EFFECT OF PHASE RATIO ON THE PERFORMANCE OF THE TRIPLE JUMP

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INTRODUCTION
Phase ratio is a measure of effort distribution in the triple jump, and defined as the ratio of three phase distances of the triple jump. Hop-dominant, balanced, and jump-dominant techniques were three triple jump techniques defined based on phase ratio. Although previous studies demonstrated that individualized optimal phase ratios exist [3], the importance of the phase ratio cannot be determined until the effect of phase ratio on the performance of the triple jump is determined. The purpose of this study was to determine the effect of phase ratio on the performance of the triple jump.

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. 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 use to record the performance of each subject from the last two steps of approach run to the landing of the jump at a frame rate of 60 frames per second. The two video camcorders were set up for a Direct Linear Transformation (DLT) procedure with panning cameras [2] to collect three-dimensional (3-D) coordinates of 21 body landmarks. The raw 3-D coordinates were filtered through a second-order recursive Butterworth digital filter with an estimated optimum cutoff frequency of 7.14 Hz. The 3-D coordinates of the whole center of mass (COM) of each subject in each video frame were estimated using the segmental procedure.

The longest actual distance a given subject could achieve using each of the hop-dominant, jump-dominant, and balanced techniques with a given velocity conversion coefficient was determined through a computer simulation using a triple jump model developed and validated in a previous study [3]. Each phase distance was expressed as the sum of the takeoff, flight, and landing distances in the model. The takeoff and landing distances of each phase were defined as the horizontal distances between the COM and the toe at in the last frame in which the toe was on the ground before the flight and the first frame in which the toe was on the ground after the flight, respectively. The flight distance was expressed as a function of takeoff velocities and height, and landing height as a projectile movement. Takeoff and landing height of each phase were defined as the vertical coordinates of COM relative to the ground in the last frame in which the takeoff foot was on the ground before the flight and the first frame in which the landing foot was on the ground after the flight, respectively. The horizontal takeoff velocity of a given phase was expressed as a function of the horizontal landing velocity of the previous phase and the loss in the horizontal velocity during the given support phase. The vertical takeoff velocity of a given phase was expressed as a function of the vertical landing velocity of the previous phase and the gain in the vertical velocity during the given support phase. The loss in the horizontal velocity during a given support phase was expressed as a function of the gain in the vertical velocity and the velocity conversion coefficient [3, 4]. The takeoff and landing horizontal and vertical velocities of the last step of approach run were estimated from smoothed coordinates of COM.

In the simulation, the takeoff and landing heights and distances of the hop, step, and jump phases, landing velocities of the last step of the approach run, and velocity conversion coefficient were input parameters of the model for each subject. The gains of the vertical velocity during the support phases of the hop, step, and jump were optimized variables. The loss in the horizontal velocity during each support phase was estimated from the gain in the vertical velocity and velocity conversion coefficient as described in previous studies [3, 4]. The lower boundary of the gain in the vertical velocity during each support phase was also set as described in previous studies [3, 4]. The upper boundaries of the gain in vertical velocity and the vertical takeoff velocity for each subject were set to as the observed maximums of the corresponding variables of the given subject. The increment of the gain in vertical velocity in each support phase was 0.2 m/sec, while the velocity conversion coefficient was altered from 0.35 to 1.30 [4] with a step length of 0.05.

The simulated longest actual distance obtained using a given technique with a given velocity conversion coefficient was referred to as the performance of the given technique for the given velocity conversion coefficient. The technique corresponding to the maximum of the performances of the three techniques at a given velocity conversion coefficient was referred to as the local optimum technique, while the other two techniques were referred to as the local sub-optimum techniques. The absolute maximum of the performances of a given technique within the range of observed velocity conversion coefficient was referred to as the ultimate performance of the given technique. The performances of the local optimum and sub-optimum techniques for each given velocity conversion coefficient were obtained in the simulation.

Two-way analyses of variance (ANOVA) with repeated measures were performed to compare the performances among techniques across the entire range of the velocity conversion coefficient. The dependent variable of each analysis was performance while the independent variables were technique and velocity conversion coefficient, respectively. Pre-determined post-hoc paired t-tests were performed to locate the differences when a main effect was detected. A Type I error rate of 0.05 was used as an indication of statistical significance.
RESULTS
Phase ratio and velocity conversion coefficient significantly affect the performance when the velocity conversion coefficient was between 0.35 and 0.55 (p = 0.007, p = 0.001). On average the performance of the hop-dominant technique was 0.26 m and 0.47 m, respectively, longer than those of the balanced and jump-dominant techniques (Figure 1). The performance of each technique increased as the velocity conversion coefficient decreased (Figure 1).

Phase ratio and velocity conversion coefficient had no significant effects on performance when the velocity conversion coefficient was between 0.60 and 0.75 (p = 0.935, p = 0.524) (Figure 1).

Phase ratio and velocity conversion coefficient also significantly affect the performance when the velocity conversion coefficient between 0.80 and 1.30 (p = 0.001, p = 0.002). On average, the performance of the jump-dominant technique was 0.78 m and 0.49 m, respectively, longer than those of the hop-dominant and balanced techniques (Figure 1). The performance of each technique increased as the velocity conversion coefficient increased (Figure 1).

DISCUSSION
Optimum triple jump techniques in terms of phase ratio exist when the velocity conversion coefficient is between 0.35 and 0.55, and between 0.80 and 1.30. Using a sub-optimum technique resulted in significantly lose in the performance of the triple jump. Using a jump-dominant technique resulted in the largest lose in performance when the hop-dominant technique is the optimum. Using a hop-dominant technique resulted in the largest lose in performance when the jump-dominant technique is the optimum. Considering that the performance of each technique for a given velocity conversion coefficient was defined as the longest actual distance obtained using the given technique, the observed differences in performance between the optimum technique and a sub-optimum technique should be considered as the minimal lose in the performance due to using the sub-optimum technique. Previous review [1] and our recent review of literature failed to find any other technical factors that affect the performance of the triple jump in such a magnitude. These results, therefore, suggest that the optimum technique in terms of the optimum phase ratio is critical for the performance in the triple jump, and support the view that identifying optimum effort distribution for a given athlete is the central factor in triple jump techniques as described in the literature [1].

The results of this study also demonstrated that the performances of the optimum techniques were functions of velocity conversion coefficient. The performance of the hop-dominant technique increased as the velocity conversion coefficient decreased while the performance of the jump dominant technique increased as the velocity conversion coefficient increased. The hop-dominant technique had its ultimate performance when the velocity conversion coefficient reached the observed minimum (0.35) while the jump-dominant technique had its ultimate performance when the velocity conversion coefficient reached the observed maximum (1.30). The performances of the all three techniques were shortest when the velocity conversion coefficient was between 0.60 and 0.75. These results suggest that triple jumpers should maximize or minimize their velocity conversion coefficients to maximize their performances.

The results of this study do not support the balanced technique as an optimum technique for the triple jump. The results of this study demonstrated that although some subjects could obtain the maximum performance using the balanced technique when the velocity conversion coefficient was between 0.60 and 0.75, the differences in the performance between the balanced technique and other two techniques are not significant. In addition, performances of the triple jump were shortest when the velocity conversion coefficient was between 0.60 and 0.75. These results combined together suggest that balanced technique is not an optimum technique for the triple jump.

The velocity conversion coefficient apparently is a biomechanical factor that has the primary influence on the optimum phase ratio. This velocity conversion coefficient reflects that efficiency of gaining vertical velocity in terms of the loss in horizontal velocity during each phase of the triple jump [4]. The important effects of this coefficient on the optimum phase ratio have been discussed in details in previous studies [3, 4]. Future studies are needed to determine and understand the factors that affect this coefficient, which will provide significant information for selecting and training elite triple jumpers.

![Figure 1. Performance of the triple jump as functions of technique and velocity conversion coefficient.](image)

REFERENCES