THE EFFECT OF ANATOMICAL AND ROBUSTNESS CONSTRAINTS ON OPTIMUM JUMPING PERFORMANCE

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INTRODUCTION

Using a simple criterion, such as maximum jump height, in a simulation model optimisation study may lead to a theoretical performance which is not achievable due to the violation of anatomical constraints or due to the effects of timing perturbations on performance. The aim of this study was to determine the effects of imposing anatomical and robustness constraints on the optimisation of the height reached in a running jump.

METHODS

A planar eight-segment torque-driven subject-specific computer simulation model of the contact phase in running jumps for height was developed. The model included eight torque generators, comprising contractile and elastic elements in series, situated on both sides of the ankle, knee, hip and shoulder joints to allow for co-contraction. Wobbling masses were included in the shank, thigh and trunk segments using non–linear spring-damper representations. The foot-ground interface was modelled using non-linear, spring-damper systems situated at the toe and the heel (Figure 1).

Figure 1: Eight-segment simulation model of the foot contact phase in running jumps from one leg.

The model was customised to an elite high jumper by determining subject-specific inertia and torque parameters. Anthropometric measurements of the jumper were taken and segmental inertia parameters were calculated using a mathematical model [1]. Torque measurements were taken during eccentric-concentric movements at the ankle, knee, hip and shoulder joints using an isovelocity dynamometer (Cybex NORM), with crank angular velocities ranging from 50°/s to 450°/s, in order to express maximum voluntary torque as a function of joint angle and angular velocity [2].

The simulation of a running jump for height was matched to an actual performance by varying the torque generator activation time histories and allowing small adjustments to the initial conditions in order to minimise the difference between the kinematics of simulation and performance. Using the matching simulation as a starting point, an unconstrained optimisation of the contact phase was carried out to maximise the height reached by the centre of mass during the flight phase. This was achieved by varying the torque generator activation time histories, the initial configuration conditions and the approach velocity in order to obtain a simulation with maximum height. A second optimisation was carried out using constraints to ensure that the knee and ankle joint angles remained within anatomical limits during takeoff and flight. In a third optimisation perturbations of 5 ms in activation timings of the knee extensor torque were also introduced and the score to be maximised was taken to be the minimum height reached in a group of perturbed simulations.

RESULTS AND DISCUSSION

Table 1. Optimised jump heights for the three conditions

	approach velocity [ms^{-1}]	jump height [m]
performance (track)	7.4	2.01
matching simulation	7.4	1.95
optimisation 1	7.4	2.74
optimisation 2	7.4	2.63
optimisation 3	7.4	2.32

Without any constraints the theoretical maximum jump height in optimisation 1 was an unrealistic 2.74 m while imposing anatomical constraints in optimisation 2 reduced this to 2.63 m. Perturbing the activation timings by 5 ms in optimisations 1 and 2 did not change jump heights but violated the anatomical constraints and the knee and ankle.

Requiring robustness to timing perturbations in optimisation 3 further reduced the jump height to 2.32 m. Perturbing the activation timings of optimisation 3 by 5 ms did not result in reduced jump height.

CONCLUSIONS

When maximising performance using simulations it is important that considerations of anatomical constraints and robustness to timing perturbations are taken into consideration. Failure to do this can result in maximal solutions that are unrealistic and unachievable. Since the jumper in this study had a personal best high jumping performance of 2.31 m and since perturbations at hip and ankle must be accommodated it appears that activation timing must be better than 5 ms.

REFERENCES

1. Yeadon MR. *J Biomech* **23**, 67-74, 1990.
2. Yeadon MR, et al. *J Biomech* **38**, 2005.