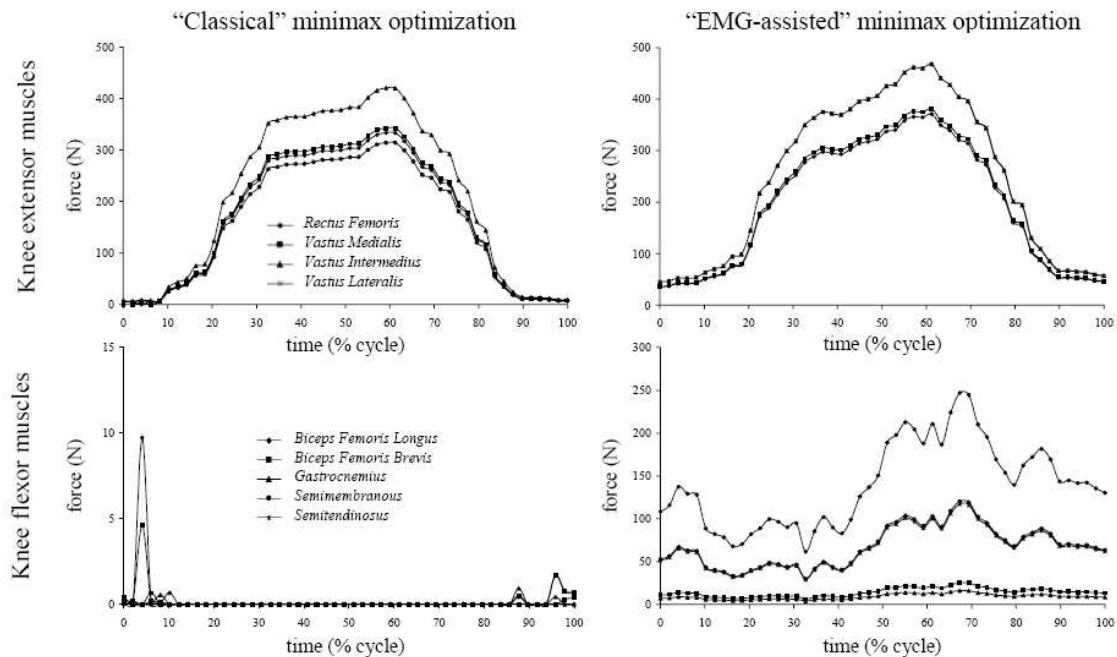


Figure 1. IMF developed by 4 extensor muscles (top) and 5 knee flexor muscles (bottom) around the knee during a squat cycle. Solutions from classical minimax optimization are on the left; those from the proposed EMG-assisted minimax optimization method on the right.

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