OPTIMISING PHASE RATIO IN TRIPLE JUMPING USING COMPUTER SIMULATION

[1,2]S.J. Allen, [1]M.A. King, and [1]M.R. Yeadon
[1]School of Sport, Exercise and Health Sciences, Loughborough University, UK
[2]Corresponding Author; email: s.j.allen@lboro.ac.uk, web: www.lboro.ac.uk/

SUMMARY

The triple jump is an athletic event comprising an approach run followed by three consecutive phases. The 'phase ratio' is the distance of each of these phases expressed as three percentages of the total distance jumped. No consensus has been reached as to whether optimal phase ratios exist. This study aimed to determine the optimal phase ratio for an athlete using computer simulation. A simulation model was matched to performance data by varying torque generator activation timings using a genetic algorithm (GA), resulting in an overall difference of 3%, and a distance of 12.50 m. The distance jumped by the simulation model was maximised in the same fashion by the GA. The optimisation process resulted in a substantial improvement from the matched simulation, 13.32 m, and a balanced technique with a phase ratio of 33.6% : 31.7% : 34.8. This is within the range of phase ratios used by elite triple jumpers so can be considered a feasible optimum.

INTRODUCTION

The triple jump is an athletic event involving three consecutive phases during which athletes must distribute their 'effort' in order to maximise the total distance (Figure 1). The 'phase ratio' is the distance of each phase expressed as three percentages of the total distance jumped. Triple jump techniques with respect to phase ratio have been defined as being: (a) hop-dominated – where the hop percentage is at least 2% greater than the next largest phase percentage; (b) jump-dominated – where the jump percentage is at least 2% greater than the next largest phase percentage; and (c) balanced – where the largest phase percentage is less than 2% greater than the next largest phase percentage [1]. It has been stated that the identification of the optimum phase ratio for an athlete, 'should take priority over all other problems of triple jump technique because, without a solution to this problem, all others must be considered in ignorance' [1]. Despite this no consensus has been reached as to whether optimum phase ratios for triple jumping exist, and if so, what they are. The aim of this study was to determine the optimum phase ratio for an athlete using computer simulation.

METHODS

A 13-segment planar torque-driven computer simulation model was used to simulate each ground contact phase of the triple jump [2] (Figure 2). Kinematic data were captured at 240 Hz during a single triple jump performance of 13.00 m and were used to provide initial conditions for each simulation. Torque and anthropometric measurements were also taken from the triple jumper in order to make the model

subject-specific [3]. Optimisation was used in two different ways: (a) torque-driven simulations were matched to performance data in order to assess the accuracy of the model; and (b) technique was optimised using torque-driven simulations in order to maximise the total jump distance. A GA [4] was used to either minimise the objective difference function, or maximise the total jump distance, by varying 246 and 243 parameters respectively. These parameters represented torque generator activation timings and magnitudes, and kinematics at touchdown. The whole body kinematics, and angular momentum at takeoff from each phase were used in order to calculate the initial orientation and velocities at the touchdown of the subsequent phase as described by [2]. The objective function for each matched torque-driven simulation was the RMS of six parts [2]: percentage difference in horizontal velocity of COM at takeoff; percentage difference in vertical velocity of COM at takeoff; overall RMS difference in (trunk) orientation in degrees during ground contact; overall RMS difference in whole-body configuration in degrees during ground contact; percentage absolute difference in time of contact; absolute difference in orientation at touchdown of the subsequent phase in degrees calculated as described by [2]. In all cases 1° was considered to be equivalent to 1% and objective difference function values are reported as percentages [2].

Figure 2: Thirteen-segment simulation model with wobbling masses within the shank, thigh, and trunk segments, torque drivers at the ball, ankle, knee, hip, and shoulder joints (grey circles), angle drivers at the elbow joints (white circles), and spring-dampers at three points on each foot.

RESULTS AND DISCUSSION

Simulations were shown to match performance data closely with an overall difference of 3.0% across the whole jump. This led to a total jump distance of 12.50 m and a phase ratio of 34.8% : 31.0% : 34.2%, which is considered to be a balanced technique.

Optimisation of technique led to a substantial increase in the total jump distance of 13.32 m and also exhibited a balanced technique: 33.6% : 31.7% : 34.8%. Optimised simulations all employed a 'double arm' technique (Figure 2) which has previously been shown to be optimal for triple jumping [2].

Optimising all three phases of the triple jump as a single unit was an extremely difficult challenge for the GA, necessitating the optimisation of 243 parameters. However the result was a substantial improvement upon the matched simulation and is within the range of phase ratios seen in elite triple jumping [1], indicating that it is a feasible optimum.

It is unknown whether, and if so how, changes in factors such as strength and approach velocity affect the optimum phase ratio for a given athlete, or whether there is a universal optimum independent of these parameters.

Alternatively it may be that there are a number of optima, incorporating hop-dominated, jump-dominated, and balanced techniques, of which the result of this study is one. This would explain the lack of consistency in phase ratios employed by elite performers [1]. Future studies might constrain the simulation to different techniques with respect to phase ratio to see whether equally good performances can be obtained with each.

CONCLUSIONS

The technique identified by the optimisation process involved a phase ratio that is considered to be balanced; that is the distance of the longest phase is less than 2% greater than the next longest phase. The phase ratio in the optimised simulation did not differ greatly from that employed in the matched simulation – both were balanced techniques – indicating that the athlete was utilising a technique close to his optimal phase ratio.

hop

step
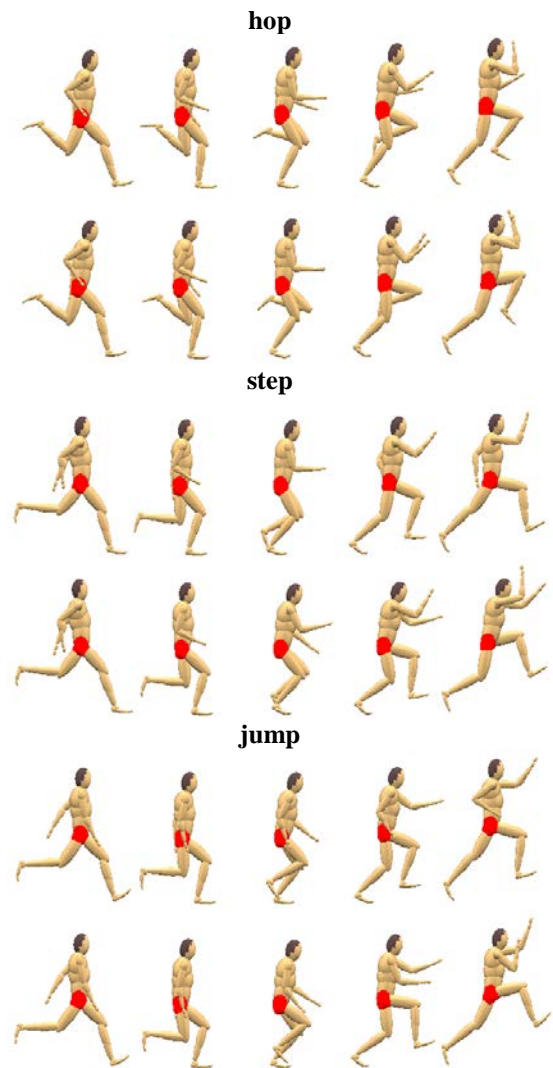
jump

Figure 2: Graphics depicting matched (top) and optimised (bottom) simulations for each phase of the triple jump.

REFERENCES
1. Hay JG, et al., *Journal of Biomechanics.* **26**:7-21, 1993.
2. Allen SJ, et al., *Journal of Biomechanics.* **43**:3156-3161, 2010.
3. Yeadon MR, *Journal of Biomechanics.* **23**:67-74, 1990.
4. Carroll DL, *AIAA Journal.* **34**:338-346, 1996.

hop   **step**   **jump**
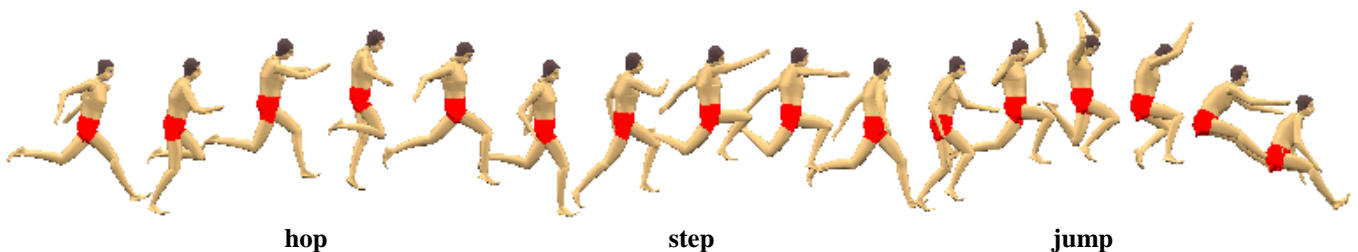
Figure 1: Graphics sequence of a triple jump.