ANALYSIS OF THE TRANSFORMATION OF THE VELOCITY OF THE CENTER OF GRAVITY IN RUNNING SINGLE LEG HORIZONTAL JUMP

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The purpose of this study was to analyze the transformation of the center of gravity (CG) in the running single leg horizontal jump and to investigate the influence of the forward rotation of the takeoff leg in achieving vertical CG velocity. The subjects were 98 male long jumpers, whose mean best official jump among their recorded trials was 7.16 ± 0.66 m. Their takeoff motion was videotaped with two high-speed cameras. Horizontal CG velocity at touchdown and vertical CG velocity at toe-off had significantly positive correlations with jumping distance; the decrease in horizontal CG velocity during the takeoff phase was significantly and negatively correlated with jumping distance. Forward rotation of the spring-mass model did not contribute to an increase in vertical CG velocity, although it did contribute to an increase in horizontal CG velocity just before toe-off.

KEY WORDS: running jump, CG velocity, spring-mass model

INTRODUCTION: In the running single leg horizontal jump as the long jump, the velocity of the center of gravity (CG) is the most important determinant of jumping distance. Many investigations have suggested a significant relationship between approach speed and jumping distance (Hay, 1986; Lees et al., 1994), but in these studies, vertical CG velocity at takeoff was not significantly correlated with jumping distance (Hay et al., 1986). Moreover, the strength of the relationship between approach velocity and jump distance decreased at higher performance levels (cited in Hay, 1986), which may imply that takeoff technique becomes more important than approach velocity at higher levels of performance (Muraki et al., 2008). The most important factor in the takeoff phase is to maintain horizontal CG velocity and transform it into vertical velocity with minimum loss (Hay, 1986). Three technical factors increase the vertical velocity of the CG during the takeoff phase: a pivoting of the body over the takeoff foot (in which the takeoff leg rotates forward as the foot makes contact with the ground), a swinging of the free limbs, and an extension of the body, particularly the takeoff leg (Ae, 1989). In pivoting of the body over the takeoff foot, the takeoff leg rotates forward in the contact point of the foot, and that contributed to obtain vertical CG velocity in the first phase of the takeoff phase. Few studies have focused on the transformation of CG velocity among individuals with a variety of jumping distances and approach speed (Hay, 1986; Phillips & Lees, 2005). The purpose of this study was to analyze the transformation of the velocity of the center of gravity in the running single leg jump and to investigate the influence of the forward rotation of the spring-mass model in achieving vertical CG velocity.

METHODS: The subjects in this study were 98 male long jumpers (body height, 1.73 ± 0.07 m; official best jump among the recorded trials, 7.16 ± 0.66 m) who participated in competitions held in Japan. Their takeoff motions were videotaped with two high-speed VTR cameras: either HSV-500C3 (250Hz, NAC Co., Japan), EXILIM EX-F1 (300Hz, CASIO Co., Japan), or LUMIX DMC FZ-300 (240Hz, Panasonic Co., Japan). The trial in which each jumper obtained his maximum official jumping distance was digitized using a Frame Dias IV system (DKH Co., Japan). Three-dimensional coordinates of 23 markers defining a 14-segment model were reconstructed by using a direct linear transformation (DLT) technique. The data for the coordinates were smoothed with a Butterworth low-pass digital filter with optimal cutoff frequencies, determined by means of the residual error method proposed by Wells and Winter (1980). The calculated kinematic parameters were the velocity and acceleration of the CG and the spring-mass model in a sagittal plane. The spring-mass model was a model connecting the CG and the foot of the takeoff leg contact point (Jacobs & Schenau, 1990), and the angle between this model and the horizontal direction was defined as the model angle. After that, the CG acceleration was analyzed into tangential and centripetal direction components using the model angle, and the tangential and centripetal components of CG acceleration were reanalyzed into horizontal and vertical direction components, respectively. The kinematic parameters were normalized as 100% takeoff phase time. Statistical analysis was conducted using SPSS (IBM SPSS Statistics Version 22, SPSS, Chicago, IL). Pearson's correlation coefficient was used to determine the relationship between the jumping distance and the kinematic parameters during the takeoff phase; the significance level was set at $p < 0.01$.

RESULTS: The mean jumping distance was 7.16 ± 0.66 m (range: 8.57 m–6.00 m). The mean horizontal CG velocity at the instant of touchdown (TD) was 9.54 ± 0.54 m/s (range: 10.82–8.48 m/s), and this variable had a significant correlation with jumping distance (r = 0.93, $p < 0.01$). The mean vertical CG velocity at the instant of toe-off (TO) was 3.20 ± 0.31 m/s (range: 3.85–2.57 m/s), and this variable was also significantly correlated with jumping distance (r = 0.77, $p < 0.01$). The changes in CG velocity during the takeoff phase were−1.42 ± 0.48m/s (horizontal velocity: ⊿HCGV) and 3.39 ± 0.37 m/s (vertical velocity: ⊿VGGV), and there were significant correlations between both variables and jumping distance (⊿HCGV: r = −0.42, $p < 0.01$; ⊿VCGV: r = 0.57, $p < 0.01$).
Figure 1 shows the changes in model angle and model angular velocity. The spring-mass model showed a forward rotation during the takeoff phase. The model of angular velocity indicated a faster rotation during the first half of the takeoff phase, and there were significant positive correlations between jumping distance and angular velocity from 0% (TD) to 68% during the takeoff phase (r = 0.29–0.54, $p < 0.01$).

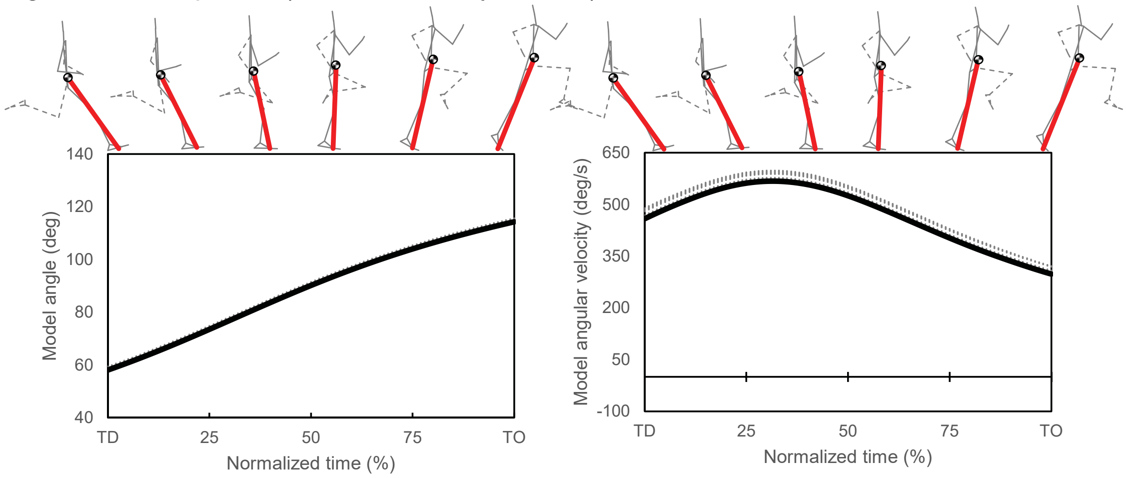

Figure 1: Change in model angle (left) and model angular velocity (right) during the takeoff phase.

Figure 2 shows the changes in CG velocity in the horizontal direction, along with horizontal CG acceleration (black solid line) and the centripetal (blue dashed line) and tangential (red dashed line) components of horizontal CG acceleration. Figure 3 shows the changes in the CG velocity in the vertical direction, as well as the vertical CG acceleration (black solid line) and the centripetal (blue dashed line) and tangential (red dashed line) components of vertical CG acceleration. The horizontal CG acceleration was negative from 0% (TD) to 75% during the takeoff phase and then positive from 76% to 100% (TO). The centripetal component of horizontal CG acceleration had positive values from 50% to 90%, and the values from 61% to 75% were significantly and positively correlated with jumping distance (r = 0.24–0.28, $p <$ 0.01). The tangential component of horizontal CG acceleration had positive values from 82% to 100% (TO). The vertical CG acceleration had positive values from 0% (TD) to 88% and became negative from 89% to 100% (TO). The tangential component of vertical CG acceleration was smaller than the centripetal component, and it had positive values from 50% to 81%.

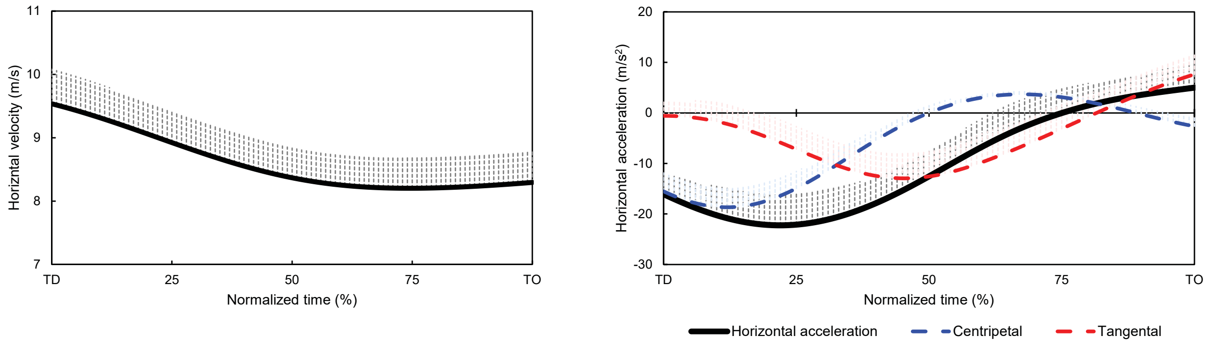

Figure 2: Change in horizontal CG velocity and CG acceleration during the takeoff phase.

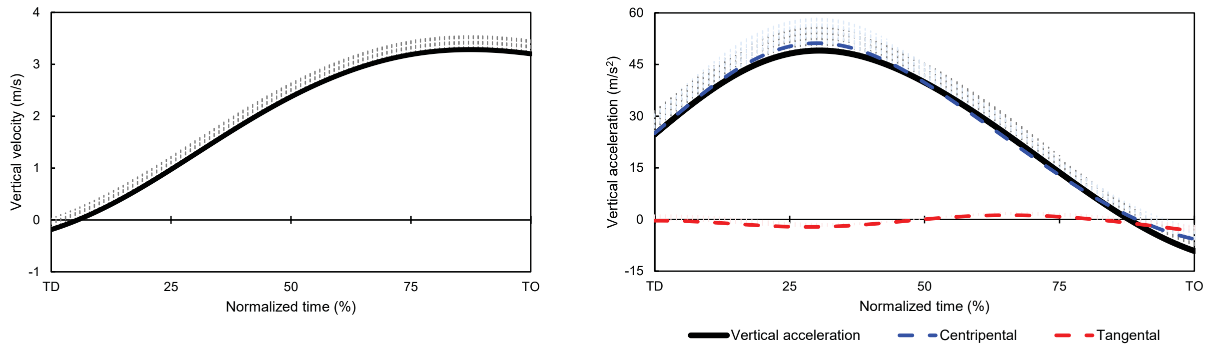

Figure 3: Change in vertical CG velocity and CG acceleration during the takeoff phase.

DISCUSSION: In the takeoff phase, transforming horizontal CG velocity into vertical CG velocity with minimum loss of horizontal CG velocity was important to maximize jumping distance. Horizontal CG velocity at the instant of TD and vertical CG velocity at the instant of TO were greater in the subjects with the longest jumps. Although the loss of horizontal CG velocity was significantly and negatively correlated with jumping distance, the loss of horizontal CG velocity during the takeoff phase was greater in the subject with the greater horizontal CG velocity at TD. Therefore the loss of horizontal CG velocity was a contributing factor toward obtaining vertical CG velocity and greater jumping distance.
The centripetal component of horizontal acceleration during the first half of the takeoff phase was negative, this suggest that the large decrease in horizontal CG velocity during the early part of the takeoff phase was caused by the centripetal component of CG acceleration. The tangential component of horizontal acceleration just before TO was positive, indicating that forward rotation of the model contributed to the increase in horizontal CG velocity just before TO.
The tangential component of vertical CG acceleration was smaller during the takeoff phase than the centripetal component; this finding suggests that vertical CG velocity during the takeoff phase was obtained by means of the centripetal component of CG acceleration. Moreover, the tangential component of CG acceleration was negative during the first phase of the takeoff phase, this suggests the possibility that the forward rotation of the model during the first phase of the takeoff phase did not contribute to the increase in vertical CG velocity.

CONCLUSION: Horizontal CG velocity at the instant of TD and vertical CG velocity at the instant of TO had a significant positive correlation. The jumpers who obtained the longest jumping distance obtained greater horizontal CG velocity during the approach phase and transferred their horizontal CG velocity into vertical CG velocity with the great loss of horizontal CG velocity. The spring-mass model rotated forward during the takeoff phase, and the tangential component of CG acceleration did not contribute to the increase in vertical CG velocity, although the model rotation just before TO did contribute to the increase in horizontal CG velocity.

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