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Role of arms in somersaulting from compliant surfaces: A simulation study of springboard standing dives

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Abstract

The role of arms in compliant-surface jumping for maximizing backward somersault rotations is studied using multi-segment models and is applied to springboard diving. The surface (springboard) is modeled by a rigid bar with a rotational spring with a hinged end and point mass at the tip. Planar four- and five-segment human models are used (with the fifth segment representing the arms) and are driven by torque actuators at the ankle, knee, hip, and shoulder. Each joint torque is the product of maximum isometric torque and three variable functions depending on instantaneous joint angle, angular velocity, and activation level, respectively. Movement simulation starts from a balanced initial posture and ends at jump takeoff. The objective is to find joint torque activation patterns during board contact so that the number of backward rotations in flight is maximized. Kinematic differences in jumps with and without arms are mainly in smaller takeoff vertical velocity and more flexed knee and hip in the former. In both jumps, joint torque/activations are similar in their minor flexion-full extension patterns. Maximum hip torque is larger with arms but maximum knee torque is larger without arms. Except at the knee, more joint work can be done with arm swing. Total angular momentum is increased considerably by arm motion because of its remote contribution. Consequently segment remote contributions to total angular momentum are much larger in jumping with arms. Shoulder strength helps generate angular momentum only to a certain limit. If more work is used to generate horizontal velocity away from the board, the amount of total angular momentum is reduced.

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1. Introduction

Maximizing somersault rotations from compliant surfaces is one of the key features in various sport activities such as trampoline jumps, gymnastics, and springboard diving. To complete the required number of rotations, athletes need to generate sufficient vertical velocity (which determines how long they can stay in the air) and angular momentum at takeoff. Because total angular momentum is conserved after takeoff, athletes can increase the rotation potential only during ground/trampoline/springboard contact.

Compliant-surface jumping has been studied through different approaches. Sanders and Wilson (1992) showed that in drop jumping (dropping from a height onto a surface and jumping for maximum height) participants accommodate to changes in surface compliance by changing the center of mass (c.m.) acceleration patterns relative to the surface. A later study (Sanders & Allen, 1993) investigated joint torque changes in accommodation to changes in surface compliance. Farley and colleagues (Farley, Houdijk, Strien, & Louie, 1998; Ferris & Farley, 1997) examined changes in leg stiffness in bouncing gaits on compliant surfaces. Cheng and Hubbard (2004, 2005) simulated maximum-height jumps from a diving springboard.

In addition to the above pure-jumping researches, somersaulting from a compliant surface has been simulated for tumbling gymnasts (King & Yeadon, 2004; Yeadon & King, 2002). However, because of relatively large surface stiffness on the gymnastic floor (Yeadon & King, 2002), ground contact time is short (around 0.1 s), leaving almost no time for control strategy adjustment.

Other compliant-surface somersaulting studies have involved springboard diving, in which both the running and standing dives are required competition tasks. In the former, divers take several steps to the board tip, execute a hurdle jump, and re-catch the board for either forward or reverse rotations. In standing dives, however, divers begin at the tip facing the board, and maintain contact until takeoff into backward or inward rotations. Total angular momentum during flight for different rotation requirements in springboard diving was compared (Miller & Sprigings, 2001; Sanders & Wilson, 1987). Angular momentum contributed by each body segment was investigated in springboard running dives (Miller & Munro, 1985) and platform diving (Hamill, Richard, & Golden, 1986). About one-third of the contributions is due to the arms, and segment remote components (defined in the next section) dominate the total angular momentum. However, no such detailed study was found in standing dives.

Recently, Sprigings and Miller (2004) investigated optimal knee extension timing in springboard and platform dives from the reverse group (with a running approach). A five-segment planar model driven by joint torque actuators was used, and muscular force–velocity properties were considered, but the force–length property was not included. Moreover, once a torque actuator was on, it could not be set off or on again, resulting in limited control adjustment.

The purpose of this study is to investigate the effect of arm swing on maximizing somersault rotations from a compliant surface. More specifically, the kinematic and coordination