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ORIGNAL ARTICLE

Two dimensional analysis of changes in athlete's center of mass during the long jump flight phase

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Abstract

The purpose of the study was to identify the most efficient technique that helps the Sri Lankan long jumpers to maintain their center of mass with the projectile trajectory. Twelve (n =12) male long jump athletes participated in this study and they were divided into three groups based on the flight technique they use. The performances were recorded in the sagittal plane using four (04) cameras with a sampling frequency of 50Hz. The coordinates of athletes' center of mass were identified for each time frame using the Kinovea (0.9.3 version), and displacement of the center of mass was predicted using kinematic variables. The residuals (predicted - actual displacement) were taken for the statistical analysis. The one-way ANOVA was performed to determine whether the mean residuals of the three techniques are statistically different or not. According to the results, the mean residual of horizontal and vertical displacement of the three techniques was significantly different ($p < 0.05$). The Turkey method ensured that hitch-kick had lesser the mean residual of vertical displacement and it was significantly different from the other two techniques, and no significant differences were observed between hitch-sail and hang. The mean residuals of horizontal displacement of three techniques were significantly different, hitch-kick had lesser mean residual than hitch-sail, and hitch-sail had lesser mean residual than hang technique. Finally, this study revealed that hitch-kick is the most efficient technique that helps the Sri Lankan athletes to maintain their center of mass in projectile trajectory..

1. Introduction

The long jump is a field event where the athletes combine their ability of speed, strength, power and balance to achieve the horizontal displacement in track & field athletics. It can be divided into four phases for the biomechanical analysis purposes. They are approach run phase, take-off phase, flight phase, and landing phase [1]. The main focus of this study on flight phase and on flight techniques. The common flight technique used by athletes are hang, sail, and hitch-kick, where athletes use different bodily movement to control the forward rotation that resulted immediately after the take-off phase. The flight techniques are categorized based on the technical characteristics. It was able to find that Sri Lankan athletes use combination of hitch-kick and sail techniques, therefore it is named as hitch-sail technique.

Previous studies have stated that flight distance cannot be increased by circling action of arms and legs in the air due to conservation of angular momentum [2]. Total angular momentum is remained constant when no external torque acts on an object, it is conservation of angular momentum. But here athletes need to work against wind or with the wind, therefore

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angular momentum will not be conserved and it will cause the path of the center of mass of an athlete. Therefore, how the center of mass of athlete is changed while performing these three techniques and which techniques have efficiency to maintain the center of mass in a parabolic trajectory path, was the identified problem. To solve this problem, two dimensional biomechanical analyses was performed and actual path of center of mass was compared with mathematical model of parabolic projectile motion of an object with zero aerodynamic factor.

2. Method

Twelve (n =12) male long jump athletes participated in this study and they were divided into three groups based on their flight technique (2½ hitch-kick group, n = 4; hitch-sail group, n = 4; and hang group, n = 4). There was a detailed discussion between participants, coaches, and researcher, to explain the procedure of the test, objective of this study, and benefits of this test. Anthropometric measurements (height & weight) of all athletes were taken before the test begun. All athletes were allowed to warm-up with their own way. Then they were asked to perform three full jumps after their lateral joints were marked with reflective markers. The best jump from three trials was taken for the data analysis.

Four (04) video cameras (3-Nikon D7200 & 1-D5600, lens: 18m – 55m, focus: 3.5f – 5.6f, and speed - 50Hz) were used to record the performance from the take-off to touch-down. First two cameras were placed right & left side, 10m away from the midpoint of take-off board and perpendicular to the sagittal plane, and other two cameras were placed 10m away from the line of movement and parallel to the pit. Height of both camera was 1.2m. There was 6m distance from two cameras (figure 1) [4]. A 1.5m pole was used for calibration and two (02) Godox TT650 speed lights and Godox X1R-N TTL wireless flash trigger were used to synchronize the cameras.

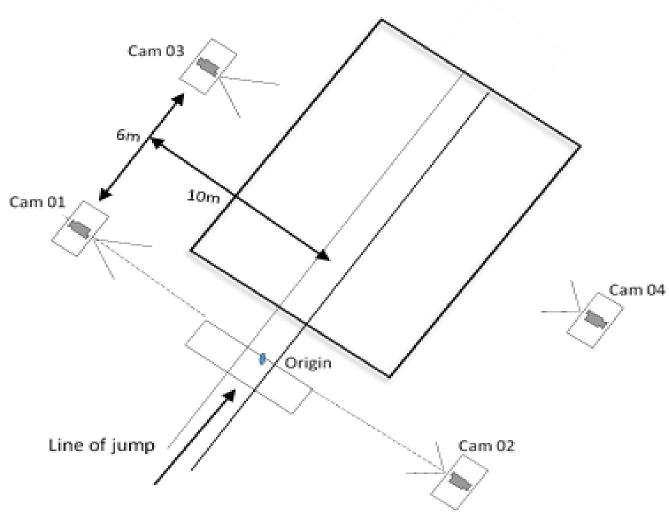

Figure 1: Experimental Set up

To track athlete's centre of mass, two dimensional analysis was performed using the Kinovea 0.9.3 movement analysing software, and and coordinates of the fourteen (14) joints of human body were tracked manually from take-off to touch-down. Using the coordinates of joints and Dempster's segmental parameter, segment centre of mass was calculated using equation (1 & 2) [3]:

$$x_{cm} = x_{proximal} + R_{proximal}(x_{distal} - x_{proximal}) \quad (1)$$

$$y_{cm} = y_{proximal} + R_{proximal}(y_{distal} - y_{proximal}) \quad (2)$$

Where, x_{cm} & y_{cm} are segment center of mass position in horizontal direction & vertical direction respectively. ($x_{proximal}, y_{proximal}$) & ($x_{distal}, y_{distal}$) are the coordinates of the proximal and distal end of segment, and $R_{proximal}$ is the percentage value used to calculate the distance of segment's center of mass from the proximal end. Equation (3) was used to find $R_{proximal}$.

$$r_{proximal} = R_{proximal} \times l \quad (3)$$

Where, $r_{proximal}$ is the distance of segment's center of mass from proximal end, and l is the length of segment. Finally, the total body's center of mass position was calculated using equation (4 & 5).

$$X_{CM} = \frac{\sum_{i=1}^{k} m_i \times x_{cm}}{M} \quad (4)$$

$$Y_{CM} = \frac{\sum_{i=1}^{k} m_i \times y_{cm}}{M} \quad (5)$$

Where, X_{CM}, Y_{CM} m_i, x_{cm}, y_{cm}, M, & k are total center of mass location of body in horizontal (X) direction, Vertical (Y) direction, segment mass, segment's center of mass in horizontal & vertical direction, total body mass, and number of segments respectively. The m_i can be calculated using Dempster's body segment parameters [3].

$m_i = p_s \times M$; p_s- Dempster's percentage value of segment mass to the total body mass.

Then athlete's trajectory path was predicted, using kinematic variables. Equation 6 was used to predict the horizontal displacement, and equation 7 was used to predict vertical displacement.

$$X = D_{TO} + U_x \times t \quad (6)$$

$$Y = H_{TO} + (V_y \times t) + (\tfrac{1}{2} \times a \times t^2) \quad (7)$$

Where, X & Y, D_{TO}, H_{TO}, U_x, V_y , a, & t are horizontal & vertical position of COM, take-off distance, take-off height, horizontal velocity, vertical velocity, acceleration, & time respectively.

Residual values were calculated by subtracting actual values from predicted values for each time frames. Then it was taken for the data analysis. To determine the effective technique, it was hypothesized that lower residual value would contribute to maintain the path of center of mass with projectile trajectory.

3. Results

Initially, each groups were analyzed to determine the significant differences within the samples. In hitch-kick group analysis, no significant difference was found in residuals of horizontal (P= .475 > .05) and vertical displacement (P= .984 > .05) within the samples. A significant difference was found between the samples in the residual of horizontal displacement in hitch-sail technique (P= .000) at .05 level of significant, and no significant difference was found in the residual of vertical displacement (P= .996). In hang group, no significant differences were found between the residuals of horizontal displacement as well as in vertical displacement (P= .233 > .05 & P= .390 > .05) within the samples.

The one-way ANOVA was performed at .05 level of significance, to test whether the mean residuals of each technique were significantly different or not, and the Tukey pairwise comparison was performed to identify the significant technique from them. The lowest mean residual was considered as the best technique, as residual gets lower COM will be close to the projectile trajectory. Table 1 shows the One Way ANOVA results of technique comparison. The significant differences were found between the mean residuals of three techniques in horizontal and vertical displacements (P = .000 < .05). The Tukey pairwise comparison showed that hitch-kick had lesser mean residual than hitch-sail, and hitch-sail had lesser mean residual than hang group in horizontal displacement. For vertical residual, hitch-kick had lesser mean residual and was significantly difference than other two techniques, and no significant difference was found between hang and hitch-sail group.

Table 1: One-way ANOVA results

	Factor	Mean	SE mean	SD	p-value	Grouping
Horizontal	Hitch-kick	0.044	0.002	0.024	000	C
	Hitch-Sail	0.058	0.003	0.038		B
	Hang	0.093	0.003	0.047		A
Vertical	Hitch-kick	0.120	0.006	0.082	000	B
	Hitch-Sail	0.190	0.012	0.159		A
	Hang	0.211	0.006	0.089		A

Normality test was performed to validate the results. The test results showed that residuals of horizontal displacement of hitch-kick & hitch-sail were not normally distributed as p – value less than .05 level of significant, but the residual values of hang technique were normally distributed (figure 2, 3, & 4).

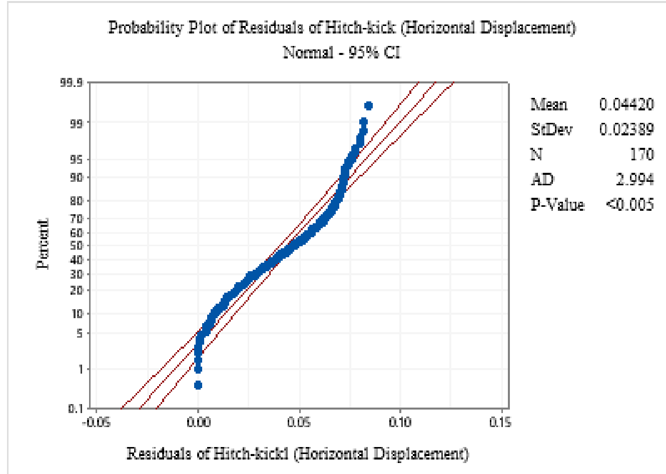

Figure 2: Probably Plot of Residuals of Hitch-Kick (Horizontal Displacement)

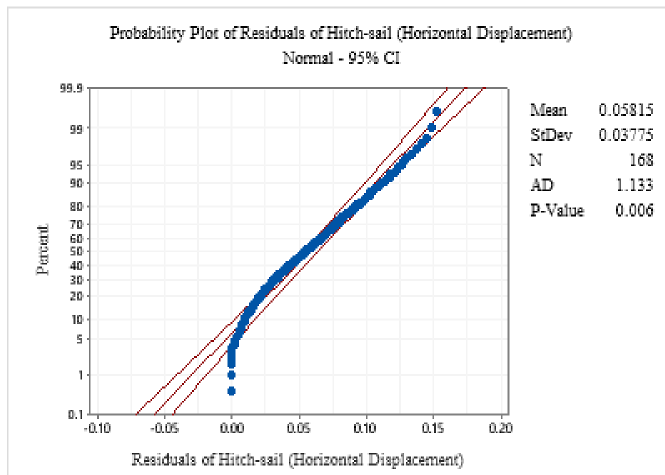

Figure 3: Probably Plot of Residuals of Hitch-sail (Horizontal Displacement)

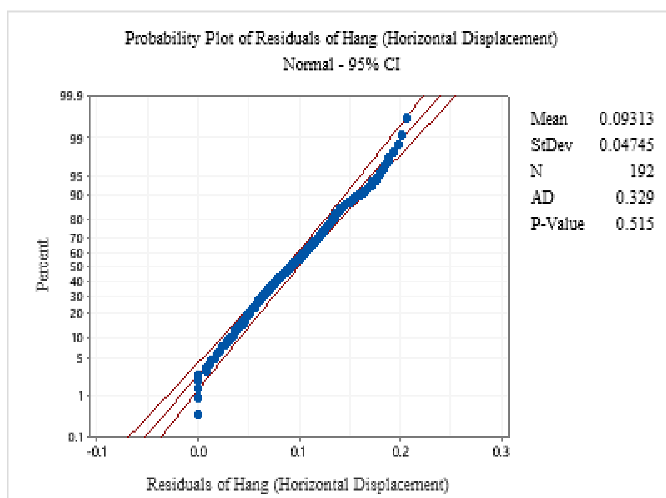

Figure 4: Probably Plot of Residuals of Hang (Horizontal Displacement)

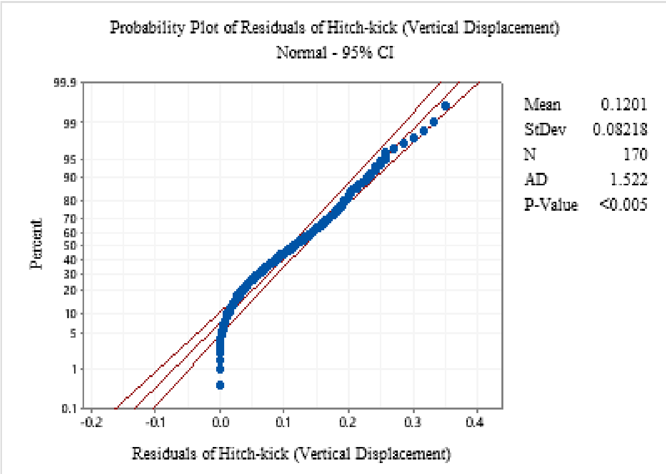

Figure 5: Probably Plot of Residuals of Hitch-kick (Vertical Displacement)

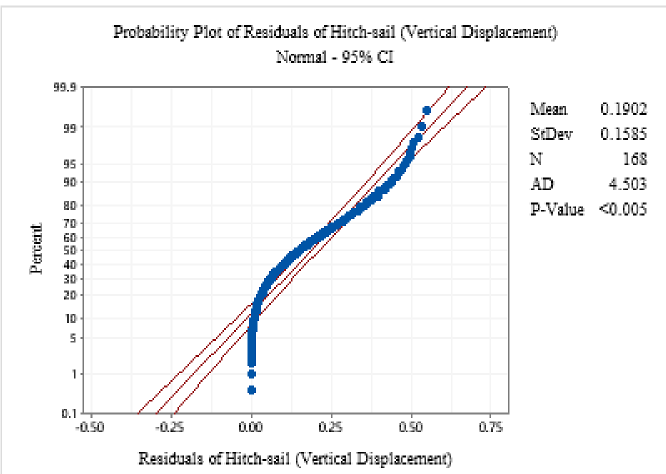

Figure 6: Probably Plot of Residuals of Hitch-sail (Vertical Displacement)

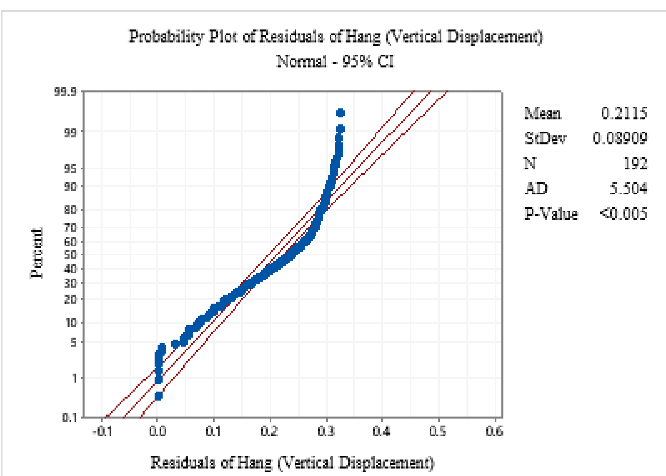

Figure 7: Probably Plot of Residuals of Hang (Vertical Displacement)

The residuals of vertical displacement of all techniques were not normally distributed as p – value less than .05 level of significant (figure 5, 6, & 7).

Table 2: The Kruskal-Wallis test results

	Factors	N	Median	Mean Rank	P-value
Horizontal	Hang	192	0.092	353.6	.000
	Hitch-kick	170	0.048	190.2	
	Hitch-sail	168	0.055	241	
	Overall	530		265.5	
Vertical	Hang	192	0.237	325.3	.000
	Hitch-kick	170	0.117	196	
	Hitch-sail	168	0.154	267.5	
	Overall	530		265.5	

The Kruskal-Wallis test was performed, as residuals were not normally distributed. The test results (Table 2) revealed that there was a significant difference in the residuals of three techniques in both horizontal and vertical displacement (p = .000 < .05).

4. Discussion

The first analysis of hitch-kick technique showed no significant differences between the samples, which clearly explore that there were no differences between residuals of samples of horizontal and vertical displacement (p = .475 & p = .984). In the hitch-sail technique analysis, significant difference was found between the samples of Horizontal displacement residuals (p = .000). It might have happened due to human error during the video interpretation. No significant difference was found between the samples of vertical displacement residuals (p = .996). In hang analysis, no significant differences were found between the samples of residuals of horizontal and vertical displacement (p = .233 & p = .390). As there were no significant differences between the samples within techniques, researcher could be able to compare three technique using one-way ANOVA.
The ANOVA test results support the hypothesis. There were significant differences between mean residuals of horizontal and vertical displacement of three techniques at .05 level of significance (p = .000). It ensured that at least one mean residual of three techniques was significantly different from others. The Tukey pairwise comparison revealed that hitch-kick technique had lesser mean residual of horizontal & vertical displacement than hitch-sail & hang technique. This finding explores that hitch-kick technique is more efficient that helps athlete to maintain their center of mass with the projectile trajectory, than other two techniques. From the Tukey result no differences were found between mean residuals of vertical displacement of hitch-sail and hang technique. But there was a significant difference between mean residuals of horizontal displacement of hitch-sail & hang technique. The hitch-sail

technique had lesser mean residual than hang technique, which illustrate that hitch-sail is better technique that helps to keep center of mass horizontally with projectile trajectory, than hang technique. To validate the test, normally test was performed. All the test results showed that all the residuals of horizontal and vertical displacement of all three techniques were not normally distributed except residual of horizontal displacement of hitch-sail. Therefore, above stated results may be wrong. To further investigate the validity of result, nonparametric test was performed. The Kruskal-Wallis test supported previous findings, that at least one median residual of horizontal and vertical displacement was different from other techniques. From the mean ranking, hitch-kick mean rank of horizontal displacement (190.2) had lesser value than overall mean rank (265.5) compare to other techniques' mean rank (hitch-sail – 241 & hang – 353.6). And in vertical displacement analysis also, hitch-kick mean rank (196) had lesser value than overall mean rank (265.5) other two techniques (hang - 325.3, & hitch-sail - 267.5). So it was able to conclude that hitch-kick technique is most efficient technique that helps Sri Lankan male athletes to keep their center of mass with project trajectory. The technique used during the flight phase changes many of the mechanics throughout the jumping motion. Generally, athletes who use hitch-kick technique, generate higher amount of angular momentum than hang, sail, & hitch-sail techniques, therefore they could control their forward rotation throughout the jump. But in other cases angular momentum direction is changed. The common reasons for this result may be the angular momentum generated during the flight phase & the segment positions that help to overcome the air resistance. Further investigations with more participants may help to clarify the relationship between path of center of mass and flight technique. Kinematic analysis with a higher sampling frequency would produce more accurate results. Movement out of the sagittal plane of analysis may restrict the validity of the results of the present study. Therefore, three-dimensional methods are suggested for greater clarity of the results.

5. Conclusions

In conclusion, Hitch-kick was found as an efficient technique among other two flight technique used by the Sri Lankan long jump athletes. And it's suggested to athletes and coaches to use or teach the hitch-kick technique to achieve better distance, as it has lower loss in horizontal and vertical displacement.

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