OPTIMAL CONTROL SIMULATIONS OF STANDING LONG JUMPS WITH FREE AND RESTRICTED ARM MOVEMENT

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INTRODUCTION

Using the arms during standing long jumps allows subjects to jump farther. Ashby and Heegaard (2002) showed that subjects were able to jump 37 cm (21%) farther with free arm motion than when arm motion was restricted. Two mechanisms have been hypothesized to account for this improvement. First, studies of the standing high jump have shown that arm swing generates a downward force on the body during the propulsion phase, which slows the shortening velocities of hip and knee extensors and allows for greater muscle torque production (Feltner et al., 1999; Harman et al., 1990). Second, studies of the standing long jump have suggested that when the arms are restrained the jumper must limit activation of the lower-limb extensors during the propulsive phase to eliminate excessive forward rotation that would preclude proper landing (Ashby and Heegaard, 2002). By contrast, swinging the arms during the jump can help alleviate excessive forward rotation about the center of gravity (CG) to better position the body segments for landing.

To clarify the role of arms in the standing long jump, we used optimal control theory to create simulations of maximum length standing jumps for free and restricted arm movement. The optimal control solutions with free and restricted arm movement were analyzed to explore the two hypothesized means for the improvement in standing long jump performance.

METHODS

The standing long jump was simulated with a 2-D five-segment (foot, shank, thigh, head-neck-trunk, arm) link model. The ankle, knee, hip, and shoulder joints were modeled as revolute joints and were actuated by joint torques. The magnitude of torque generated by the joint actuators was a function of the activation, the joint angle, and the joint angular velocity. The model for restricted arm movement was the same as that for free arm movement except that no shoulder torque was applied and the shoulder angle was fixed throughout the jump.

The optimal activations to generate maximum length jumps were found using a simulated annealing algorithm. The maximal jumps were determined for two different cases for jumps with both free and restricted arm movement. The objective for Case 1 was to maximize the horizontal position of the body's CG at landing without consideration for the landing configuration of the segments. The objective for Case 2 was to maximize the position of the toe at landing while maintaining an acceptable landing configuration (i.e., one that would allow subjects to land without falling down).

RESULTS AND DISCUSSION

Consistent with previous experimental findings, the simulated jump distances were greater with unrestricted use of the arms (compare upper and lower rows of Table 1).

Table 1: Horizontal CG Displacement

	Case 1	Case 2
Free arm motion	1.67 m	1.66 m
Restricted arm motion	1.37 m	1.29 m

The arm swing in jumps with free arm motion slowed the rate of hip extension during the propulsive phase, which allowed the joint actuator to generate more torque (Figure 1). The hip actuator was maximally activated between 0.12 s and 0.02 s before take-off in jumps with free and restricted arm motion, yet the torque generated was 60-80 N·m greater for the jumps with free arm movement over this time period. These results support the hypothesis that arm motion allows for greater torque production.

With free use of the arms, the CG displacement was 1.67 m when there were no requirements on the landing configuration (Case 1). The CG displacement was essentially equivalent (1.66 m) when an acceptable landing configuration was required (Case 2). This demonstrates that the landing requirement did not reduce activations during the propulsive phase of the jump because the arms were able to compensate for the excessive forward rotation of the trunk. When arm motion was restricted, the CG displacement was 1.37 m for Case 1 and 1.29 m for Case 2. This supports the hypothesis that to position the body segments properly for landing, the jumper must hold back during the propulsive phase in jumps with restricted arm movement.

Thus, our analysis of simulated standing long jumps suggests that both of the proposed mechanisms contribute to the greater jump distances with free arm motion.

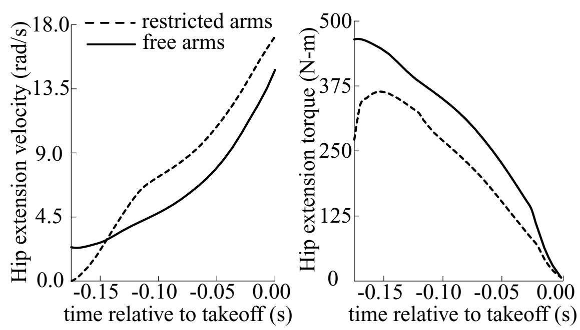

Figure 1: Hip extension velocities (left) and torques (right) just before take-off

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