Static Optimization Can Predict Muscle Co-contraction during Hopping

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Introduction: Accurate prediction of individual lower-limb muscle forces are vital in better understanding knee joint injuries. Specifically, the knowledge of how muscles contribute to ligament loading and joint reaction forces is important in furthering our understanding of the causes of different joint diseases. Knee ligament injuries, such as an anterior cruciate ligament (ACL) injury, have been shown to sometimes lead to severe knee joint diseases, such as osteoarthritis (OA) [1]. Musculoskeletal modelling is a powerful biomechanical tool that enables the quantification of muscle and joint forces. However, it is challenging to find a reliable and computationally efficient method to predict individual muscle forces, especially for demanding activities such as hopping. Previous studies have shown that dynamic optimization, a computationally costly method, is similar to static optimization (SO) in its ability to predict muscle activations during walking [2]. A similar result was found when using different optimization methods to predict muscle forces for running and walking [3]. This study proposes that the same concept applies during hopping movements and thus, the aim of this study is to compare individual muscle force results of two commonly-used optimization methods i.e. SO and computed muscle control (CMC).
Methods: Ten healthy subjects were recruited to perform single-leg hopping maneuvers. Full body marker trajectories and ground reaction forces were collected using a motion capture system and ground-embedded force plates, respectively. Subject specific musculoskeletal models were generated using OpenSim [4] by scaling a generic 23 degree-of-freedom musculoskeletal model with 92 musculotendon units. The landing phase encompassed the period from initial foot strike to maximum knee flexion (0-100%). For each trial, an inverse kinematics analysis calculated joint kinematics using the recorded marker trajectories while joint moments were calculated using a traditional inverse dynamics approach. Two optimization methods (SO and CMC) were used to predict muscle forces by partitioning the net joint moments over individual muscles.
Nine major lower-limb muscles were compared including vasti (VAS), rectus femoris (RF), iliopsoas (ILPSO), gluteus maximus (GMAX), gluteus medius (GMED), hamstrings (HAMS), gastrocnemius (GAS), soleus (SOL), tibialis anterior (TIBANT). To compare the similarity in muscle force predictions between the two optimization methods, a correlation coefficient (R) was calculated between the outputs from SO and CMC for each muscle. The significance (p-value) of each correlation was also computed.
Results: The majority of major muscle forces predicted by SO and CMC during hopping were similar in temporal profile ($p<0.05$ for all subjects) and magnitude (Figures 1 & 2). However, large differences in muscle force prediction were observed for HAMS, ILPSO and GAS (Figure 1). In general, the magnitude of the muscle forces predicted by SO were lower than those predicted by CMC for these three muscles. However, their temporal patterns were similar regardless of optimization methods.
Discussion: The aim of this study was to compare the ability of two different optimization methods (SO and CMC) to predict muscle forces during a hopping movement. The results of our study suggest that while SO can predict muscle co-contraction to a certain extent, SO can underestimate the muscle force for biarticular muscles such as the HAMS and GAS. This study builds upon previous studies that showed that similar muscle forces can be predicted for dynamic optimization and SO during walking [2] and for CMC and SO during walking and running [3]. In light of our findings and those of earlier studies, we conclude that SO can be used to predict lower-limb muscle co-contraction during hopping movements. However, care must be taken in interpreting the magnitude of force predicted by SO for the biarticular muscles. Despite this limitation, given that SO is a robust and computationally efficient method for predicting muscle forces, SO should be used to study the role of muscles during hopping activities in medium to large cohorts of people with neuromuscular disorders or joint degenerative diseases, such as ACL injuries or knee osteoarthritis.
Significance: This study provides evidence that static optimization is a reliable and computationally efficient method to predict individual muscle forces during hopping movements. Our findings suggest that this method can be applied to study the role of muscles during hopping activities in large subject cohorts, including those with musculoskeletal disorders.
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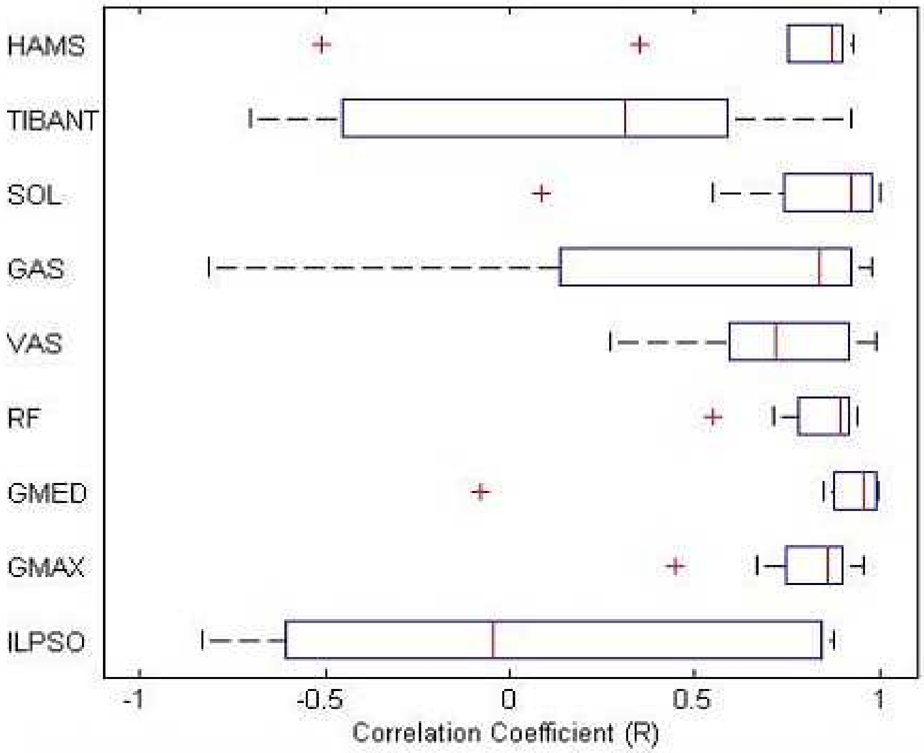

Figure 1: A histogram displaying the correlation (R) between muscle forces predicted using static optimization and computed muscle control for the major lower-limb muscles during hopping. Muscle acronyms are defined in the methods.

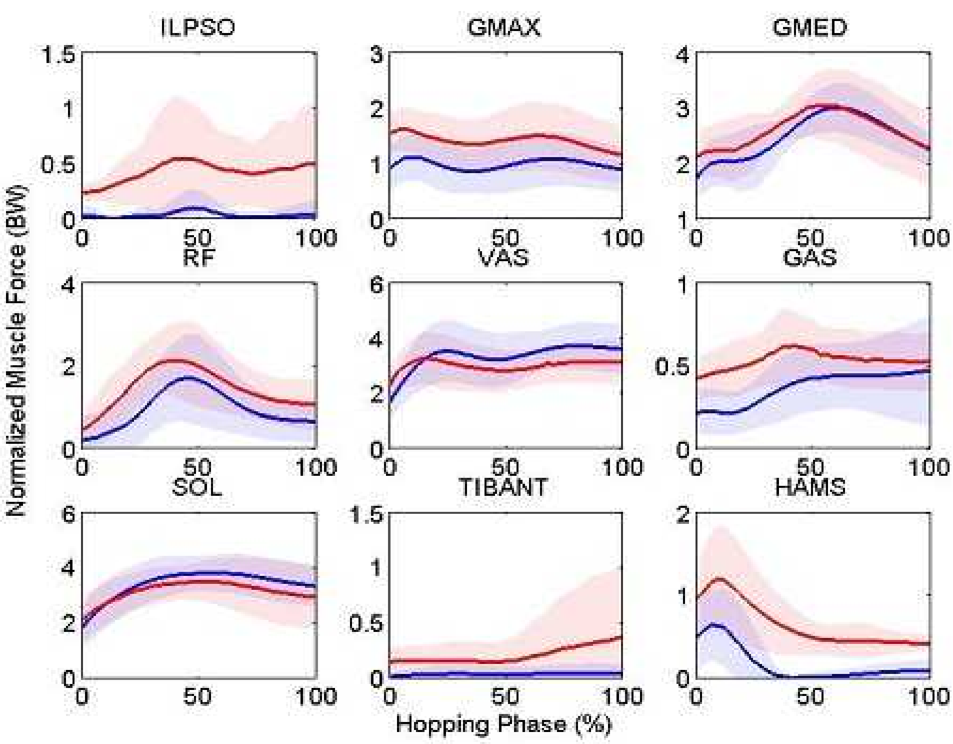

Figure 2: Muscle forces during hopping predicted using static optimization (in blue) and computed muscle control (in red). BW; body weight.