SENSITIVITY OF DYNAMOMETRIC EXPERIMENTS TO MUSCLE PARAMETERS

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INTRODUCTION

Musculoskeletal models, used to predict muscle forces, are commonly based on Hill muscle models [1]. Four muscle-dependent parameters define the Hill model: tendon slack length L_T^s, optimal muscle fiber length L_M^O, maximal isometric muscle force $F_M^{\max}$, and muscle pennation angle α. Parameter values are generally taken from literature and do not account for individual differences. However, it is also possible to estimate these parameters from dynamometric experiments since the experimentally obtained relation between joint angle and moment depends on the parameters. The goal of this abstract is to show how sensitivity analysis, previously applied to gait and running simulations [2], can be used to design a test protocol to estimate parameters from dynamometric experiments.

METHODS

Isometric dynamometric experiments were simulated, using a static optimisation approach, to predict muscle activations. These muscle activations were input to the Hill model to calculate musculotendon forces. The resulting joint moment M_{nom} was then calculated based on the forces and moment arms. To asses the sensitivity of the joint moments to the parameters defining the Hill model, each parameter p_i was varied individually by $\pm\Delta p_i$ and the joint moment $M_{i\pm}$ was computed. Sensitivity of the joint moment to p_i is then defined as:

$$S_i = \frac{\left|M_{i+} - M_{i-}\right| / (2M_{nom})}{\Delta p_i / p_i}.$$

To quantify the influence of a parameter perturbation on the joint moment, measured by the dynamometer, we multiplied S_i by M_{nom}:

$$MS_i = M_{nom} S_i = \frac{\left|M_{i+} - M_{i-}\right| / 2}{\Delta p_i / p_i}.$$

Hence, an MS_i of 50Nm can be interpreted as a parameter perturbation of 20% ($\Delta p_i/p_i$) changing the measured moment by 10Nm ($|M_{i+} - M_{i-}|/2 = MS_i \, \Delta p_i/p_i$).

The sensitivity of the knee moment to the parameters of 13 knee flexors/extensors was determined for isometric experiments using perturbations of ±5% ($\pm\Delta p_i/p_i$). The influence of the knee angle (15º, 30º, 60º, 90º, and 105º), hip flexion angle (low or high), and demanded moment (maximal or submaximal) was studied. Based on MS_i, the most sensitive experiment is selected for each muscle parameter.

RESULTS AND DISCUSSION

In general, the joint moment is most sensitive to L_T^s. A moderate sensitivity is found for L_M^O and $F_M^{\max}$. The sensitivity for α is low.

Table 1 shows the muscle parameters with an MS_i of at least 50Nm in one of the simulated experiments. For these parameters, a perturbation of 20% influences the joint moment by at least 10Nm, a measurable difference given the accuracy of dynamometric measurements.

For L_T^s and L_M^O, the highest MS_i is found in experiments demanding half of the maximal joint moment at low to moderate knee flexion angles for the knee extensors and at low knee flexion angles for the knee flexors. High hip flexions give slightly higher sensitivities.

For $F_M^{\max}$, the highest MS_i is found in experiments demanding the maximal joint moment. Knee and hip angles at which the maximal MS_i is found, are muscle specific.

The focus of current research is exploring the potential of isokinetic dynamometry for muscle parameter estimation.

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Table 1: Classification of muscles by the MS_i of the most sensitive experiment for the four muscle parameters. Only knee flexor/extensor muscles with an MS_i of at least 50Nm are included.

	50Nm < $MS_i \leq$ 100Nm	100Nm < MS_i
L_T^s	m. gastrocnemius medialis, m. vastus medialis	m. rectus femoris, m. vastus lateralis, m. vastus intermedius, m. biceps femoris caput longum, m. semimembranosus
L_M^O	m. vastus intermedius, m. vastus lateralis, m. biceps femoris caput longum, m. semimembranosus	
$F_M^{\max}$	m. semitendinosus, m. vastus lateralis, m. vastus medialis, m. vastus intermedius	
α	m. semimembranosus	