Optimality in Human Movement

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Introduction

Analysis of gait and motion strategies, in both able-bodied persons and those with a pathology affecting the musculoskeletal system, is used to understand the central nervous system's solution for producing movement in the over-constrained human body. The use of movement analysis in prescribing treatment or predicting outcome, however, is limited by the current assessment-based interpretation approach.

Mathematical modelling methods can provide an opportune complement to the current movement analysis techniques by quantifying the causal relationship between muscle activation and joint movement, and the motion strategy adopted in this redundant force system.

We are currently using several approaches to solve the question of how muscles work together optimally and under certain limitations to produce joint moments and movement. These projects are performed in collaboration with Karolinska University Hospital.

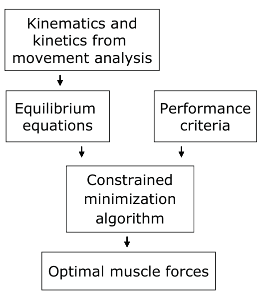
Aims in optimization

Due to the redundant nature of the musculoskeletal system, the number of muscle forces exceeds the degrees of freedom at any joint, and can be solved with optimization techniques.

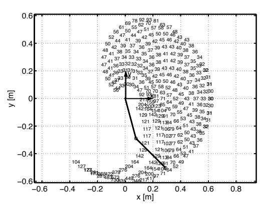
Both static and dynamic optimization have been used with good results for the desired purpose. In static optimization, forces are evaluated quasistatically during a movement. Dynamic analysis solves for a movement pattern, based on a desired beginning and end state, a time interval, and a minimization function.

Static optimization

In static optimization, joint kinematics, joint moments and muscle configurations throughout a movement are put into a constrained minimization algorithm that solves for muscle force solutions with a desired minimization function, using Lagrange multipliers.



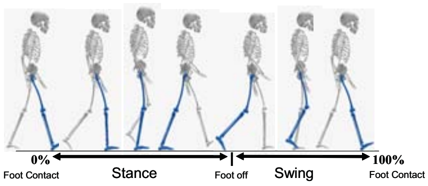
If individual muscle capacities are known, a possible application of this technique is to calculate the maximum supportable load in all positions, which could be useful in clinical applications involving preservation of moment-generation in paralyzed persons through orthopedic surgery.



Supportable load (N) as a function of wrist position in 2D.

Muscle forces during gait

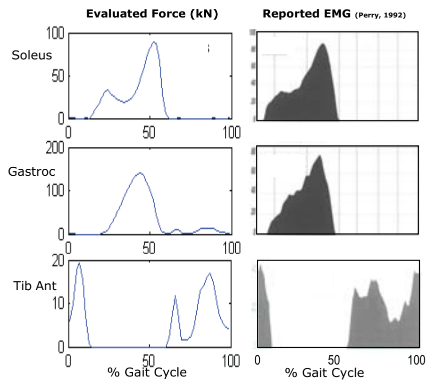
Walking is a repetitive sequence of limb motion to move the body forward while simultaneously maintaining stability. A single sequence of these movements is called a gait cycle, beginning with foot contact and classified into stance and swing phases.



Motion data is acquired by placing passive markers on anatomical landmarks and recording marker positions with cameras (at Karolinska University Hospital). Simultaneous ground reaction data are collected and used to calculate joint kinetics, and muscle activation is measured using surface electromyography.

Assessment of muscle forces during normal and pathological gait can be useful in understanding how abnormal muscle activation or skeletal configuration leads to the observed movement pattern, and can be useful while planning clinical treatment of the movement pathology.

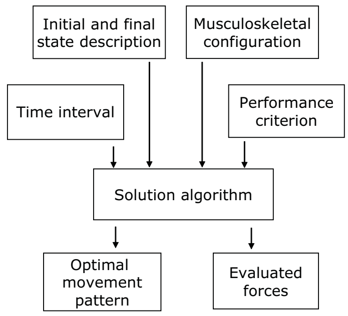
In a current project, muscle forces from experimental gait data are evaluated using static optimization. Different minimization functions are also tested. Preliminary results show good correlation between evaluated muscle forces and reported muscle activation patterns.



Calculated muscle forces and muscle activation.

Dynamic optimization

In dynamic optimization, temporal finite element approximation of dynamic systems is used to find the state variables and forces at all time instances, and the dynamics of optimal muscle control between the initial and final states is calculated.

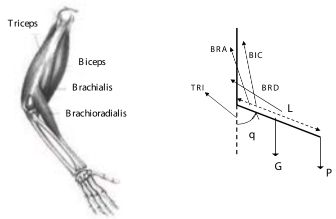


Dynamic analysis of arm

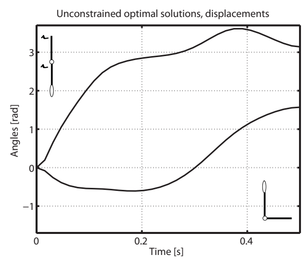
Several muscle groups are involved in the movement of the human arm and can give rise to various complex motions.

To study one degree of freedom movement, the upper arm is considered fixed in a vertical position, and the lower arm segment flexes at the elbow. Four main muscle groups are involved in this movement: biceps brachii, triceps brachii, brachialis and brachioradialis.

To study two degrees of freedom movement, additional flexion at the shoulder is considered. Additional shoulder muscles, namely the latissimus dorsi, the pectoralis major and the deltoideus, are then involved in the motion.



As an example of a force-optimized movement, the following figure shows the upper and lower arm directions when analyzing a movement from a straight vertical arm position to one with a horizontal upper arm and vertical lower arm.



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