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LOWER LIMB MOMENTS OF FORCE CONTRIBUTION IN HOPPING EXERCISE

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INTRODUCTION

Muscles can generate force and develop mechanisms to exchange energy among segments, whether they are performing isometric, concentric or eccentric actions[1]. Muscles are not always capable to deliver the energy that they produce to the target segment because its force does not accelerate that segment, instead acts to accelerate other segments. This means that the muscle works in a synergistic way, producing energy so that other muscles can use it to accelerate or decelerate segments in order to reach the target segment [1]. Induced acceleration analysis (IAA) is based in the fact that body segments are kinetic chains of multiarticulated bodies that cause a dynamic coupling effect [1,2]. This approach allows us the estimation of the causal effect between changes observed in the kinematic and kinetic parameters, and the changes at the muscle actions that cause the difference observed in the task. In order to perform the IAA, this study uses a model based on Kepple's work [3]. The overall aim of this study was to evaluate the use of IAA to improve the understanding of the musculoskeletal synergies during one leg hopping. In order to achieve this goal, the analysis followed two steps: 1) to provide a complete description of the ankle, knee and hip net joint moments of force during the task and 2) to compute the IAA results and identify any relation between the net joint moments and the accelerations induced by those moments.

METHODS

Five subjects, 3 women and 2 men participated in this study. They were all physically active and their mean age was 25.8±6.6 years. Motion capture was collected with 10 cameras Qualisys (model: Oqus-300) operating at 200Hz. 24 reflective markers and 4 marker clusters were placed in predefined anatomical protuberances and used for the reconstruction of eight body segments using Visual 3D software (Visual 3D Basic RT, C-Motion, Inc., Germantown, MD). The ankle was modeled as a universal joint, the knee as a revolute joint and the hip as a spherical joint. Ground reaction force (GRF) was collected with a Kistler force plate (type: 9865B). The task consisted in a sequence of unilateral jumps with the dominant lower limb. To establish a control parameter for the hopping height, a squat jump (SQJ) was performed prior to the hopping task. The minimum height for the hopping jumps was 60% of the maximum height achieved in the SQJ. They were instructed to keep the hands on the waist to minimize arm motion because the head, arms and trunk were modeled as a single segment[3]. The subjects were asked to perform the hops until we had at least 2 consecutive, consistent and homogeneous jumps, in terms of height. Kinematic and kinetic variables were processed with a lowpass 4th order Butterworth filter with a frequency cut of 6 Hz. The curves were plotted and normalized to the stance phase of the hop. For each dynamic trial, Visual 3D computed the net joint moments, as well as joint orientations and locations of the center of pressure relative to the contact foot. In this study two different contact models were used to establish the connection between the foot and the environment. The first one, here designated as free-foot system, modeled the foot-floor interface using a hinge joint to connect the foot to the floor with the axis of the hinge passing through the center of pressure in a direction parallel to the X axis of the foot. The second model, called fixed-foot system, constrained the foot to the floor so that no motion of the foot was permitted. During the hopping trials analyzed in this study the heel did not contact the floor and thus the free-foot system was used for the initial induced acceleration analysis. The fixed-foot system was subsequently applied to each data trial in an effort to parse out the synergies between the muscles crossing the ankle joint and the more proximal lower extremity muscle groups.

RESULTS AND DISCUSSION

When the free-foot model was used, the estimated contributions of the ankle plantar flexors to the vertical GRF were found to be much higher than the knee contribution (Figure 1). However, analyzing the induced rotational acceleration of the "joint" between the foot and the floor (Figure 2), both the ankle and the knee moments induce nearly equal and opposite acceleration, with the contribution of the hip moment being residual. Thus the net action of the foot and ankle moments is a stable foot with little overall acceleration and it is likely the two muscles groups are acting in a synergistic way.

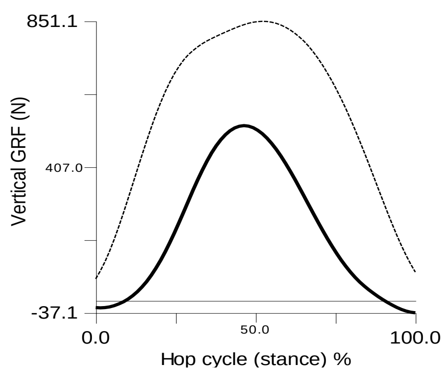

Figure: 1 Comparison of the contribution of the ankle (dashed line), knee (solid line) and hip (dotted line) joint moments to the vertical ground reaction force, using the free-foot model.

In Figure 3 it can be seen that the contribution of the knee moment to the vertical GRF is substantially larger than the other moments' contribution. With this fixed-foot model, the vertical acceleration of the body would be mostly produced by the knee extensors (which have the larger induced vertical GRF), followed by the ankle moment. In this particularly case, the contribution of the joint moments is distributed by the other joints, being the knee extensors responsible for the vertical motion of the body.

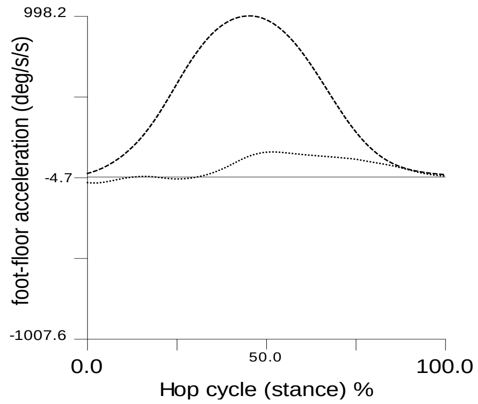

Figure 2: Comparison of the contribution of the ankle (dashed line), knee (solid line) and hip (dotted line) joint moments to the rotational acceleration of the foot-floor "joint", using the free-foot model

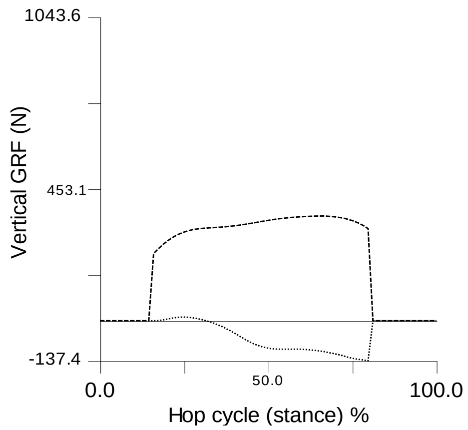

Figure 3: Comparison of the contribution of the ankle (dashed line), knee (solid line) and hip (dotted line) joint moments to the vertical ground reaction force, using the fixed-foot model

CONCLUSIONS

This analysis begins with a free-foot model containing only one joint with 1 degree of freedom between the ground and the foot. The AAI showed that with this model the action of the knee extensors produces a rotation of the lower leg from the ground, but at the same time this rotation is essentially "canceled" by the upward rotation generated by the foot plantar flexor muscles. This result shows that the plantar flexors promote a stable base for the proximal muscles act. Its role is to "transform" the model in a foot-fixed, allowing the knee extensors to accelerate the body upwards.

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REFERENCES

1. Zajac FE, *J Biomech*. **35(8)**:1011-1018, 2002.
2. Zajac FE, *J Biomech*. **26(1)**:109-124, 1993.
3. Kepple TM, et al., *Gait & Posture*. **6**:1-8, 1997