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Synergistic interaction between ankle and knee during hopping revealed through induced acceleration analysis

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ABSTRACT

The forces produced by the muscles can deliver energy to a target segment they are not attached to, by transferring this energy throughout the other segments in the chain. This is a synergistic way of functioning, which allows muscles to accelerate or decelerate segments in order to reach the target one. The purpose of this study was to characterize the contribution of each lower extremity joint to the vertical acceleration of the body's center of mass during a hopping exercise. To accomplish this, an induced acceleration analysis was performed using a model with eight segments. The results indicate that the strategies produced during a hopping exercise rely on the synergy between the knee and ankle joints, with most of the vertical acceleration being produced by the knee extensors, while the ankle plantar flexors act as stabilizers of the foot. This synergy between the ankle and the knee is perhaps a mechanism that allows the transfer of power from the knee muscles to the ground, and we believe that in this particular task the net action of the foot and ankle moments is to produce a stable foot with little overall acceleration.

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1. Introduction

A synergy is defined by a group of elements that has a specific organization and specific properties that enables them to maintain high stability and low variability during performance (Latash, Gorniak, & Zatsiorsky, 2008). Muscles can generate force and work efficiently to exchange energy among segments, whether they are performing isometric, concentric or eccentric actions (Zajac, 2002; Zajac, Neptune, & Kautz, 2002). Muscles can work in both functional and synergistic ways, that is, they generate and propagate the force so individual segments gain and loose energy according with the type and aim of the mechanical task (Zajac, 2002). The forces produced by the muscles can deliver energy to a target segment they are not attached to, by transferring this energy throughout the other segments in the chain. This is a synergistic way of functioning, which allows muscles to accelerate or decelerate segments in order to reach the target segment (Zajac, 2002).

Induced acceleration analysis (IAA) is a technique based in the dynamic coupling effect caused by the multiarticulated nature of the body (Zajac, 1993, 2002; Zajac & Gordon, 1989). Dynamic coupling means that when a muscle contracts it produces acceleration, not only in those segments that are spanned by that muscle but on all body segments of the chain, due to the intersegmental forces. Thus, this technique allows the direct quantification of a joint moment contribution to the acceleration of each joint of the body and to the body center of mass.

Simple multijoint motor tasks such as vertical jumps have been used to study this intersegment coordination and synergistic behavior. Bobbert, Huijing, and Schenau (1986) studied the behavior of the human triceps surae muscletendon complex during plantar flexion in unilateral jumping and concluded that the biarticular action of *gastrocnemius* increases significantly the jumping performance. Gregoire, Veeger, Huijing, and van Ingen Schenau (1984) reported that, at the end of the push-off of vertical jumps, the hip and knee joints showed high extension velocities and the power delivered by the monoarticular extensors of the hip and knee joints was carried to the distal joint (ankle) through the biarticular muscles. Simultaneously, the ankle joint showed high plantar flexion velocity, meaning that the biarticular muscles crossing these joints were able to contract at a relatively low speed. As a consequence, biarticular muscles would be able to produce force at a low contraction velocity, thus generating higher force, and being able to transfer the energy from the proximal muscle groups to the more distal ones. Moreover, Pandy and Zajac (1991) suggested that the ankle plantarflexors (soleus, gastrocnemius, and the other plantarflexors) contribute appreciably to trunk power during the final 20% of the jump. This contribution is hard to measure for individual muscles but dynamical simulations have been used to estimate these individual muscle roles and muscle control of the energy flow between segments (Anderson & Pandy, 2003; Delp et al., 1990, 2007; Pandy, 2001; Zajac & Gordon, 1989).

The aim of this study was to use IAA to quantify the contributions of lower limb joint moments to the CM vertical acceleration during a one leg hopping exercise. We believe that this technique will give a better insight on the understanding of the musculoskeletal synergies occurring during this task.

2. Materials and methods

2.1. Experimental procedure

Five subjects, three women and two men, participated in this study. They were all physically active, none of them had history of lower extremity injury or pain and their mean age was 25.8 ± 6.6 years. Informed consent was given by each subject prior to testing and the work was approved by the ethics committee of the Faculty of Human Kinetics, Technical University of Lisbon. Motion capture was collected with a ten camera Qualisys system (model: Oqus-300) operating at 200 Hz. Twenty-four reflective markers were placed on predefined anatomical protuberances (acromial, stern, anterior-superior and posterior-superior iliac spines, lateral and medial femoral epicondyles, lateral malleolus of the fibula, medial malleolus of the tibia, 1st and 5th metatarsal heads. Additionally, semi-rigid marker clusters were placed on the lateral aspect of each thigh, shank and foot segments. These were used for the reconstruction of an eight body segment model (trunk, pelvis, right and left thighs, right and