Inverse optimal control reveals square of muscle power minimisation in post-stroke gait

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Summary

This study investigated how the nervous system controls muscles during post-stroke gait. Muscle forces were obtained in a previous study using an EMG-driven musculoskeletal model. The closest predictions were obtained in the inverse optimal control by minimising the sum of muscle powers squared. This objective function, though rarely used in static optimisation, may be especially important for understanding abnormal gait patterns caused by conditions like spasticity.

Introduction

Optimal solutions for muscle force sharing is generally obtained by minimising or maximising a given objective function which is supposed to approximate neural control strategies. Various objective functions have been explored in the literature [1]. The most effective one, especially for pathological gait remains an open question. This study applies inverse optimal control to identify, among various potential objective functions, those associated with post-stroke gait.

Methods

Lower limb muscle forces of 10 gait cycles at self-selected speed of 2 post-stroke men (high and low functioning) were previously obtained with a calibrated EMG-driven musculoskeletal model [2] and were considered the reference in this study. Maximal isometric forces, physiological cross-sectional areas, muscle velocities… were also accessible in the published results and allowed computing 15 objective functions commonly used in biomechanics, such as sum of muscle forces, activations, or stresses (squared, cubed), sum of muscle powers squared... Inverse optimal control was used to identifying the objective functions that generate the muscle forces closest to the reference when minimised using static optimisation [3]. The output of the identification is a weight vector of dimension 15*1 (Figure 1). Paretic and non-paretic legs, and stance and swing phases of gait where processed separately.

Results and Discussion

The results are focused on the paretic legs (Figure 1). The highest weights were obtained for 3 objective functions: sum of muscle activations (#5), sum of muscle activations cubed (#7), and sum of muscle powers squared (#13). This last objective function corresponds to weights of 0.91 and 0.66 for the stance and swing phases of gait of the low functioning patient. Other objective functions show weights lower or even null, as for the sum of muscle forces squared (#2) and sum of muscle stresses (#9).

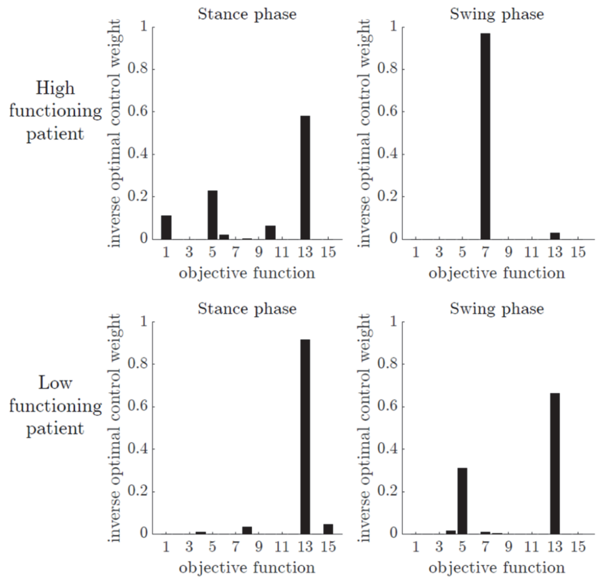

Figure 1: Weights for the 15 objective functions obtained by inverse optimal control

Sum of muscle activations cubed has been already reported to provide reliable results for total knee arthroplasty gait [4]. Sum of muscle powers squared has been rarely evaluated but seemed to be relevant for post-stroke gait. This was the only objective function explicitly involving muscle velocity which plays an important role in spasticity (i.e. hyper-excitability of the stretch reflex).

Conclusions

Inverse optimal control revealed that the minimisation of the sum of muscle powers squared predict muscle forces best matching the results of an EMG-driven musculoskeletal model in post-stroke gait.

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