Investigating the validity of uniform scaling of maximum isometric force in musculoskeletal models

K. A. Allott, M. T. G. Pain, G. M. Blenkinsop, S. J. Allen
School of Sport, Exercise, and Health Sciences, Loughborough University, United Kingdom
Email: k.allott@lboro.ac.uk

Summary

An OpenSim model with default maximum isometric force parameters was used to simulate maximum effort isovelocity flexion and extension of lower limb joints as per isokinetic dynamometer testing. The strength ratios (athlete/model) per joint action ranged from 0.62 to 1.0, indicating disparities in the accuracy of default parameters between muscle groups. Therefore, uniformly altering maximum isometric muscle force could make some muscle groups too weak or strong. This may have implications for the accuracy of muscle force distribution estimations using load-sharing algorithms.

Introduction

The accuracy of estimated muscle forces in musculoskeletal models depends on the muscle-tendon parameters, typically derived from elderly cadavers or young healthy populations [1]. The default maximum isometric force parameters in OpenSim models have previously been uniformly doubled to represent the strength of athletes when simulating dynamic tasks [2]. However, force distribution amongst muscles differs between and within healthy and athletic populations [3]. The suitability of uniformly increasing muscle strength across multiple joints has not previously been investigated. Therefore, this study compared the moments produced by an athlete performing maximum effort isovelocity contractions of the major lower limb joints to simulated moments from an OpenSim model with default muscle strength parameters.

Methods

Dynamometry methods

One athlete (age 31 years, height 1.85 m, mass 95 kg) performed maximum effort single-leg concentric contractions for flexion and extension of the ankle, knee, and hip on an isokinetic dynamometer (ConTrex, CMV AG, Switzerland). Moments were measured within the prescribed isovelocity regions for increasing isovelocities at equal intervals from $0°\cdot s^{-1}$ (optimum joint angle) to the maximum allowed velocity ($200°\cdot s^{-1}$, ankle; $350°\cdot s^{-1}$, knee; $250°\cdot s^{-1}$ hip).

Computational methods

An OpenSim model [4] with default muscle-tendon parameters was linearly scaled to the participant then used to simulate the movement of each dynamometer trial. The model was constrained to one degree of freedom by prescribing angle changes from the dynamometer data and locking all other joints. The model was actuated by 40 Millard equilibrium muscle-tendon actuators [5]. Agonists were maximally activated throughout. Maximum joint moments were calculated for each joint action at each isovelocity and used to calculate the overall mean strength ratio between the athlete and model, and the ratio at the lowest ($60°\cdot s^{-1}$, ankle, knee; $50°\cdot s^{-1}$, hip) and highest ($200°\cdot s^{-1}$, ankle; $350°\cdot s^{-1}$, knee; $250°\cdot s^{-1}$, hip) velocities.

Results and Discussion

Average moments across isovelocities were not higher for the athlete than for the model at any of the joints and the strength ratio was lower at the highest velocities (Table 1). Uniformly increasing the maximum isometric force of lower limb muscles may lead to unrealistically high strengths for the ankle plantarflexors and hip extensors. As maximum isometric force scales both tendon stiffness and the force-length-velocity relationship of muscle models, a model that is too strong could lead to unrealistic conclusions about muscle contributions to maximum effort dynamic movements. Differences in the strength ratio between muscles could lead to different solutions from load-sharing algorithms, which typically minimise the sum of squared muscle activations.

Table 1: Strength ratio between athlete and OpenSim model.

	Strength ratio (athlete/model)		
	average	low velocity	high velocity
Ankle plantarflexion	0.65	0.57	0.50
Ankle dorsiflexion	0.70	0.67	0.68
Knee extension	1.00	1.06	0.89
Knee flexion	0.94	0.98	0.91
Hip extension	0.62	0.73	0.39
Hip flexion	0.98	0.82	1.00

Conclusions

Uniformly increasing maximum isometric muscle force from default values in OpenSim musculoskeletal models could result in some muscle groups being too strong. This could have implications for the accuracy of muscle force distribution estimations using load-sharing algorithms.

References

[1] Handsfield, G. et al. (2014). *J Biomech*, **47**: 631-638.
[2] Pandy, M. et al. (2021). *Scand J Med Sci Sports*, **31**: 1882-1896.
[3] Balshaw, T. et al. (2024). *J Appl Physiol*, **137**: 789-799.
[4] Lai, A. et al. (2017). *Ann Biomed Eng*, **45**: 2762-2774.
[5] Millard, M. et al. (2013). *J Biomech Eng*, **135**: 1-11.