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The effect of increasing strength and approach velocity on triple jump performance

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ABSTRACT

The triple jump is an athletic event comprising three phases in which the optimal phase ratio (the proportion of each phase to the total distance jumped) is unknown. This study used a planar whole body torque-driven computer simulation model of the ground contact parts of all three phases of the triple jump to investigate the effect of strength and approach velocity on optimal performance. The strength and approach velocity of the simulation model were each increased by up to 30% in 10% increments from baseline data collected from a national standard triple jumper. Increasing strength always resulted in an increased overall jump distance. Increasing approach velocity also typically resulted in an increased overall jump distance but there was a point past which increasing approach velocity without increasing strength did not lead to an increase in overall jump distance. Increasing both strength and approach velocity by 10%, 20%, and 30% led to roughly equivalent increases in overall jump distances. Distances ranged from 14.05 m with baseline strength and approach velocity, up to 18.49 m with 30% increases in both. Optimal phase ratios were either hop-dominated or balanced, and typically became more balanced when the strength of the model was increased by a greater percentage than its approach velocity. The range of triple jump distances that resulted from the optimisation process suggests that strength and approach velocity are of great importance for triple jump performance.

1. 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. Hay (1993) stated that the peak ground reaction forces (GRFs) recorded during the support phase of the step in triple jumping are 'much greater than a human limb is exposed to in any other voluntary activity for which data could be found'. Measured forces range from 12.6 to 22.3 times bodyweight (Amadio, 1985; Ramey and Williams, 1985; Perttunen et al., 2000). Given the magnitude of these peak GRFs it is reasonable to suggest that strength is of great importance to triple jump performance. However, the isolated effects of changes in strength on performance are hard to gauge experimentally. Increasing strength has been shown to improve optimal performance in computer simulations of vertical squat jumping in which the height reached is solely determined by the amount of work done by the muscles (Bobbert and Van Soest, 1994). Seyfarth et al. (2000) found that the outcomes of computer simulations of the long jump were particularly sensitive to muscle strength and eccentric force enhancement, but the mechanism for improvement in performance in a running jump is harder to define, since it cannot be easily related to work done by muscles; there is no simple relationship between energy and performance.

During the ground contact of a running jump, horizontal velocity is 'converted' to vertical velocity as the centre of mass (CoM) 'pivots' over the foot; vertical velocity can be generated whilst the joints of the stance leg are flexing (Dapena and Chung, 1988). Horizontal velocity must therefore be 'traded off' against vertical velocity. A comparison between high jumping and long jumping indicates that athletes achieve the higher vertical takeoff velocities needed for high jumping by planting the stance leg at a larger angle from the vertical, putting the CoM of the body lower and further behind the foot (Alexander, 1990; Wilson et al., 2011). This causes the angle between the velocity vector of the CoM and the vector from the CoM to the centre of pressure (CoP) (the 'radius' of the circle on which the CoM pivots) to decrease, leading to a higher inwards radial velocity (i.e. the distance between the CoM and the CoP shortens) and a lower tangential velocity (Dapena and Chung, 1988). During this period the joints of the stance leg, especially the knee, are in eccentric conditions and are therefore dissipating energy. Typically, proportionately more horizontal velocity is lost as gains in vertical velocity increase, due to the requisite increase in plant angle leading to more energy dissipation by the stance leg and

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larger changes in potential energy of the mass centre. It has been proposed that the ability of an athlete to ‘convert’ horizontal velocity to vertical velocity is subject-specific (Yu and Hay, 1996; Allen et al., 2013) but the effects of strength and approach velocity on this relationship have not been investigated. It is possible that an increase in strength would allow a more efficient conversion of horizontal velocity to vertical velocity because the leg would be better able to resist flexion, and hence energy dissipation due to eccentric muscle actions.

The ‘phase ratio’ comprises the distances of each phase expressed as three percentages of the total distance. Triple jump techniques 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 (Hay, 1992). There have been a number of attempts to determine the effect of phase ratio on triple jump performance using various approaches including: observations of elite jumpers (Miller and Hay, 1986; Hay, 1992, 1993, 1995, 1997, 1999; Song and Ryu, 2011); the differences between elite and novice jumpers (Simpson et al., 2007); statistical relationships between velocity tradeoffs during the contact phases (Yu and Hay, 1996; Yu, 1999); and even an operations research approach (Brimberg et al., 2006).

Attempts have also been made to optimise technique using a subject-specific computer simulation model of all three phases of the triple jump (Allen et al., 2016). The results indicated that for the individual in the study a hop-dominated or balanced technique would be optimal, and that a jump-dominated technique would lead to a reduction of approximately 3% in triple jump distance. The best performance of the triple jumper in this study was 14.35 m which is below that of elite competitors and therefore it is difficult to generalise the findings to an elite population. It has been observed that athletes approach more slowly when triple jumping compared to long jumping, indicating that approach velocity in triple jumping is submaximal (Hay, 1993). Hop-dominated techniques are associated with higher forces than jump-dominated techniques, especially during the step stance phase (Allen et al., 2016); therefore employing a jump-dominated technique may lead to a reduction in GRF magnitude and allow an increase in approach velocity (Hay, 1995), since higher velocities are also associated with higher forces.

Table 1
Overall jump distances.

Strength	***Velocity***			
	100%	***110%***	***120%***	***130%***
100%	14.05 m	14.67 m	15.12 m	15.12 m
110%	14.87 m	15.54 m	16.03 m	16.53 m
120%	15.48 m	16.34 m	17.10 m	17.58 m
130%	16.20 m	17.06 m	17.94 m	18.49 m

In order to generalise technique obtained from a simulation model across a population of athletes of various strengths and sprinting speeds it is necessary to vary these factors during the optimisation process. The aim of this study was therefore to determine the effects of increasing the strength and approach velocity of an athlete on total jump distance and phase ratio using a planar whole body forward dynamics computer simulation model of the ground contact parts of all three phases of the triple jump. In order to fufil this aim, the following specific questions will be answered:

1) Do increases in strength and approach velocity result in increases in jump distance?
2) Do increases in strength and approach velocity result in altered optimal phase ratios?
3) Do increases in strength and approach velocity change the capacity of the model to convert horizontal to vertical velocity?
4) Do increases in strength and approach velocity change the optimal plant angles at the touchdown of each phase?

2. Methods

2.1. Data collection and parameter determination

The study was conducted in accordance with the Loughborough University Ethics Committee guidelines. Subject-specific torque and inertia parameters were calculated from measurements taken from a national standard male triple jumper (age: 22 years; mass: 72.6 kg; height: 1.82 m; best performance: 14.35 m). Maximal voluntary joint torque data was obtained, assuming bilateral symmetry, using an Isocom isovelocity dynamometer for flexion and extension of the ankle, knee, hip, and shoulder on the right hand side of the body (King et al., 2006). Ninety-five anthropometric measurements were taken along with body mass and used as input to the inertia model of Yeadon (1990) in order to calculate subject-specific segmental inertia parameters which allowed calculation of the whole body CoM location and moment of inertia. Kinematic data was collected at the Loughborough University indoor High Performance Athletics Centre from a single triple jump performance from an approach run of self-selected length. Forty-five 25 mm retroreflective markers were placed on the athlete in order that locations of joint centres could be determined. Eighteen Vicon MX cameras, covering a volume of 18 m × 2 m × 2.5 m spanning the last stride of the approach and the complete triple jump, captured data at 240 Hz. Approach velocity was defined as the horizontal velocity of the whole body CoM at the touchdown of the hop stance phase. The performance resulted in an approach velocity of 8.1 m s^{-1} and a triple jump distance of 13.00 m, employing a balanced technique (35.5%:30.4%:34.1%). Orientation, defined as the angle of the trunk in a global reference frame, and configuration angles were calculated by considering the joint centre coordinates in the sagittal plane.

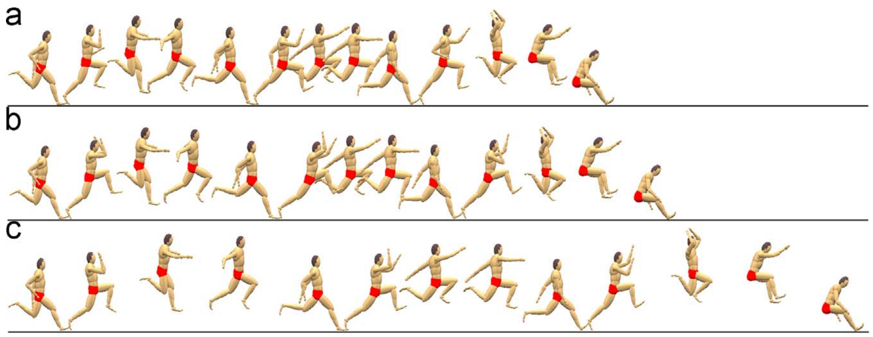

Fig. 1. Techniques employed in a) the matched simulation, b) the optimised simulation with 100% strength and approach velocity, and c) the optimised simulation with 130% strength and approach velocity.

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