OPTIMISATION OF PERFORMANCE IN RUNNING JUMPS FOR HEIGHT

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This study investigates the effect of approach conditions and takeoff technique on optimum performance. A planar eight-segment computer simulation model was used to simulate the takeoff phase in high jumping. Optimisations based on performances in the laboratory and at an athletics track were carried out to maximise the height reached by the mass centre in the flight phase. Three pairs of optimisations were performed: (i) optimisation of technique, (ii) optimisation of technique and initial conditions, (iii) optimisation of technique, initial conditions and approach velocity. In the first pair of optimisations the increases in height were 0.12 m and 0.17 m respectively. In the second pair of optimisations the additional increases in height were 0.09 m and 0.19 m and in the third pair further increases of 0.42 m and 0.02 m were obtained.

KEY WORDS: optimisation, high jump, simulation, model.

INTRODUCTION: In high jumping, the performance of an athlete is determined primarily by the vertical velocity of the mass centre at the instant the athlete leaves the ground. The approach phase is used to place the athlete in a favourable position (Dapena, 1988) from which to generate this vertical velocity during the takeoff phase. The contact or takeoff phase, considered to be the most important part of a high jump (Dapena and Chung, 1988), is affected by a number of factors. Despite the considerable research into high jumping, investigations into optimal technique are very limited. The aim of this study was to investigate the effect of approach conditions and takeoff technique on optimal performance in running jumps for height.

METHOD: A computer simulation model of the contact phase in high jumping was developed and customised to an elite high jumper through the determination of subject-specific inertia, strength and elastic parameters. The simulation model was evaluated and was then used to investigate the effect of technique and initial configuration and approach conditions on performance.
Ninety-five anthropometric measurements were taken on the subject and segmental inertia parameters were calculated using the geometric inertia model of Yeadon (1990b). One running jump for maximum height was recorded in a laboratory setting and one high jumping trial was recorded at an athletics track. In both data collections two 50 Hz cameras and a 200 Hz camera were used to record the kinematic data. Fifteen body landmarks (wrist, elbow, shoulder, hip, knee, ankle and toe on each side of the body plus the centre of the head) were digitised in each field of the movement sequence from each of the three camera views. The 12 Direct Linear Transform (DLT) parameters for each camera were determined, and these parameters along with the synchronised digitised co-ordinates of the movement data were used to reconstruct the 3D locations of each digitised point using the method of Karara (1980). The coordinate data were then used to calculate the athlete's orientation and configuration angles throughout each movement, along with the mass centre velocity and whole-body angular momentum about the mass centre (Yeadon, 1990a; Yeadon, 1990c). The time histories of the orientation and configuration angles were fitted using quintic splines (Wood and Jennings, 1979) in order to obtain angle and angular velocity estimates throughout the movement.
A planar eight-segment torque-driven forward dynamics computer simulation was developed for the foot contact phase in running jumps. The model comprised foot, calf, and thigh of the takeoff leg; shank and thigh of the free leg; trunk + head; upper arm and lower arm with torque generators situated at 5 of the joints (ankle, knee and hip of the takeoff leg; hip of the free leg and shoulder). Wobbling masses represented as non-linear spring-damper systems were included in the shank and thigh segments of the takeoff leg and in the trunk segment. The foot-ground interface was modeled in a similar way with vertical and horizontal non-linear

stiffness and damping components situated at the toe and the heel (Figure 1).

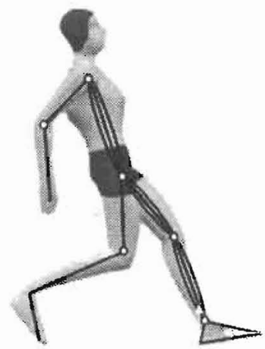

Figure 1:-Eight-segment simulation model of the foot contact phase in running jumps.

Ten torque generators acting around the five joints were used to represent the extensor and flexor muscle groups. Each muscle group was represented by a rotational elastic element in series with a contractile element. The torque produced by the contractile element was modelled using a nine parameter surface fit (Equation (1)). The torque produced by the series elastic element was modelled as a linear function of the joint angle see (Equation (2)).

$$T_{ce} = A(t)F(\theta_{ce}, \theta_{ce}) \tag{1}$$

where: T_e = torque produced by contractile element at time t, θ_{ce} = angle of the contractile element, A(t) = muscle activation function, F = nine parameter function.

$$T_{see} = K_e\theta_{see} \tag{2}$$

where: T_{see} = torque produced by the series elastic element at time t, K_e = series elastic stiffness parameter, θ_{see} = angle of the series elastic element.

The maximum torque capable of being produced at each torque generator was determined using the nine parameter function. The actual torque produced was then calculated by multiplying this maximum torque value by an activation profile.

Two different profiles were used to represent the activation time histories of the agonist and antagonist muscle groups. Six parameters were needed to define the activation time histories of the agonists and five parameters were needed to define the activation time histories of the antagonists. The six parameters of the agonists defined two quintic functions representing the ramp up to maximum activation and the ramp back down. The five parameters for the antagonists also defined two quintic functions representing the ramp down from maximum to minimum activation and then back up.

Subject-specific model parameters comprising inertia, strength and spring-damper parameters were used in the model. The inertia parameters were determined using the anthropometric measurements taken on the subject and the model of Yeadon (1990b). The strength parameters were determined from isovelocity data collected on the subject. The visco-elastic parameters were determined using a kinematically driven model. Different sets of stiffness parameter values for the foot-ground interface were calculated for the two trials to take into account the fact they were performed on different surfaces.

The eight-segment torque-driven model was implemented using the simulation software AutolevTM3 which is based on Kane's method of formulating the equations of motion (Kane and Levinson, 1996). Input to the model comprised mass centre velocity, orientation and angular velocity of each segment at touchdown, and the activation profile for each of the torque generators. The output from the model comprised whole body angular momentum, mass centre velocity, and orientation and angular velocity of each segment at takeoff.

Simulations, which closely matched the actual performances, were obtained using the Simulated Annealing optimisation algorithm (Corana et al, 1987) to minimise the difference between performance and simulation in terms of linear and angular momentum and body orientation at takeoff, joint configuration angles throughout the simulation, and time of contact by varying the torque generator activation time histories. This evaluation procedure was assessed using a percentage / angle difference score between the performance and simulation (Equation (3))

$$\sqrt{\frac{1}{2}\left(\frac{10^4}{n}\sum_{i=1}^{n}\left(\frac{s_i - v_i}{v_i}\right)^2 + \frac{1}{m}\sum_{i=1}^{m}(s_i - a_i)^2\right)} \tag{3}$$

where: S = score, s_i = value of variable i from simulated performance, v_i = value of variable i from actual performance, a_i = value of angle variable i from actual performance, n = number of non-angle variables and m = number of angle variables.

The torque generator activation time histories used in the matching simulations were used as initial estimates in subsequent optimisations of jumps for height. The activation parameters of each torque generator were then varied between specified limits.

Using the initial conditions from the recorded performances and by varying the 55 torque generator activation parameters (six for each agonist and five for each antagonist) only, the simulation of a jump for height was maximised in terms of height reached by the mass centre. This was achieved using the Simulated Annealing optimisation algorithm (Corana et al., 1987) and maximising a function defining the success of a performance. A second pair of optimisations were carried out which allowed the initial conditions at touchdown, comprising the joint angles and angular velocities, to vary, as well as the torque generator activation time histories, whilst keeping the approach speed the same as in the two actual performances. A final pair of optimisations allowed the torque generator activation time histories and initial conditions as well as the approach speed at touchdown to vary. In order that the simulated movements were realistic, penalties were included in the function defining maximum height which reduced the function score if undesirable movements of the body, such as hyperextension of the knee, occurred.

RESULTS AND DISCUSSION: Good agreement was obtained between simulation and performance with differences of 2% and 6% for the trials in the laboratory and at the track respectively, providing confidence in the model's ability to simulate running jumps. The centre of mass of the subject reached a peak height of 1.81 m in the recorded trial in the laboratory and 2.01 m in the recorded trial at the track from approach velocities of 4.4 ms-1 and 7.4 ms-1 respectively. In the optimisation of technique only, the height reached by the mass centre increased by 0.12 m and 0.17 m in the jumps in the laboratory and at the track respectively to give jump heights of 1.93 m and 2.18 m respectively.

In the second pair of optimisations in which technique and initial conditions were allowed to vary the peak height reached by the mass centre increased to 2.02 m and 2.37 m in the jumps in the laboratory and at the track respectively. This corresponded to increases from the recorded trial of 0.21 m and 0.36 m respectively.

In the final pair of optimisations, optimum approach speeds of 7.40 ms-1 and 7.39 ms-1 resulted in final maximum jump heights of 2.44 m and 2.39 m respectively. Without including penalties in the objective function considerably higher heights (close to 3 m) were obtained. This, however, was only achieved through hyperextension of the knee and ankle joints which would have resulted in injury.

The heights reached by the centre of mass in the final pair of optimisations were considerably higher than the subject's personal best. In his personal best performance, however, the subject's centre of mass will almost certainly have reached a height above the 2.31 m he cleared. Additionally in competition a jumper must produce appropriate angular momentum for bar clearance whereas in these simulations little or no rotation was produced and so the simulated height may be an overestimate. The optimisations carried out in this study also do not take into account the robustness of the performance. An athlete is unlikely to adopt technique which is not robust and in which slight perturbations from the technique will result in a poor performance. The optimum performances found here may not be robust and future work will involve investigating optimisations which include a measure of resilience to perturbations.

CONCLUSION: This study highlights the importance of both technique and approach conditions on overall performance and also identifies that the performance of an elite high jumper may be limited by the need to protect joints from hyperextension and therefore probable injury.

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