# HORIZONTAL-TO-VERTICAL VELOCITY CONVERSION IN THE TRIPLE JUMP

Bing Yu
Division of Physical Therapy, University of North Carolina at Chapel Hill, Chapel Hill, North Carolina, USA

## INTRODUCTION

Triple jump is one of the four jumping events in track and field. A triple jump consists of an approach run followed by a hop that is a takeoff from one foot and a landing on the same foot, a step that is a takeoff from one foot and a landing on the other foot, and a jump that is a takeoff from one foot and a landing on both feet in the sand pit. During each support phase of the triple jump, athletes gain vertical velocity for the takeoff following the support phase. Simultaneously, they inevitably lose horizontal velocity. To have the longest jumping distance, the loss in the horizontal velocity during each support phase has to be minimized while gaining vertical velocity (Hay and Miller, 1985) because losing horizontal velocity tends to shorten the actual distance.

In a recent study on triple jump techniques (Yu and Hay, 1996), it was found that the loss in the horizontal velocity can be expressed as a linear function of the gain in the vertical velocity during each support phase of the triple jump for each individual athlete. The slope of this linear function, A,, was referred to as the horizontal-to-vertical velocity conversion coefficient. This relationship between the loss in the horizontal velocity and gain in the vertical velocity suggests that the gain in the vertical velocity occurs at the expense of the horizontal velocity during each support phase of the triple jump. This means that there is a conversion of the horizontal velocity to the vertical velocity during each support phase of the triple jump. Further, this relationship suggests the loss in the horizontal velocity per unit gain in the horizontal velocity is not a constant and is a function of the gain in the vertical velocity and the horizontal-to-verticalvelocity conversion coefficient. This means that, in terms of the loss in the horizontal velocity, the efficiency of the gain in the vertical velocity may be affected by the gain in the vertical velocity and the horizontal-to-vertical velocity factor. An understanding of these effects appears to be essential for the understanding of the effect of phase ratio on the actual distance and will provide the basis for the further biomechanical studies on optimum techniques of the triple jump. The purpose of this study was to examine the effects of the gain in the vertical velocity and the horizontal-to-vertical velocity conversion coefficient on the horizontal-to-vertical velocity conversion during each support phase of the triple jump.

## METHODS

A total of ten elite triple jumpers (six males and four females) were used as the subjects. These subjects included four of the finalists of the men's triple jump competition in the 1992 U.S. Olympic Trials, two of the finalists of the men's triple jump competition in the 1995 U.S. Track and Field National Championships, two of the finalists of the women's triple jump competitions in the 1990 U.S. Track and Field National Championships, and two of the finalists of the women's triple jump competitions in the 1995 U.S. Track and Field National Championships. Each subject had at least four legal or foul trials in which they completed the full sequence of the jump (that is, they did not abort the jump part way through) and were videotaped in their entirety.

A Direct Linear Transformation procedure with panning cameras (Yu et al., 1993) was used to collect three-dimensional (3-D) coordinates of 21 body landmarks. Two S-VHS video cameras were used to record the control object and the performances of the subjects at a frequency of 60 Hz. The total control volume covered the space in which the last two strides of the approach run, the hop, the step, and the jump occurred. A global reference frame was defined so that the x axis was parallel to the runway pointing in the jumping direction; the y axis was perpendicular to the x axis pointing to the left side of the runway; and the z axis was perpendicular to the surface of the runway and pointing upward.

The videotape records of the control object and each of the selected trials were digitized with the aid of a S-VHS videocassette recorder, a 14 inch color monitor, a micro-computer, and Peak2D computer software (Peak Performance Technologies, Denver, CO). Control volume calibrations, mathematical time-synchronization of the digitized two-dimensional (2-D) data from the two cameras, and the transformation from digitized 2-D data to real life 3-D coordinate data were all conducted using a set of customized computer programs.

The real-life 3-D coordinate data of 21 body landmarks were filtered using a forth-order Butterworth digital filter (Winter et al., 1974) at a estimated optimum cutoff frequency of 7.4 Hz (Yu and Hay, 1995). The 3-D coordinates of the center of mass of the whole body (G) were calculated using the basic segmental procedure described by Hay (1993) and the segment inertial data of Clauser et al. (1969). The horizontal and vertical velocities at the touchdown and takeoff of each support phase ($v_{x(td),i}$, $v_{z(td),i}$, $v_{x(to),i}$, $v_{z(to),i}$) were determined from the locations of G (Yu and Hay, 1996). The change in each of the horizontal and vertical components of the velocity of G during a given support phase was determined as the difference between the component at the takeoff and the corresponding component at the touchdown of the support phase.

A multiple regression analysis with dummy variables was conducted to determine the relationship between Avx and Avz during the three support phases for each subject. A multiple regression analysis with dummy variables is a statistical procedure used to develop and compare different regression equations using a single multiple regression model. The dummy variables in this kind of regression analysis are used to distinguish different regression equations. The regression model suggested by the results of a previous study (Yu and Hay, 1996) was used as the full model

$$\Delta v_{x,i} = A_0 + B_0 P_i + A_1 \Delta v_{z,i} + B_1 P_i \Delta v_{z,i}$$

A forward elimination procedure was used to determine the optimum regression equation and the magnitudes of A, , B, , A,, and $B_1$ for each subject. The 0.05 level of confidence was chosen to indicate statistical significance of each regression coefficient and the overall regression.

The horizontal-to-vertical velocity conversion rate for support phase **i** was designated as $\lambda_i$ and defined as the ratio of absolute value of $\Delta v_{x,i}$ to $\Delta v_{z,i}$, that is:

$$\lambda i = \frac{\left|\Delta v_{x,i}\right|}{\Delta v_{z,i}} = \frac{\left|A_0 = B_0 P_i + A_1 \Delta v_{z,i} + B_1 P_i \Delta v_{z,i}\right|}{\Delta v_{z,i}}$$

(**i** = 1, 2, 3)

**RESULTS**

A linear relationship between the loss in the horizontal velocity of G and the gain in the vertical velocity of G during support phases was obtained for each subject. The best regression equation for this relationship for each subject was exclusively of the form $\Delta v_{x,i} = A_0 + B_0 P_i + A_1 \Delta v_{z,i}$
The correlation coefficients for overall regressions ranged from 0.71 to 0.95 with p-values less than 0.013.

The regression coefficients A, and $B_0$ were functions of A, . Their relationships can be expressed as

$$A_0 = -0.946 - 2.976A_1$$

$$B_0 = 0.296 + 1.167A^2_1$$

No evidence suggested that these relationships were significantly different between male and female athletes.

The horizontal-to-vertical velocity conversion rate was simplified as a function of A, and $\Delta v_{z,i}$

$$\lambda i = \frac{-0.946 - 2.976A_1 + (0.296 + 1.167A_1^2)P_i + A_1\Delta v_{z,i}}{\Delta v_{z,i}}$$

$$(i = 1, 2, 3;\ P_1 = 0,\ P_2 = P_3 = 1)$$

The horizontal-to-vertical conversion rates for all three support phases were sensitive to A, and $\Delta v_{z,i}$. The sensitivity of the conversion rate to $\Delta v_{z,i}$ increased with the increase in the absolute value of A, (Figure 1).

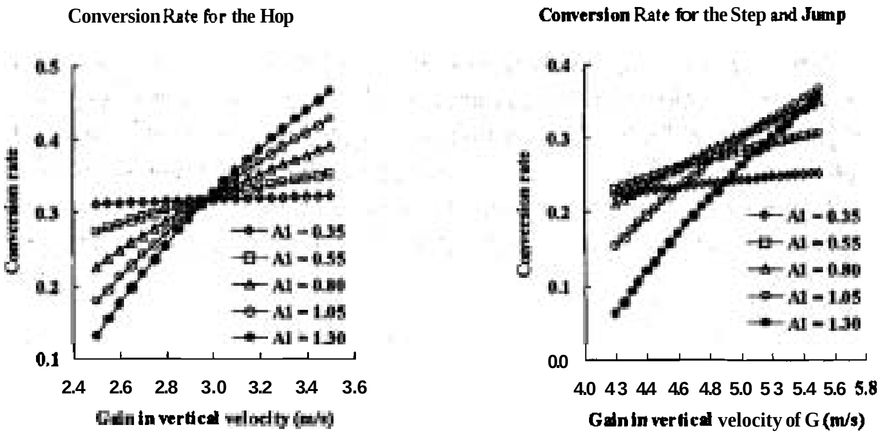


Figure 1. Horizontal-to-vertical velocity conversion rates for the three support phases in the triple jump.

## DISCUSSION

The relationship between $\Delta v_{x,i}$ and $\Delta v_{z,i}$ for each subject in this study was consistent with those previously reported (Yu and Hay, 1996). This relationship between the loss in the horizontal velocity of G and the gain in the vertical velocity of G during each support phase might be a result of the conversion of mechanical energy during the support phase. If this relationship is due to a conversion of kinetic energy from the horizontal to vertical directions, then the magnitude of A, is likely to be a reflection of some physical or technical characteristics of the athlete. One possibility is that the magnitude of A, for a given athlete is a function of the maximum contraction speed of his muscles or the maximum force which his muscles are capable of generating. Another possibility is that the magnitude of A, is a function of the leg stiffness which is the ratio of force generated by the leg and the compression distance of the leg.

The horizontal-to-vertical conversion rate was sensitive to A,. The results suggest that the greater the absolute value of A, , the lower the conversion rate for a small gain in the vertical velocity but the greater the exchange rate for a large gain in the vertical velocity (Figure 1). These results indicate that an athlete with a high absolute value **of $A_1$** was efficient in maintaining the horizontal velocity while achieving a small gain in the vertical velocity. Also, an athlete with a low absolute value of A, was efficient in maintaining the horizontal velocity while achieving a large gain in the vertical velocity.

The horizontal-to-vertical conversion rate was sensitive also to $\Delta v_{z,i}$ , especially for a high absolute value of A, . The results suggest that, with a given absolute value of A, , the greater is the gain in the vertical velocity of G, the greater is the conversion rate. These results indicate that the greater is the gain the vertical velocity, the greater is the loss in the horizontal velocity per unit gain in the vertical velocity. The horizontal-to-vertical conversion rate was virtually independent of $\Delta v_{z,i}$ for a low absolute value **of $A_1$** .

The effect of A, on the horizontal-to-vertical velocity conversion rate is the basis before determining the optimum phase ratio for a given athlete (Yu and Hay, 1996). For an athlete with a low absolute value of A, , a long hop distance benefits the actual distance, and a hop-dominated technique is optimum. For an athlete with a high absolute value of A,, a short hop distance benefits the actual distance, and a jump-dominated technique is optimum.

The magnitude of A, may also be a parameter for identifying elite long and triple jumpers. An athlete with low magnitude of A, may be a potential elite long jumper while an athlete with high magnitude of A, may be a potential elite triple jumper.

## REFERENCES

Clauser, C. E., McConville, J.T., and Young, J. W. (1969). Weight, volume and center of mass of segments of the human body. pp. 46-55, 59. AMRL Technical Report 69-70, Wright-patterson Air Force Base, OH.

Hay. J. G. (1993). The Biomechanics of Sports Techniaues. 3rd Ed. Englewood Cliffs, NJ: Prentice-Hill.

Hay, J. G. and Miller J. A. (1985). Techniques used in triple jump. International Journal of Sport Biomechanics, 1,185-196.

Winter, D. A., Sidwall, H. G., and Hobson, D. A. (1974). Measurement and reduction of noise in kinematics of locomotion. Journal of Biomechanics, 7: 157-159.

Yu, B. and Hay, J.G. (1995). Angular momentum and performance in the triple jump: a cross-sectional analysis. Journal of Applied Biomechanics, 11, 81-102.

Yu, B. and Hay, J.G. (1996). Optimum phase ratio in the triple jump. Journal of Biomechanics. 29(10): 1283-1289.

Yu, B., Koh, T. J., and Hay, J. G. (1993). A panning DLT procedure for three-dimensional videography. Journal of Biomechanics. 26,741-751.

## FIGURE CAPTIONS

1. The horizontal-to-vertical velocity conversion coefficient A1 is defined as tan(b). The horizontal-to-vertical velocity conversion rate 1 for a given gain in the vertical velocity is defined as 1/tan(a).

2. The relationships between the loss in the horizontal velocity of G and the gain in the vertical velocity of G during three support phases for a selected subject.

3. The relationships between regression coefficients.

4. The effects of the horizontal-to-vertical velocity conversion coefficient A1 and the gain in the vertical velocity of G on the horizontal-to-vertical velocity conversion rate during three support phases.

Table 1. Regression coefficients (A1 , A0 , and BO) for the linear relationships between the loss in the horizontal velocity and the gain in the vertical velocity, correlation coefficients (r) for overall regressions, and p-values of overall regression.

| Gender | Subject | A1 | A0 | BO | r | P |
|---|---|---|---|---|---|---|
| Male | A | 1.299 | -2.959 | -2.263 | 0.815 | 0.001 |
| | B | 0.946 | -1.876 | -1.180 | 0.885 | 0.000 |
| | C | 0.924 | -1.666 | -1.453 | 0.896 | 0.000 |
| | D | 0.408 | -0.180 | -0.614 | 0.710 | 0.008 |
| | E | 0.366 | -0.157 | -0.348 | 0.952 | 0.000 |
| | G | 0.837 | -1.619 | -1.053 | 0.941 | 0.000 |
| Female | F | 0.592 | -1.068 | -0.618 | 0.763 | 0.013 |
| | H | 0.422 | -0.525 | -0.410 | 0.827 | 0.000 |
| | I | 0.602 | -0.875 | -0.811 | 0.740 | 0.003 |
| | J | 0.579 | -0.585 | -0.894 | 0.723 | 0.012 |