OPTIMAL CONTROL SIMULATIONS DEMONSTRATE HOW USING HALTERES (HAND-HELD WEIGHTS) CAN INCREASE STANDING LONG JUMP PERFORMANCE

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INTRODUCTION

Swinging the arms during the standing long jump has been shown to increase distance performance [1,2]. Studies have also suggested that using halteres (hand-held weights) as the ancient Greek Olympians did can further improve jump distance by at least 17 cm [3]. Since the combined body and halteres system must follow a parabolic trajectory during flight, throwing the halteres backwards just before landing could further enhance performance by thrusting the body forwards [3].

The present study used optimal control simulations of the standing long jump to assess if performance is improved by using halteres, and if so, how the performance increase is achieved. In addition, simulations were performed to determine how the size of the halteres influences jump distance and if further performance gains can be achieved by releasing the halteres before landing.

METHODS

The take-off and flight phases of the standing long jump were simulated using a 2-D seven segment (foot, shank, thigh, head-neck-trunk, upper arm, forearm, halteres) link model of the human body [2] (Figure 1). The ankle, knee, hip, shoulder, and elbow joints were modeled as revolute joints and were actuated by individual joint torques. The magnitude of torque generated by the joint actuators was governed by the activation, joint angle, and joint angular velocity [2].

The optimal activations that would maximize jump distance were found using a simulated annealing algorithm. Optimal solutions were determined for three types of jumps: i) jumping without halteres, ii) jumping with halteres (different total masses of 4, 6, 8, 10, and 12 kg) without releasing them during the flight, and iii) jumping with halteres with the option of releasing them during flight to improve jump distance.

RESULTS AND DISCUSSION

Using halteres during the standing long jump improved performance by much more than the 17 cm suggested by Minetti and Ardigó [3]. The jump distance for the nominal simulation (no halteres used) was 2.35 m (Table 1). Performance improved for all the different masses, but was greatest for the simulations using the 8 kg halteres. For the case in which releasing the halteres before landing was not allowed, the simulated jump distance was 2.74 m, an improvement of 39 cm.

Analysis of the simulation mechanics showed that 12 cm of this 39 cm improvement was due to the greater horizontal position of the center of gravity at take-off due to extending the halteres ahead of the body. The remaining 27 cm of improvement was due to the 22% greater velocity of the center of gravity at take-off. This greater velocity was primarily due to the increased kinetic energy (292 J) (obtained by swinging the arms back and forth before take-off [3]) and potential energy (45 J) of the halteres at the beginning of the simulation. However, some of the improvement in the take-off velocity for the jump with halteres can be explained by the additional 45 J of work performed by the joint actuators during the propulsive phase.

Table 1: Jump distances for the three types of jumps.

Type of jump	Jump distance
i) jump without halteres	2.35 m
ii) jump with 8 kg halteres without release	2.74 m
iii) jump with 8 kg halteres with release	2.89 m

Releasing the halteres during flight increased the jump performance an additional 15 cm, for a total jump distance of 2.89 m. However, optimal performance was not obtained by releasing the halteres just before landing as previously suggested [3]. The optimal time to release the halteres was about 0.18 s after take-off when the arms were extended above the head near the top of the jump (Figure 1). Releasing the halteres just before landing only resulted in an improvement of about 1 cm relative to not releasing them.

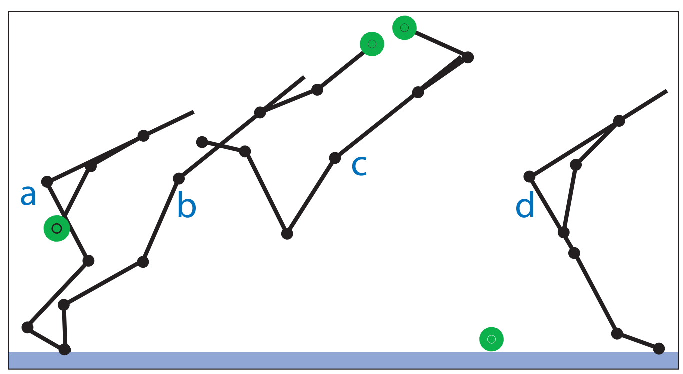

Figure 1: Body configurations at the starting point (a), take-off (b), the point where the halteres are released (c), and landing (d) for the simulated jump with 8 kg halteres.

REFERENCES

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2. Ashby BM and Delp SL, *J Biomech*, submitted.
3. Minetti AE and Ardigó LP, *Nature* **420**, 141-142, 2002.