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COMPUTER SIMULATION OF THE TAKEOFF PHASE IN RUNNING JUMPS

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Our purpose was to investigate the effects of initial conditions and takeoff technique on the performance of running jumps. Matching simulations and optimum simulations were determined for the three takeoff phases of a triple jump performance, a running jumping for height and a running jump for distance. For the triple jump, the optimised simulations used symmetrical 'double-arm' shoulder flexion whereas the triple jumper had used an asymmetrical 'single-arm' technique. For the jumps for height and distance, optimising each performance for height / distance demonstrated that the initial conditions at touchdown have a substantial effect on the resulting performance. Whilst the takeoff phase is clearly important, if the touchdown conditions are not close to optimal then a jumper is unable to compensate for these shortcomings to achieve a performance close to optimum.

KEY WORDS: running jumps, optimisation, computer simulation.

INTRODUCTION: Running jumps can be generally considered to consist of three main phases: the approach, the takeoff and the flight phase. The takeoff is often considered to be the most important of the three phases (Dapena, 1988) with the approach used to place the athlete in the optimum initial conditions for the takeoff phase.

In high jumping and long jumping there are differences in the athlete's optimal initial conditions due to the specific requirements of each performance. The optimal approach velocity for long jumping is faster than for high jumping where an 'intermediate' approach velocity is optimal (Greig & Yeadon, 2000; Alexander, 1990). Using a theoretical model, Alexander (1990) found that long jumping has a steeper (smaller) optimum plant angle (the angle between the vertical and the line joining the ankle and hip of the takeoff leg) than in high jumping where the optimum plant angle is further away from the vertical. The shallower (larger) plant angle utilised by high jumpers facilitates the production of vertical velocity. The steeper plant angle utilised in long jumping allows the athlete to gain vertical velocity whilst maintaining a fast horizontal velocity (Hay, 1981). In addition a straight plant leg is optimal for both high jumping (Grieg and Yeadon, 2000) and long jumping (Seyfarth, Blickhan & Van Leeuwen, 2000) and a greater backward lean of the trunk at touchdown is needed for high jumping Dapena (1988) while in long jumping the trunk angle is closer to vertical (Graham-Smith & Lees, 2005).

In triple jumping, one specific issue is an understanding of the optimum arm action during each takeoff phase in order to maximise performance (Hay, 1992) with current techniques broadly split into two types: the single-arm technique in which the arms move asymmetrically; and the double-arm technique, where symmetrical flexion of the upper arms occurs during takeoff from an extended starting position. There has been little research on optimum arm technique although Jonathan Edwards (who improved his best performance by 0.85 m in breaking the triple jump world record three times in 1995) attributed his improvement to the adoption of a symmetrical 'double-arm' technique (Edwards, 2009).

The approach phase (initial conditions at touchdown) and the takeoff phase are both clearly important for a successful performance of a running jump for height or distance. The relationship between these two phases is complex with it not being clear what effect changes in takeoff technique can have on performance for a particular combination of approach characteristics. The purpose of this study was to use subject-specific computer simulation models to investigate optimal technique during the takeoff phase in running jumps for height and distance.

METHODS: Subject-specific computer simulation models were developed for the takeoff phase of running jumps (Figure 1). The equations of motion for each simulation model were developed using the Autolev software package (Kane & Levinson, 1985) with the two models having slightly different features.

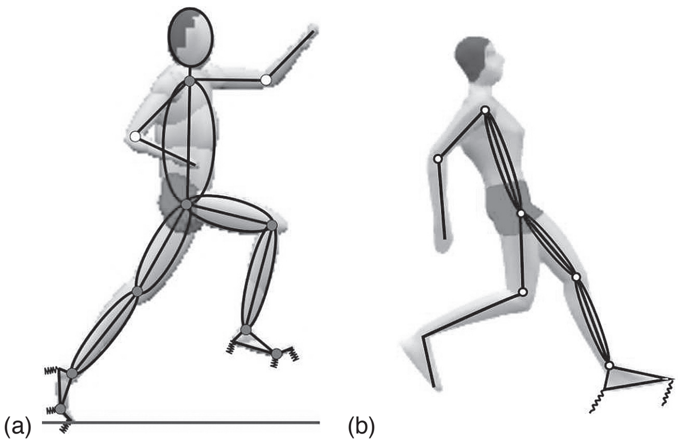

Figure 1: Computer simulation models of the takeoff phase in (a) triple jumping (Allen, et al., 2010) and (b) running jumps for height / distance (Wilson et al., 2007).

Each simulation model was customised to an elite athlete based upon measurements taken on each subject. Inertia parameters (segmental length, mass, mass centre location and moment of inertia) for each rigid segment were determined from 95 anthropometric measurements on each elite athlete using the inertia model of Yeadon (1990). Strength tests on each elite athlete using an isovelocity dynamometer (King, Wilson & Yeadon, 2006; Yeadon, King & Wilson, 2006) were used to determine the maximum voluntary torque that could be produced at each joint as a function of angle and angular velocity. Visco-elastic parameters for the wobbling masses (Figure 1) and the foot-ground interface were determined using an angle-driven version of each model (Wilson, King & Yeadon, 2006; Allen, King & Yeadon, 2010).

Input to each torque-driven model consisted of the kinematics at touchdown and the activation time histories of each torque generator. Model output comprised the time histories of the foot-ground spring-damper displacements, joint angles and trunk orientation from which mass centre position and velocity together with angular momentum about the mass centre were calculated. Both simulation models were evaluated by comparing simulations to performances of each activity by an elite jumper. The activation profiles corresponding to each torque generator were varied using optimisation algorithms (Corana, Marchesi, Martini & Ridella, 1987; Goldberg, 1989) in order to obtain the best match to the performance of each activity in terms of joint angle changes and mass centre velocity / whole body angular momentum at takeoff.

The matching simulations of three types of jump were optimised by varying the activation timings to each torque generator in order to maximise performance (triple jump – maximise distance jumped; jump for height – maximise distance travelled (opt HL) and maximise height jumped (opt HH); jump for distance – maximise distance travelled (opt LL) and maximise height jumped (opt LH) giving six optimum simulations.

RESULTS: Both simulation models were successfully evaluated with good agreement between performance and simulation (Table 1). This is an important step in the modelling process as without doing this the wrong conclusions may be taken from simulations.

Optimisation of technique in each phase of the triple jump yielded an increase in jump distance from the matched simulations of 3.3%, 11.1%, and 8.2% for the hop, step, and jump respectively. In each phase the optimisation process chose a symmetrical shoulder flexion, whereas the jumper employed an asymmetrical technique (e.g. Figure 2).

Table 1
Matching simulations

	% difference
jump for height (match H)	6.9
jump for distance (match L)	10.5
hop takeoff in triple jump	3.8
step takeoff in triple jump	2.7
jump takeoff in triple jump	3.1

a

b

Figure 2: (a) Matched and (b) optimised simulation of the step phase of the triple jump.

In opt HH the optimised peak height reached by the mass centre was 0.11 m higher than the matching simulation match H, while in opt LL the optimised horizontal distance travelled by the mass centre during the flight phase was 0.29 m further than the matching simulation match L. Optimising for the opposite performance variable (opt LH and opt HL) had relatively small effects on the peak height (0.02 m) or horizontal distance travelled (0.17 m) by the mass centre during the flight phase (Table 2). The effect of the initial conditions was much larger than the effect of the changed torque generator activation technique for the running jumps for height and distance with a 0.63 m greater distance travelled in opt LL compared with opt HL even though the approach speed was greater for opt HL (Table 2)

Table 2
Jump height and distance travelled for the optimisations for height and distance [m]

	match H	match L	opt HH	opt LL	opt HL	opt LH
height	1.98	1.65	2.09	1.80	2.06	1.82
distance	3.91	4.38	3.87	4.67	4.04	4.59

DISCUSSION: In the triple jump the increases in jump distance for the optimised simulations compared with the matching simulations were mainly due to the change in technique from a asymmetrical arm movement to a symmetrical double arm movement (e.g. Figure 2). In the running jumps for height and distance the heights and distances achieved in the optimised jumps (opt HH and opt LL) were 0.11 m and 0.29 m greater than the respective matching simulations suggesting that for the given initial conditions the techniques used by the elite high jumper were relatively close to optimal. The effect of initial conditions on the optimised simulations was much greater than the takeoff technique on the heights reached and distances jumped (Table 2).

CONCLUSION: For the triple jump with given initial conditions, it would appear that a symmetrical 'double-arm' shoulder flexion technique is advantageous with the optimum simulation in all three phases adopting a 'double-arm' technique whereas the triple jumper had used an asymmetrical 'single-arm' technique. For the running jumps for height and distance, four optimised simulations (optimising each performance for height and distance) demonstrated that even with similar approach velocities the initial conditions at touchdown have a substantial effect on the resulting performance. Whilst the takeoff phase is clearly important, if the approach phase and the subsequent touchdown conditions are not close to optimal then a jumper is unable to compensate for these shortcomings during the short takeoff phase to achieve a performance close to optimum.

REFERENCES:

Alexander, R. McN. (1990). Optimum take-off techniques for high jumps and long jumps. *Philosophical Transactions of the Royal Society of London B*, 329, 3-10.

Allen, S.J., King, M.A., & Yeadon, M.R. (2010). Is a single or double arm technique more advantageous in triple jumping? *Journal of Biomechanics,* 43, 3156-3161.

Corana, A., Marchesi, M., Martini, C., & Ridella, S., (1987). Minimising multimodal functions of continuous variables with the "simulated annealing" algorithm. *ACM Transactions on Mathematical Software*, 13, 262-280.

Dapena, J. (1988). Biomechanical analysis of the fosbury flop. *Track Technique,* 104, 3307-3317.

Edwards, J. (2009). http://www.iaaf.org/GLE09/news/newsid=51022.html.

Goldberg, D.E., (1989). Genetic algorithms in search, optimization and machine learning. First edn. Boston, MA: Addison-Wesley.

Graham-Smith, P., & Lees, A. (2005). A three-dimensional kinematic analysis of the long jump take-off. *Journal of Sports Sciences,* 23, 891-903.

Hay, J.G. (1981). Fundamental mechanics of jumping. In V. Gambetta, (Ed.), *Track and field coaching manual* (pp. 148-154). New York: Leisure Press.

Hay, J.G. (1992). The biomechanics of the triple jump: a review. *Journal of Sports Sciences,* 10, 343-378.

Kane, T.R. & Levinson, D.A. (1985). *Dynamics: Theory and applications*. New York: McGraw-Hill Book Company.

King, M.A., Wilson, C. & Yeadon, M.R. (2006). Evaluation of a torque-driven model of jumping for height. *Journal of Applied Biomechanics*, 22, 264-274.

Seyfarth, A., Blickhan, R., & Van Leeuwen, J.L. (2000). Optimum take-off techniques and muscle design for long jump. *Journal of Experimental Biology,* 203, 741 – 750.

Wilson, C., King, M.A., & Yeadon, M.R. (2006). Determination of subject-specific model parameters for visco-elastic elements. *Journal of Biomechanics,* 39, 1883-1890.

Wilson, C., Yeadon. M.R. & King, M.A. (2007). Considerations that affect optimised simulation in a running jump for height. *Journal of Biomechanics*, 40, 3155-3161.

Yeadon, M.R. (1990). The simulation of aerial movement - II: A mathematical inertia model of the human body. *Journal of Biomechanics,* 23, 67-74.

Yeadon. M.R., King, M.A. & Wilson, C. (2006). Modelling the maximum voluntary joint torque / angular velocity relationship in human movement. *Journal of Biomechanics,.* 39, 476-482.

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