The Role of the Multiarticular Foot Muscles in Jumping

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Summary

To investigate the role of extrinsic toe flexors in human jumping, a musculoskeletal model, which included a three-segment foot, was created for use in jumping simulations. Foot stiffness and toe flexor contributions were varied and jump height and muscle energetics were compared between conditions. It was found that the model jumped higher, and the extrinsic toe flexors acted more motor-like with a rigid foot model.

Introduction

The ability of multiarticular muscles to transfer power between joints grants them unique utility in tasks involving proximal to distal activation sequences (e.g., jumping) [1]. The role of the multiarticular gastrocnemius in jumping tasks has been investigated in depth [2], however little research has been performed regarding the role of the extrinsic toe flexor muscles (flexor hallucis longus: FHL; and flexor digitorum longus: FDL). The FHL and FDL span the ankle, midtarsal, and metatarsophalangeal joints, and could therefore contribute to maximal jump height due to their actions about these joints. To examine the potential role of these muscles, a musculoskeletal model was developed, and jumps were simulated with the knee and hip joints locked. Jumps were performed with varied foot stiffness and toe flexor force contributions to elucidate their role in jumping.

Methods

A musculoskeletal model was developed in OpenSim to perform forward dynamics, optimal control simulations of jumping with joints above the ankle locked [3]. The goal was to maximize jump height. The model's foot consisted of three segments joined by pin joints representing the midtarsal joint and metatarsophalangeal joint. Hill-type muscle models of the soleus, gastrocnemius, and FHL and FDL were used to actuate the model. Muscle parameters from previous studies were used [2,4]. A linear spring connecting the forefoot to the toes was used to represent the plantar aponeurosis (PA). Optimizations were run in SCONE [5]. Three parameters per muscle (initial excitation level, final excitation level, and time of change in excitation) were varied in a piecewise, feedforward controller until jump height no longer increased. Simulations were performed with varied degrees of foot stiffness and toe flexor capabilities. The brake-spring-motor index (BSM) was calculated for the toe flexor muscles to characterize their function [6]. This was calculated as the net work of the muscle divided by the sum of the magnitude of positive work and the magnitude of negative work. Values close to zero indicate spring-like behavior of the muscle, while values closer to one and negative one indicate motor and brake-like behavior respectively.

Results & Discussion

The most natural model (toe flexors, plantar aponeurosis, and an unlocked midtarsal joint) produced a jump height of 13.7 cm (Table 1). In comparison, the model similar to a jumper in stiff shoes (toe flexors, plantar aponeurosis, and a locked midtarsal joint) had a maximum jump height of 15.4 cm. A difference in toe flexor energetics can account for this difference in jump height. The BSM index for the toe flexors in the natural model was 0.50, which indicates their role as being somewhere between that of a spring and a motor, while the BSM index was 0.90 for the “stiff shoe” model, indicating a much more motor-like function.

Table 1: Jump heights and toe flexor roles, assessed using the brake-spring-motor index, for jumps of varied toe flexor, PA, and midtarsal joint states.

Model Components			Model Results	
Toe Flexors	***Plantar Aponeurosis***	***Locked Midtarsal***	***Jump Height (cm)***	***BSM (-)***
√	√		13.7	0.50
√	√	√	15.4	0.90
√			13.4	0.48
√		√	15.1	0.90
	√		12.4	N/A
	√	√	14.2	N/A
			11.7	N/A
		√	13.3	N/A

Conclusion

The simulation results suggest that the role of the extrinsic toe flexors vary from nearly entirely motor-like to somewhere in-between a motor and a spring depending on the rigidity of the foot. Moving forward, the role of the extrinsic foot muscles in both performance and metabolic efficiency during other proximal to distal activation tasks, such as walking, could be investigated. It would be of particular interest to examine the impact of these muscles on subjects with changed foot stiffness, such as the elderly.

References

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