EFFECT OF SHOULDER STRENGTH ON THE FLIGHT DISTANCE IN THE STANDING LONG JUMP

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The purpose of this study was to identify the effect of different maximum shoulder joint force to the standing long jump distance. A five-segment model connected by frictionless hinge joints in plane motion was established for simulating the flight phase, and was driven by joint torques. The results show that jump distances are generally linearly related to maximum shoulder joint torque from 20 to 160 Nm. Further increase in shoulder joint strength fails to enhance the performance. Furthermore, a complete model combining both the ground contact and flight phases of the standing long jump should be used in future studies.

KEY WORDS: joint torque, dynamic simulation, optimization, long jumping.

INTRODUCTION:

Complex body coordination strategies are crucial in jumping for maximizing height/distance. Since the publication of developmental changes in the standing long jump, it has become a common test to study the fundamental motor patterns (Horita et al., 1991). Actually, standing long jump has been one of the major tests to evaluate the explosive force in the lower limbs (Aguado et al., 1997). Coordination and joint moments in children have been studied and compared with those of adults (Horita et al., 1991). Investigations on the kinematic, kinetic, and muscular characteristics leading to longer jump distance were also performed (Aguado et al., 1997; Izquierdo et al., 1998).

Various factors such as countermovement, starting postures, maximum joint/muscular strength, and swing of upper extremity, may affect the standing long jump performance. Jump distances are insensitive to the starting positions except for extremely low postures (Cheng & Chen, 2005). It has also been shown that arm swing can significantly enhance jump distance (Ashby & Heegaard, 2002; Ashby & Delp, 2006). A study of the influence of the maximum isometric shoulder torque (which determines the arm-swing strength) indicates the dependence of jumping performance on the shoulder joint strength (Cheng & Chen, 2004).

Although the previous studies investigated the effect of arm motion and shoulder joint strength on jumping distance, the calculation was based on the projectile trajectory of the center of mass (COM), and was estimated by the takeoff COM position and velocity without considering posture adjustment during flight. The purpose of this study was to investigate the effect of changing shoulder strength (maximum shoulder torque) on the standing long jump performance by computer simulation. Joint torque can be controlled in flight to produce a suitable posture for landing with maximized distance. We assumed that greater shoulder strength leads to better performance but the effect is limited by biological/mechanical factors.

METHOD:

A two-dimensional mathematical model with 5 segments connected by frictionless hinge joints was used. The 5 segments represented the feet, shanks, thighs, HT (head and trunk), and arms. Model parameters employed were from a previous study (Ashby & Heegaard, 2002). Joint torques at the ankle, knee, hip, and shoulder were used to drive the model to simulate the flight phase of the standing long jump. Because obvious hip and shoulder flexion in the jump is usually observed, to make the model more general it was assumed that all the four joints can actively flex, extend, or relax. This was different from the previous simulation (Selbie & Caldwell, 1996) in which joints only extended or relaxed. To prevent the heel from penetrating the ground, a passive torque (Pandy et al., 1990) was applied at the toe joint (actually the ball of feet).

Active joint torque T was assumed to be the product of maximum isometric torque Tmax and 3 variable factors: angle dependence f(θ), angular velocity dependence h(ω), and activation level A(t) which varied with time:

$$T = Tmax \times f(\theta) \times h(\omega) \times A(t) \qquad (1)$$

Maximum shoulder joint torque was varied from 20 to 240 Nm with 20 Nm increment and the nominal value was 120 Nm. Functions f(θ) and h(ω) can be found in similar simulation studies (Pandy et al.,1990; Selbie & Caldwell, 1996) and the effect of eccentric muscle contraction was considered in h(ω). A(t) was the effective activity of muscles across the joint, and was constrained between -1 and 1 (maximum-effort flexion and extension, respectively).
The current simulation started from jump takeoff and ends at heel-strike. The initial conditions were taken from the ending states of an optimal pre-flight simulation (from a static starting posture to takeoff) with the nominal shoulder joint strength. The objective was to maximize the horizontal distance of heel-strike by varying joint activation levels A(t). This means that the model actively changed posture in flight for landing with maximum distance. To avoid the possibility of falling backward after landing, a landing constrained was imposed. The COM velocity vector was assumed to be projected ahead of the position vector which pointed from the COM to the heel-strike position.

RESULTS:

The simulated flight phase of the standing long jump generally captured features of the actual motion (Fig. 1). Body segments extended after takeoff and then flexed before landing. It is noteworthy that the knees also extended just before landing for positioning the heel further ahead of the COM. Obvious backward swing of the arms was also observed, which was necessary for the forward motion of the lower limbs according to the conservation of angular momentum.

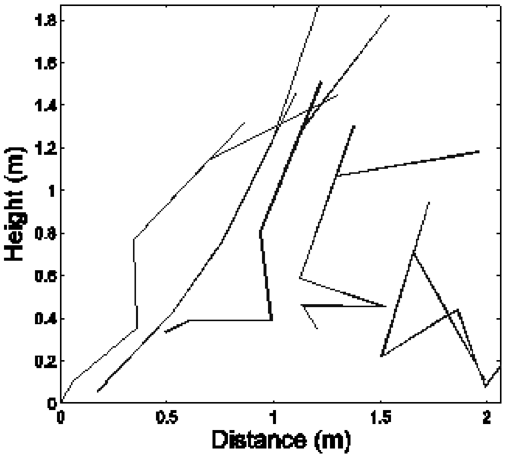

Figure 1: Body configuration for constrained landing jumps with 120-Nm shoulder joint torque at five instants in time.

Jump distances varied with different maximum shoulder joint torque (Fig. 2). The minimum distance is 1.941 meter simulated with 20-Nm shoulder joint torque, while maximum distance is 2.031 meter simulated with 200-Nm.

DISCUSSION:

The similarity between the simulated and actual motion shows the validity of the current model although only the flight phase was simulated. Joint torque activation patterns were similar in jumps from different maximum shoulder joint torque. In addition, postural adjustment performed in this study could not be simulated by the point-mass flight model in most of the previous studies considering multi-segment movement only during the ground contact phase.

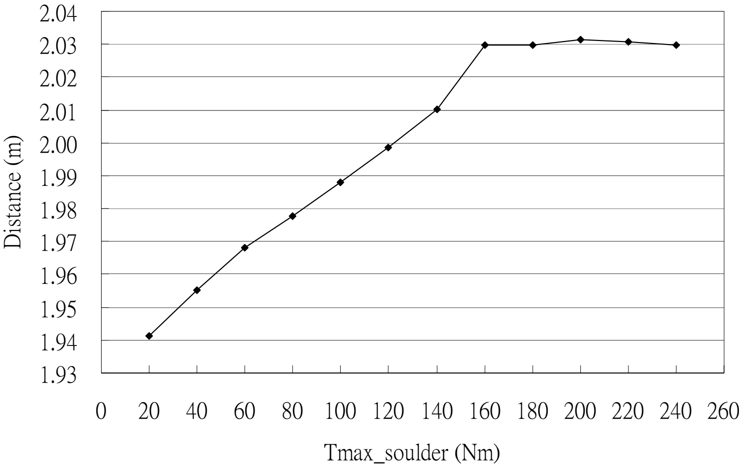

Figure 2: The result of computer simulation with different maximum shoulder joint torque.

Performance of the standing long jump was generally linearly related with shoulder joint torque which ranged from 20 Nm to 160 Nm (Fig. 2). The reason for longer jumps with arm swing during the flight phase is because the arms assisted the preparation for landing. The greater the shoulder force was, the larger distance was. Jump distance stoped increasing when the maximum torque was larger than 160 Nm. This is because greater shoulder strength helped the backward swing of the arms, which also facilitated forward positioning of the lower body. However, this mechanism had an upper limit since too much backward arm swing and forward heel positioning inevitably caused failed landing. This is why increasing arm swing strength increased distance only to a certain level.

Since the motion during ground contact affected the following flight motion, our next goal is to simulate the standing long jump from a static standing posture to landing. Although the arm motion has been shown to increase jump distance, it is not clear how the arm strength affects jump performance within the whole jumping progressing and how the coordination strategy differs. To answer these questions, computer simulation with optimization should serve to be the most valuable tool. Furthermore, the current model only assumed a simple landing condition without considering the situation after heel-strike. This should also be included in the future study.

CONCLUSION:

This study used a mathematical model and optimization to show the effect of varying shoulder joint force in the standing long jump during the flight phase. Computer simulations showed that larger shoulder joint strength causes greater performance of standing long jump but only to a certain level.

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