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Original article

Effect of approach run velocity on the optimal performance of the triple jump

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Abstract

Purpose: The purpose of this study was to determine the effect of horizontal and vertical velocities at the landing of the last step of approach run on the performance and optimal phase ratio of the triple jump.

Methods: Three-dimensional kinematic data of 13 elite male triple jumpers were obtained during a competition. Computer simulations were performed using a biomechanical model of the triple jump to determine the longest actual distance using the optimal phase ratio with altered horizontal and vertical velocities at the landing of the last step of approach run.

Results: The actual distance obtained using the optimal phase ratio significantly increased as the horizontal velocity at the landing of the last step of approach run increased ($p = 0.001$) and the corresponding downward vertical velocity decreased ($p = 0.001$). Increasing horizontal velocity at the landing of the last step of approach run decreased optimal hop percentage and increased optimal jump percentage ($p = 0.001$), while decreasing corresponding downward vertical velocity increased optimal hop percentage and decreased optimal jump percentage ($p = 0.001$).

Conclusion: The effects of the velocities at the landing of the last step of approach run on the optimal phase ratio were generally small and did not qualitatively alter optimal techniques.

Keywords: Biomechanics; Computer simulation; Optimization; Sports; Techniques

1. Introduction

Triple jump is a technically and physically demanding jump event in track and field because of requirement of the three consecutive takeoffs and landings at high speeds. The three phases (jumps) of the triple jump are named as hop, step, and jump. The performance of a triple jump is determined by the official distance that is the actual distance minus distance lost at the hop takeoff.[1] The distance lost at the hop takeoff is the distance from the toe of the takeoff foot to the front edge of the takeoff board, while the actual distance is the sum of the three phase distances. Each of the hop and step distances is measured from the toe of the takeoff foot at the corresponding takeoff to the toe of landing foot at the corresponding landing. The jump distance is measured from the toe of the takeoff foot at the jump takeoff to the nearest mark the jumper made in the sand pit. All these distances are measured parallel to the runway.

The percentage of each phase distance with respect to the actual distance is referred to as phase percentage. The ratio of the three phase percentages is referred to as phase ratio.[1] Phase ratio is a measure of effort distribution in the triple jump and has been identified as a critical factor that affects the performance of the triple jump.[1] In terms of phase ratio, triple jump techniques were categorized as (1) hop dominant, (2) jump dominant, and (3) balanced.[1] Previous studies have demonstrated that an optimum phase ratio exists for a given triple jumper that yields the longest actual distance.[2,3] The optimum phase ratio for a given triple jump is mainly determined by a parameter named as velocity conversion coefficient that is the slope of the linear relationship between the loss in the horizontal velocity and the gain in the vertical velocity for the given athlete.[2,3] A recent study demonstrates that phase ratio significantly affects the actual distance of the triple jump.[4]

Biomechanically, approach run velocity is another factor that affects the performance of the triple jump. Understanding how approach run velocity and velocity conversion coefficient interactively affect the optimal phase ratio would provide

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further information for athletes and coaches to understand triple jump techniques and select optimal phase ratio to maximize performance. As a continuation of the previous study, the purpose of this study was to determine the effects of approach run velocity and velocity conversion coefficient on the optimal phase ratio and actual distance of the triple jump. We hypothesized that the horizontal and vertical velocities of approach run would affect the longest actual distance a triple jumper could achieve with optimal phase ratio. We also hypothesized that the horizontal and vertical velocities of approach run would affect the optimal phase ratio of a triple jumper with a given velocity conversion coefficient.

2. Methods

The subjects of this study were 13 finalists of the men's triple jump competition at the 1992 US Track and Field Olympic Team Trials (Table 1). The use of human subjects was approved by USA Track & Field. Each subject had at least one legal trial in which the subject completed the full sequence of the triple jump and was entirely videotaped for quantitative data reduction.

Two S-VHS video camcorders were used to collect three-dimensional (3D) coordinates of 21 body landmarks[5] at a frame rate of 60 frames per second with a setup for a direct linear transformation (DLT) procedure with two panning cameras.[6] A control frame with 68 control points was placed at 10 consecutive positions along the runway to form a calibration volume 24 m long, 2 m wide, and 2.5 m high in which the last two steps of the approach run, hop, step, and jump occurred.[2,6]

The real life 3D coordinates of the 21 body landmarks were obtained using the DLT procedure with panning cameras.[2,6] The raw 3D coordinates were filtered through a second-order recursive Butterworth digital filter[7] with an estimated optimum cutoff frequency of 7.14 Hz.[8,9] The 3D coordinates of the whole center of mass (COM) of each subject in each video frame were estimated using the segmental procedure.[5,10] The horizontal and vertical velocities of the COM at the takeoff and landing of the last stride of the approach run, hop, step, and jump, and the losses in horizontal velocity of the COM and gains in vertical velocity of the COM during the stances of the hop, step, and jump were estimated for each trial.[2,3,11] The takeoff and landing heights and distances of the hop, step, and jump were also estimated for each trial. The takeoff and landing distances of each phase were defined as the horizontal distances between the COM and the toe in the last frame in which the toe was on the ground before the flight and in the first frame in which the toe was on the ground after the flight, respectively.[4] Takeoff and landing heights of each phase were defined as the vertical coordinates of the COM relative to the ground in the last frame in which the takeoff foot was on the ground before the flight and in the first frame in which the landing foot was on the ground after the flight, respectively.[4]

Table 1
Subjects and performances ($n = 13$).

	Height (m)	Mass (kg)	Actual distance of analyzed trial (m)
Mean	1.86	74.4	16.94
SD	0.04	5.3	0.70
Maximum	1.93	84.1	18.05
Minimum	1.78	62.7	15.45

Computer simulations were performed using a simulation model of the triple jump developed and validated in previous studies[2–4] to determine the effects of horizontal and vertical velocities of approach run on the optimal phase ratio and longest actual distance with a given velocity conversion coefficient that is defined as the slope of the linear relationship between the loss in horizontal velocity and gain in vertical velocity during each stance.[2] Each phase distance was expressed as the sum of the takeoff, flight, and landing distances in the model. The flight distance was expressed as a function of takeoff velocities and height, and landing height using equations for projectile movements. The horizontal takeoff velocity of a given phase was expressed as the sum of the horizontal landing velocity of the previous phase and the loss in the horizontal velocity during the given stance. The vertical takeoff velocity of a given phase was expressed as the sum of the vertical landing velocity of the previous phase and the gain in the vertical velocity during the given stance. The loss in the horizontal velocity during each stance ($\Delta v_{x,i}$) was expressed as a function of the gain in the vertical velocity ($\Delta v_{z,i}$):[2,3]

$$\Delta v_{x,i} = A_0 + P_i B_0 + A_1 \Delta v_{z,i}$$

(i = 1 for the hop, i = 2 for the step, i = 3 for the jump; $P_1 = 0$, $P_2 = P_3 = 1$)

A_1 is the velocity conversion coefficient. The relationships of A_0 and B_0 with A_1[3] were expressed as

$$A_0 = 0.946 - 2.976 A_1$$

$$B_0 = -0.296 - 1.167 A_1$$

The horizontal and vertical velocities of the COM at the landing of the last stride of approach run before hop takeoff were referred to as the horizontal and vertical velocities of approach run (Fig. 1).

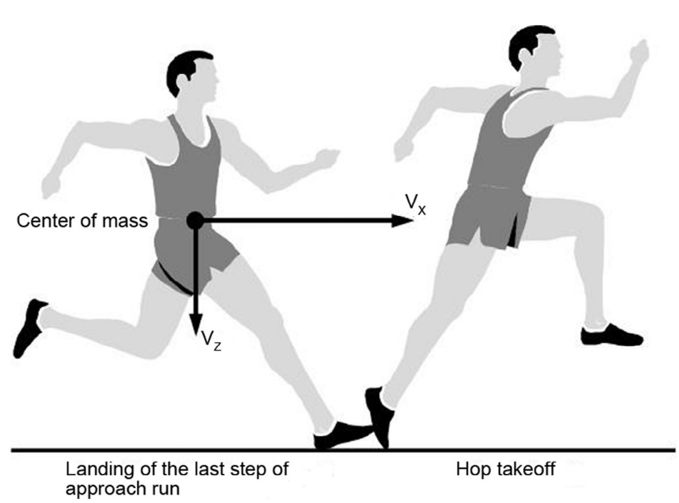

Fig. 1. Horizontal and vertical velocities of approach run in the triple jump.