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ORIGINAL ARTICLE

Variations in horizontal velocity during three consecutive take-off phases of triple jump

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ABSTRACT

It was observed that athletes gradually lose horizontal velocity during the three consecutive jump phases (hop, step and jump) in triple jump. Though loss is inevitable, this horizontal velocity needed to be carried out during the three-jump sequence(1). Maximum number of literatures has only accounted the loss while foot contact with the ground. There were few studies which has been accounted the loss in the air. Thus, this study focused on the horizontal velocity across three consecutive take-off phases including the two flight phases in between. Six national Indian male triple jumpers (age: 25-28 years) purposively selected for this study. All the movements were captured on outdoor field using three high Speed action cameras at 120 frames per seconds in linear view. The kinematic data were obtained from the recorded videos by utilizing Max track and Silicon Coach pro v0.8 software. According to the nature of the data, descriptive statistics and one way ANOVA test followed by Tukey's HSD test employed. The second take-off phase stood out with a 10.25% maximum loss among the all phases. While horizontal velocity loss is acknowledgeable in triple jump, it might be suggesting a potential area for improvement lies in refining techniques for triple jumpers.

Keywords: Performance analysis, Loss of velocity, Flight phase, High speed camera, Kinematic analysis, Tuckey's HSD test.

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INTRODUCTION

Analysing the straight forward mathematical equation $R = v^2\sin(2\theta)/g$ governing projectile motion, it becomes evident that the determination of horizontal range involves key factors such as projection velocity, take-off angle, and gravitational acceleration (V.K. Mehta & Mehta, 2013). When considering these variables, it becomes apparent that the horizontal range is primarily influenced by the projection velocity of the projectile due to its direct proportionality to the square of its value. This projection velocity can be considered as take-off velocity of the athlete in the jumping events, while the athlete acts as a projectile while in the air. Although both vertical and horizontal velocity components are crucial in jumping events, the major contribution for achieving maximum horizontal range comes from the horizontal velocity component in horizontal jump events (Linthorne, 2006). Based on this concept the present study was primarily focused on understanding the horizontal velocity of an athlete during the three consecutive take-off and two flight phases of the triple jump event.

The three consecutive take-offs of the triple jump consist of three take-off phases and two in between flight phases before the final jump (Hay, 1992). In essence, the entire sequence of the hop phase can be delineated as follows: the athlete initiates the action by taking off from the take-off board on one leg, propels themselves into the air, and lands on the same leg (Hop). Subsequently, the athlete repeats the process by taking off again from the same leg, forcefully drive forward in air landing on the other leg (Step). Finally, the athlete takes off for the last time, complete the jump sequence by landing on the designated landing pit (Hay, 1992). While studies have evaluated horizontal velocity during ground contacts (Fukashiro et al., 1981; Miller & Hay, 1986; Sang-Yeon Woo et al., 2011), there has been little examination of velocity changes especially during flight phases. For example, Sang-Yeon Woo et al. (2011) compared approach velocity to take-off velocity but did not report on velocity fluctuations during the flight phases. Similarly, Campos et al. (2013) quantified ground contact velocity differences but did not detail flight velocity patterns. Panoutsakopoulos & Kollias (n.d.) discussed overall technical models but did not provide athlete velocity profiles during the flight phases after each take-off. Hence, the precise mechanisms and magnitudes of velocity loss both during and after take-off still remain unspecified across the literature.

Several studies (Allen et al., 2013; Eissa, 2014; He et al., 2023; Isik, 2017; H. Liu et al., 2015; Lu & Wang, 2005) showed interest in studying the loss of velocity during the three take-off phases of this event. These studies only examined the velocity of the centre of mass (CM) while the foot contact with the ground. Moreover, the studies addressing the velocity losses were solely the result of differences in velocity between two consecutive ground contact phases. Based on the current knowledge of the researcher, only one study (Tsukuno et al., 2011) has ever accounted for the instantaneous change of velocity during the different phases of take-off . Research into Indian athletes is also lacking, while most of the studies (Allen et al., 2013; Ding, 2003; Eissa, 2014; Fukashiro et al., 1981; Isik, 2017; Lu & Wang, 2005; Tsukuno et al., 2011; Yi, 2006) are established from European and East Asian region.

There are two objectives included in the present study. First we assess the changes occurred in horizontal velocity during three consecutive take-off phases of triple jump, including two flight phases in between. Secondly, we compare the variation of horizontal velocity exists among these take-off phases. It was hypothesised that changes in the horizontal velocity associated with each of the selected phases will be different. Understanding the characteristic of change of velocity may guide training programs to target specific aspects of technique that improves the jump performance of the athlete.

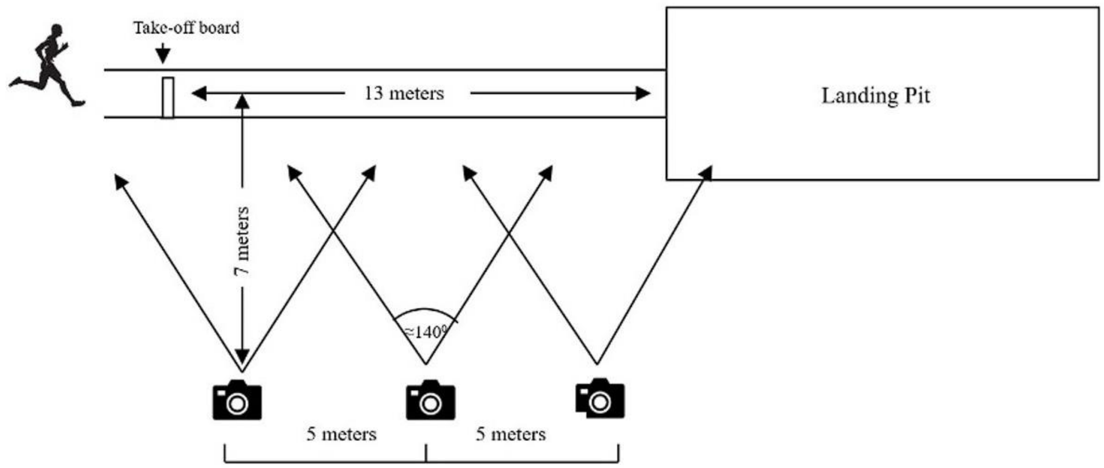

Figure 1. Camera setup for recording the movements.

METHODOLOGY

Participants

The present study comprised six (6) male Indian national-level Triple jumpers (age 25-28 years). These participants were the top 6 finalists of the men's triple jump event during the 58th Senior National Athletics Championship,2018 held at Indira Gandhi National Stadium, Guwahati (India). All the jumpers have been purposively selected for the study and are capable of jumping over 16 meters distance. Each finalist's top 3 legal attempts were only selected and analysed for this study. The range of the official performance recorded was 16.38 ± 0.43 meters and ranged from 15.88 meters to 17.09 meters during the competition. Since the data were collected during the official competition, no anthropometric data were collected. All the data were collected an official permission letter was signed by the Concerned referee, Technical Delegates and the Media Manager before the competition. A consent form was also collected from the athletes and their coaching staff. This study has been approved by the Research Advisory Committee of Tripura University, India.

Instruments and tools

Three (3) GoPro Hero 5 action cameras were used to record the movements. All the cameras were set in linear mode for the recording. The movements were recorded with a resolution of 1920 x 1080 pixels at 120 frames per second. The camera height was fixed at 1.20 meters. The position of the cameras is presented in the following Figure (A). A standard calibration stick of length 1 meter was used as a reference of the recorded videos. The calibration stick was first set in perpendicular direction with surface (x-axis) and then also set in parallel to the surface (y -axis). The calibration process was done in front of each optical axis of the three cameras.

Analytic procedure

The required kinematic parameters were obtained from the recorded movements by using Max Track and Silicon Coach Pro v 0.8 software. A set of 21 two-dimensional body segments were digitized for the linear transformation of the data.

The percentage of loss were calculated with reference to the initial velocity of the before the first touch-down of the first take-off. Mathematically,

$$\text{Percentage of the loss of horizontal velocity} = \frac{V1-V2}{U} \text{x } 100$$

Where V1 = velocity in the previous phase, V2 = velocity in the following phase,
U = initial velocity before the touch-down of the first take-off phase.

The statistical analysis was done by using "*R*" and MS Excel'07. The normality of the data was confirmed by the Shapiro-Wilk test at .05 significance level. The descriptive data for the five phases (First take-off, first flight, second take-off, second flight & third take-off) are presented by mean value and the standard deviation. The comparison of the five phases were done with the one-way ANOVA test at .05 significance level. Following the result of F-statistics, the Tuckey's Honest Significant Difference (HSD) was done to identify the pairwise difference among the phases (First take-off, first flight, second take-off, second flight & third take-off).

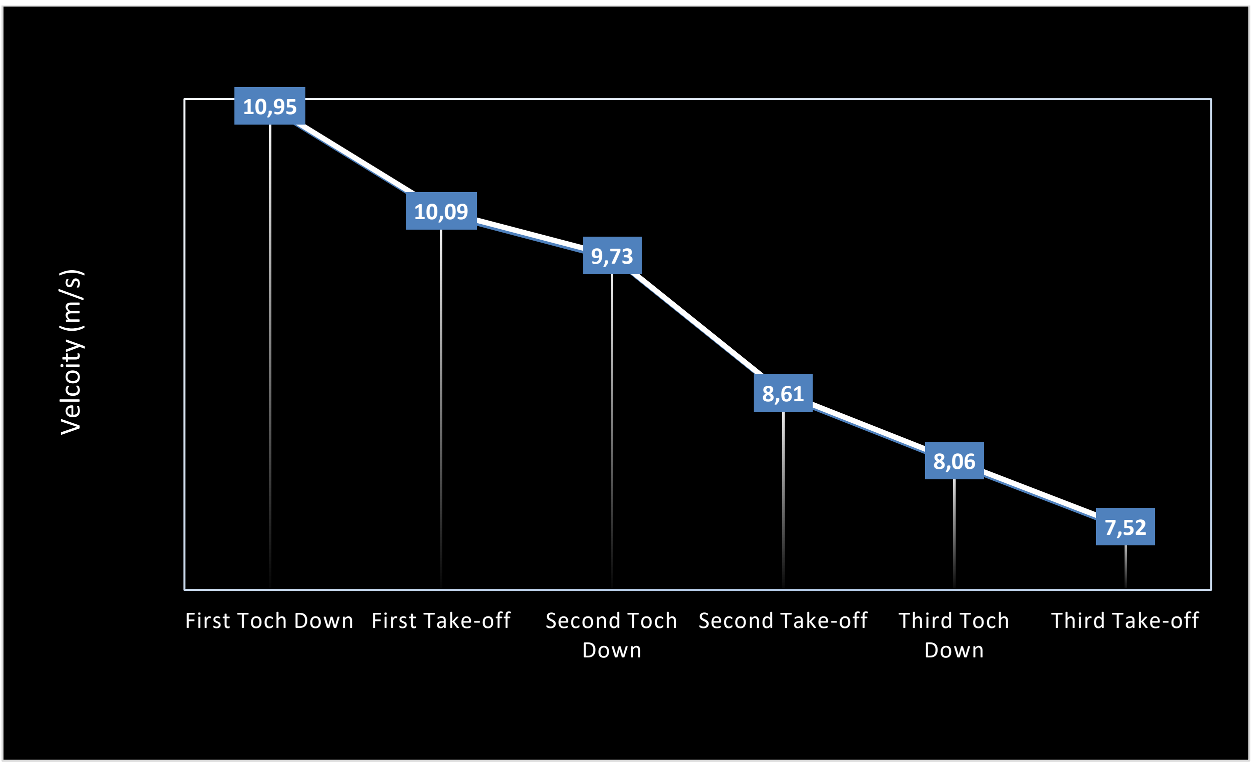

Figure 2. Presentation of Velocity Curve during the three consecutive take-off phases.

RESULTS

Table 1 shows the loss of horizontal velocity during the different phases of the triple jump for 6 participants. It breaks down the velocity loss during each of the 3 take-off phases and 2 flight phases.

The mean total velocity loss from entry in hop and exit at final jump was 33.66% with a relatively small standard deviation of .050, indicating the total loss was consistent across participants. The second take-off showed the greatest mean velocity loss at 10.25%, while the first and the third take-off was found 7.74% and 5.76% respectively.

Table 1. Percentage of Loss of horizontal velocity during the three consecutive take-off and in between two flight phases of the Triple Jump.

Participants	First take-off	First flight	Second take-off	Second flight	Third take-off	Total loss
1	7.70%	7.44%	9.92%	2.14%	6.07%	33.28%
2	8.74%	5.97%	10.22%	5.89%	8.31%	39.13%
3	12.50%	6.34%	7.97%	1.81%	5.80%	34.42%
4	8.84%	4.60%	13.26%	8.66%	4.70%	40.06%
5	3.26%	2.17%	13.54%	4.94%	2.17%	26.09%
6	5.37%	2.50%	6.62%	7.01%	7.49%	28.98%
Mean	**7.74%**	**4.84%**	**10.25%**	**5.07%**	**5.76%**	**33.66%**
SD	**0.029**	**0.020**	**0.025**	**0.025**	**0.020**	**0.050**

Table 2. Comparison among the three consecutive take-off phases in the Triple Jump and two flight phases in between.

Phases	Mean	SD	Sum of Squares		Mean Squares		F-ratio	*p*-value
			Between the groups	Within the groups	Between the groups	Within the groups		
First take-off	0.86	0.34						
First flight	0.54	0.24						
Second take-off	1.12	0.26	1.46872	2.1638	0.36718	0.086554	4.2421	.009*
Second flight	0.55	0.26						
Third take-off	0.63	0.23						

Table 3. Result of multiple comparison among the phases after Tuckey's Honest Significant Difference (HSD) test.

Phases 1	Phases 2	Std. Error	Sig.	95% Confidence Interval	
				Lower bound	Upper bound
First take-off	First flight	.16986	.362	-.1822	.8155
First take-off	Second take-off	.16986	.541	-.7622	.2355
First take-off	Second flight	.16986	.393	-.1922	.8055
First take-off	Third take-off	.16986	.696	-.2788	.7188
Second take-off	First flight	.16986	**.017***	.0812	1.0788
Second take-off	Second flight	.16986	**.019***	.0712	1.0688
Second take-off	Third take-off	.16986	**.041***	-.0155	.9822
Third take-off	First flight	.16986	.978	-.4022	.5955
Third take-off	Second flight	.16986	.986	-.4122	.5855
First flight	Second flight	.16986	1.000	-.5088	.4888

*Note. *at .05 significance level.*

The Table 2 presented the comparison of the five phases (First take-off, first flight, second take-off, second flight & third take-off) with the help of one-way ANOVA test. The value of F-ratio (4.2421) indicates that there are statistically significant differences in performance scores among the phases (*p* = .009*).

The result of the Tuckey's HSD represented the multiple pair wise differences in the phases. It is showed (Table 3) that second take-off has a significantly higher loss in horizontal velocity pair wise comparison done with first flight phase (*p* = .017), second flight phase (*p* = .019), and the second take-off phases (*p* = .041) in the triple jump. While other pairwise multiple comparison of the different phases showed no significant difference.

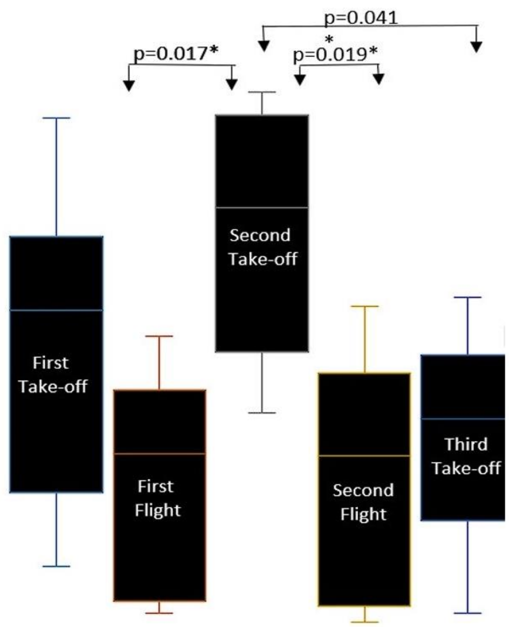

Figure 3. Box plot presentation of the comparison among the groups.

DISCUSSION

The present the study primarily intended to determine the variation occurs in the horizontal velocity during the five consecutive phases (First take-off, first flight, second take-off, second flight & third take-off) in the triple jump event. It was found that after the maximum changes occurs in the second take-off phase as loss of the horizontal velocity. This loss in the horizontal velocity was 10.25 % (1.12 ± 0.26 m/s). Whereas after the first flight phase this loss was lowest which is 4.84 % (0.54 ± 0.24 m/s). Further the result of the ANOVA test followed by the Tuckey's HSD test confirmed that in the second take-off phase the loss of horizontal velocity was significantly higher (Figure 3) than the first flight phase (*p* = .017), the second flight phase (*p* = .019) and the third take-off phase (*p* = .041).

Research has shown that loss of the velocity is inevitable during the three take-off phases in the triple jump event (Allen et al., 2013; Campos et al., 2013; Yu, 1999). The current study found that the average horizontal velocity at take-off was found to be 10.09 ± 0.42 m/s for the hop, 8.61 ± 0.23 m/s for the step and 7.52 ± 0.31 for the jump phase (Figure 2). In comparison to the result of the present study similar trends is observed in the various studies. Miller & Hay (1986) reported the horizontal velocity during the Hop, Step and jump was found 9.5 m/s, 8.7 m/s and 7.3 m/s, respectively. The results documented by Miller & Hay (1986) have shown a similar range to the result of the present study (Figure 2). On a study done by Fukashiro et al (1981) reported the horizontal velocity during the hop, step and jump were 8.48 ± 0.23 m/s, 7.76 ± 0.06 m/s and 6.59 ± 0.56 m/s respectively. This horizontal velocity outcomes are relatively lower than the current study. The performance of the athlete of this present study ranged from 15.88 to the 17.09 meters, while compared with performance recorded by Fukashiro et al (1981) was ranged from 13.78 to the 15.33 metres. Since, approach velocity maintains a strong positive correlation with jump performance (Isik, 2017) , hence it can be assumed that this might be the for why Fukashiro et al (1981) have the relatively lower horizontal velocity with the current study during the three take-off phases.

As loss is unavoidable, the current study compared loss of horizontal velocity in the three consecutive take-off phases and the in between two flight phases before the final jump. The total 33.66% of the horizontal velocity loss was observed after the completion of all five phases (Table 1). The average loss of the horizontal velocities in the First take-off, first flight, second take-off, second flight & third take-off was 0.86 m/s, 0.54 m/s, 1.12 m/s, 0.55 m/s and 0.64 m/s, respectively (Table 2). Hay & Miller (1985) on their study observed 34 % loss of the horizontal velocity after the completion of three take-off phases. In the present study the maximum loss observed during the second take-off phase i.e. after support phase step (1.12 m/s). This is accounted for 10.25% of the horizontal velocity recorded during the last phase of the approach run. This loss was comparatively higher while compared with the all-other phases (Table 3). Significantly, the loss of the horizontal velocity in the second take-off phase was significantly higher than the first flight phase (p = .017), the second flight phase (p = .019) and the third take-off phase (p = .041) (Figure 3). A study on elite Chinese triple jumpers has shown the maximum loss was observed during the step 0.63 ± 0.12 m/s (He et al., 2023). Whereas during the first take-off and the third take-off, the loss of horizontal velocity was comparatively low (0.55 ± 0.21 m/s and 0.23 ± 0.2 m/s respectively) (He et al., 2023). Hay & Miller (1985) also reported that maximum loss occurred in the step phase, which is accounted for the 14% (1.36 m/s) of the total loss of the horizontal velocity. However, Ryu & Chang (2005) reported that horizontal speed losses during the Jump phase (1.07 m/s), whereas Hop phase and step phase lost 0.60 m/s and 0.94 m/s respectively. A study done on international women triple jumpers highlighted that in the jump phase (third take-off) loss of the horizontal velocity (1.03 ± 0.2 m/s) was greater than the other two take-off phases (hop = 0.48 ± 0.2 & step = 0.46 ± 0.2 m/s respectively) (Panoutsakopoulos & Kollias, 2008). Alike result published by Miller & Hay (1986) found that the loss of horizontal velocity was maximum (1.5 m/s) in the Jump phase (after third take-off). While the remaining two phases (Hop and step) was observed 0.7 m/s and was 1.2 m/s respectively.

These forementioned dataset alone does not provide a comprehensive discussion on distinctive loss in any specific take-off phase, somehow it provides a concept for which loss of horizontal velocity is acceptable with the performance outcome in elite athletes. The reason for which the velocity loss is unavoidable has various mechanical reasons explained by the various authors (Allen et al., 2013; Campos et al., 2013; Fukashiro et al., 1981; Yu, 1999). A biomechanical model established by Yu (1999) explained that during the take-off resultant velocity is redirected into the horizontal and vertical components. This transformation into horizontal and vertical velocity components inherently involves slowing down the athlete and also helps to generate a vertical propulsion force (Fukashiro et al., 1981). The generation of the vertical propulsion force is due to the conversion of kinetic energy into elastic potential energy stored in muscles (Allen et al., 2013). The deceleration of horizontal velocity and energy conversions during take-off inevitably result in an unavoidable loss of total velocity (Allen et al., 2013; Campos et al., 2013).

The triple jump involves three successive take-off phases - the hop, the step and the jump. The greater velocity loss during the step take-off phase can be attributed to the biomechanical demands of taking off from the same leg twice in quick succession. Following the hop take-off and flight, the athlete must land and take-off again using the same leg during the step (Lu & Wang, 2005). Having to rapidly redirect the body and re-apply force on a single leg requires greater braking forces and neuromuscular effort compared to alternating legs (Liu et al., 2013). Specifically, the increased loads experienced during the step take-off led to greater flexion of the take-off leg, longer braking during early ground contact and enhanced muscular activation requirements. This induces greater fatigue in the take-off leg musculature, making force production less efficient and resulting in greater reductions in horizontal velocity (Hay, 1992). On the other hand, taking off from the opposite leg during the jump phase allows for some neuromuscular recovery of the take-off leg musculature used in the hop (Hay, 1992).

While velocity loss is acknowledgeable during the take-off phases, optimizing jump mechanics and transition can improve the overall performance. It is essential to admit that while the reduction in horizontal velocity during the take-off phases should be the key focus, though it may not the only factor influencing the performance. However, only minimizing loss of velocity does not necessarily increase the jump distance. In the 2017 World Championship, Ruiting Wu from China exhibited the lowest loss of velocity (0.68 m/s) during all three take-off phases. On the other hand, in that same competition, Christian Taylor claimed the championship title (17.68 meter) by having highest overall velocity loss (1.17 m/s) while compared to the all-other finalist (Tucker et al., 2018). The possible explanation from those examples may be the efficient force generation during both the take-off phases, regardless the loss of velocity. Additionally, maintaining a strong upright posture, avoiding excessive braking, and using an active sweeping leg motion could possibly help to preserve horizontal velocity (H. Liu et al., 2015; Lu & Wang, 2005).

There were some limitations which should be acknowledged. Firs, due to technical restrictions during the competition, the final jump phase of the triple jump was not recorded. Moreover, the data were taken during the Indian Senior National competition. Therefore, psychological factors of the athlete and faulty attempts are the main limitation of the study. A comprehensive approaching a controlled environment that takes account all these possible aspects could provide detailed understanding for this jump event.

CONCLUSION

The current study has investigated the variation in horizontal velocity experienced by Indian senior national triple jumpers. Initially, variation can be seen from the first take-off phase to the second take-off phase and started to decrease during the following phases. The study revealed that participants of the present study experiences maximum reduction of horizontal velocity in the second take-off phase. This might be the technical area where the loss of the horizontal velocity can be further optimized.

AUTHOR CONTRIBUTIONS

The study was designed by NGS and KD. Data were taken by NGS further it was interpreted by AJP, KD and NGS. Manuscript was prepared by the AJP and KD. All the authors approved the final version of this article for the publication.

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DISCLOSURE STATEMENT

No potential conflict of interest was reported by the authors.

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