MUSCLE FORCES ESTIMATION DURING THE SINGLE LEG TRIPLE HOP TEST USING OPENSIM

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Abstract. *In this paper, we estimated the distribution of activation and muscle forces in the preparatory phase of single leg triple hop test (SLTHT). SLTHT used for knee function assessment, by measuring the jump length. Ten physically active young women participated in the research, by performing the SLTHT while measuring, in the propulsion phase of the task, ground reaction forces, EMG, and kinematics, using an optoelectronic system (BTS-Smart). Three-dimensional markers trajectories were imported in OpenSim, and joint angles calculated using the inverse kinematics tool. Joint torques were calculated by inverse dynamics. Muscle activation and forces obtained by two techniques: Computed Muscle Control (CMC) and Static Optimization (SO), after a Residual Reduction Analysis (RRA). Joint torques have shown to be plausible, and muscles synergies from both methods were coherent with the measured electromyography (EMG). Compared to EMG profiles, Static Optimization associated with Residual Reduction Analysis outperformed CMC estimations.*

Keywords: *triple hop test, inverse dynamics, static optimization, computed muscle control, OpenSim*

1. INTRODUCTION

Functional tests in biomechanics can reveal and quantify diseases and impairments of the musculoskeletal system in clinical sets. Such tests seldom involve an accurate tracking of the muscle synergies associated with the movement. This information is likely to provide important additional information for the diagnosis, as well as the biomechanical mechanisms underlying the diseases (Augustsson et al., 2006; Hamilton et at., 2008). Muscle force patterns across agonistic and antagonistic muscles, which is the preferable variable to analyze such synergies, can only be measured with invasive techniques. Here, muscle activations and forces have been estimated from movement 3D and force platform measurements. The chosen functional task was the preparation phase of the single leg triple hop test, used for knee function assessment (Bley et al., 2014). Two different computational procedures were tested, and compared with experimental EMG, for estimating muscle force profiles after the inverse dynamics analysis: Computed Muscle Control (CMC) and Static Optimization (SO).

2. EXPERIMENTAL AND COMPUTATIONAL PROCEDURE

A group of 10 young physically active women was selected to participate in the experiment (23.2 ± 4 years, 59.3 ± 5.8 kg and 1.63 ± 0.06 m). The study has been approved by the Universidade Nove de Julho Research Ethics Committee. The volunteers performed a series of jumps, starting with the propulsion leg foot over the force platform. Reaction forces, 3D markers trajectories, and EMG data were recorded. A BTS Smart System, with 8 IR cameras, one Kistler 9286A force platform, and a FREE EMG wireless electromyography was used. The reflexive marker's collocation protocol is shown in Figure 1.

Figure 1. Reflexive Markers collocation protocol

Markers' trajectories and ground reaction forces and torques were imported in OpenSim (Delp et al., 2007), using a custom-built routine for this purpose https://simtk.org/projects/c3d2opensim. An entire-body OpenSim model with 21 segments, 92 muscles and 37 generalized coordinates (GC) was used (Hamner et al. 2010) was used. The model was scaled for each participant (Figure 2) and the joint angles determined by Inverse Kinematics, in which the Euclidean distance between a set of real and 'virtual' markers, defined on model's anatomic points. Kinematics and body inertia parameters were used to calculate joint torques, by computing the left side of the equation of motion, obtaining the joint torques (τ):

$$M(q)\ddot{q} + C(q,\dot{q}) + G(q) = \tau \tag{1}$$

where M is the mass matrix, C the Coriolis terms matrix, G the gravity vector and q the generalized angular coordinates.

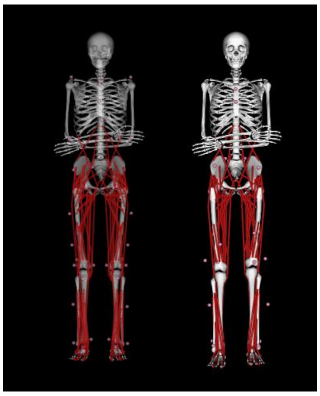

Figure 2. Original (right) and subject-specific scaled OpenSim model

Two approaches associated with inverse dynamics, to find muscle activations and forces, were tested, both of them available in OpenSim: static optimization (SO) and computed muscle control (CMC) (Alvim et al., 2018). The residual reduction algorithm (RRA) was used to reduce markers' position measuring and model errors. The trunk center of mass is changed, as well as experimental kinematical data. Thus, the sum of residuals and ground reaction forces becomes dynamically consistent. CMC uses a proportional derivative controller to adjust the model position during the simulation. The sum of squared actuator controls plus the sum of desired acceleration errors is minimized; for SO, only the sum of squared actuator controls is minimized. Additionally, CMC allows constraining the residuals directly. For validation purposes, muscle activations estimated by the model were compared with surface electromyography (EMG) of some selected muscles: gluteus maximus, gluteus medius, biceps femoris and vastus lateralis.

3. RESULTS

Figure 3 shows how the iterative application of the RRA decreased the values of the residual actuators force (left) and torque (right), for one of the directions. For the whole set of 92 muscles of the model, the forces and activations were calculated. Here, we show these which the EMGs has also been measured, for assessing the agreement between the normalized estimated force comparatively, by both methods, and the normalized and rectified EMG (Figure 4)

4. DISCUSSION AND CONCLUSIONS

Muscle forces and activations were estimated during the preparation phase of single leg triple hop test for a group of young healthy women. We observed that running recursively the RRA can generate better joint torque estimations with smaller residual torques and forces (Figure 4). Both SO and CMC give comparable results (Figure 5), yet, SO yields a smoother force estimation compared do CMC. CMC is simpler to use and constraints the residuals in a single run. The obtained individual muscle forces are coherent with the measured EMG and plausible for generating the single leg jumping preparatory phase. Further work is in progress to compare the muscle force patterns obtained here, for non-symptomatic subjects, with patellofemoral pain young women.

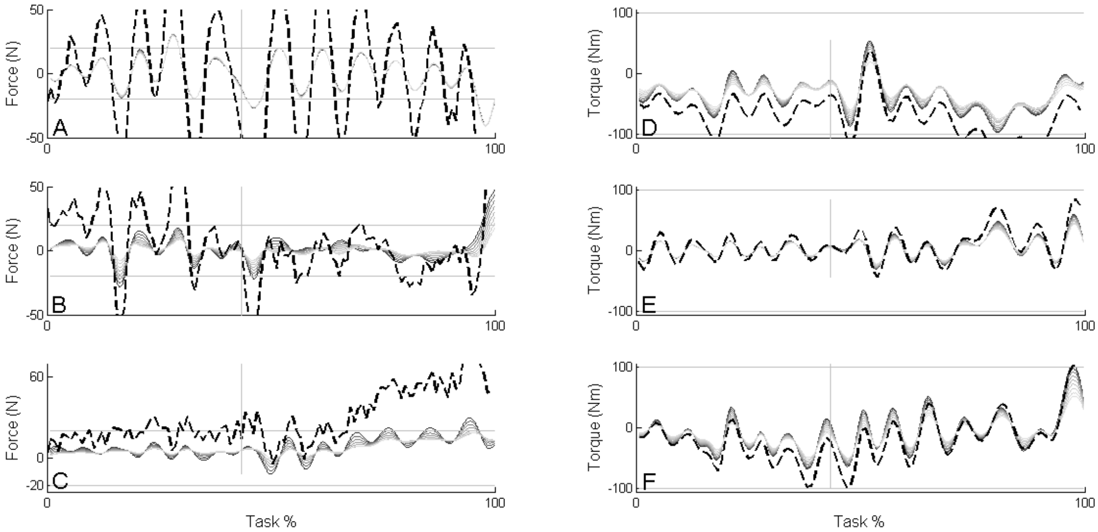

Figure 31: Iterative residuals reduction by applying the RRA recursively, for one trial. Fading gray shaded lines (from darker to lighter) represent the successive iterations. The dashed line corresponds to the static optimization result using the output of the last RRA run. Horizontal gray lines mark desired residual bounds. The vertical gray line indicates the beginning of the descending phase in the SLTHT preparation phase. For this trial, the task lasts for 1.15 seconds. Residual forces for x, y and z-axis: (A), (B) and (C), respectively. For residual torques: (D), (E) and (F).

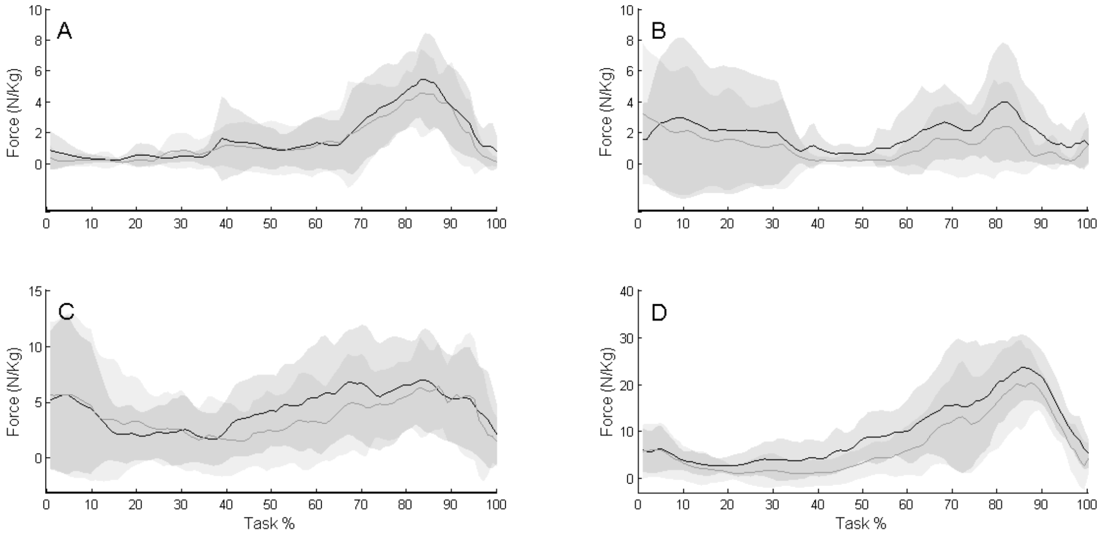

Figure 2: Average muscle force estimations by static optimization (light gray) and computed muscle control (dark gray) (n=10). One standard deviation was plotted above and below the average lines. (A) gluteus maximus; (B) gluteus medius; (C) biceps femoris long head; and (D) vastus lateralis; N.U. – normalized unities.

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7. INFORMATIONS RESPONSIBILITY

The authors are responsible for all information contained in this work.