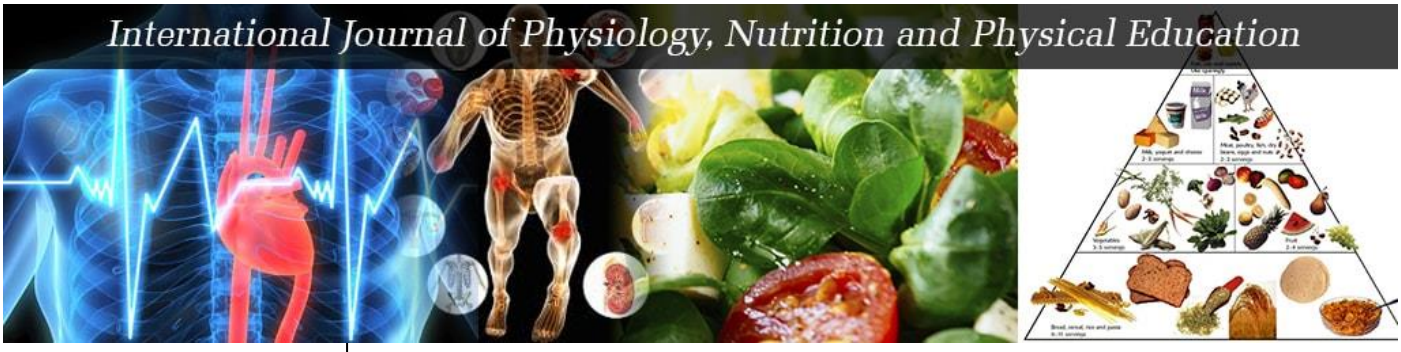

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Kinematic analysis of selected biomechanical parameters on different phases of tipple jump

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Abstract
The purpose of the study was to find out the differences in the selected kinematic variables (Distance, Flight Time, Average Velocity, and Takeoff Angle) among the three phases of Triple Jump. For the purpose of the study 20 Inter University triple jumpers were selected and their trials were recorded using digital cameras (Sony A7S2, lens: 24-105mm, 120 FPS). Each athlete's best legal trials were analyzed for the study. The analysis on each attempt was done using KINOVEA motion analysis software. The data pertaining to the selected biomechanical variables of Triple Jump phases were tested using Descriptive statistics, Univariate Analyses of Variance (ANOVA), and LSD post hoc. The level of significance was set at. 05 for testing the hypotheses. The kinematic analysis of selected biomechanical variables of different phases in Triple Jump revealed that there is significant difference in the selected biomechanical variables like Distance, Flight Time, Average Velocity, and Takeoff Angle among three phases of Triple jump (Hop, Step and Jump).

Keywords: Triple jump, kinematics analysis

Introduction
The triple jump consists of a running approach, multiple take off phases in which the athlete hop on one foot, land on the same foot, step on the opposite foot, and finally jump and land in the sand pit. It is one of the track and field events which require the jumper to repeat the generation of maximal force in order to preserve the horizontal velocity during all phases of jump (Miladinov and Bonov, 1988) [4]. Performing Triple Jump, an athlete must integrate several specific movements, which, when done properly will result in greater jumping distance. Besides, it is considered as one of the technical events, which depend up on numerous kinematic variables. The real time movement analysis on kinematic characteristics represents an essential instrument in the monitoring of the sports technique. The existence of an operational system by whom figure data, recorded by using software technologies, which will be processed, interpreted and used to describe and become more aware and exact the technical aspects. The aim of this study is to highlight the technical aspects that are definite to the Triple Jump event by kinematic analysis which studies the geometrically, spatial and temporally description of the movement by the framework of the following parameters: Time, Distance, Angles, and Velocity. The present study attempts to find out the difference in the selected kinematic variables among the different phases of Triple Jump.

Materials and Methods
Twenty Inter University Triple Jumpers of age group 18-25 years were randomly selected as the subjects for the study. Distance, Flight Time, Average Velocity, Takeoff Velocity and Angle of Takeoff of each phases (Hop, Step and Jump) in Triple Jump were selected as the variables for the study. The trials were recorded using digital cameras (Sony A7S2, lens: 24-105mm, 120FPS). The performance distance comprises of 25metres had been analyzed and divided the total distance in to 3 zones (9m, 8m, 9m). A 0.5m overlap occurred between zones 1and 2 and between zones 2 and 3. Each zone was covered by a single camera and an additional camera was used to record the total area in order to capture the whole sequence Camera (1), camera (2) and camera (3) covering the first, second and third zones were

positioned at the midpoint of each zones to the left side of the runway at a distance of 10 meter from the left edge near the approach path. The camera lens was oriented perpendicular to the plane of motion (sagittal) at a height of 1.35 meters which was approximately equal to one half of the height of the athlete when he was in the air after the take off. Each attempt was captured and saved in to a computer in AVI format. Each athlete's best legal trials were analyzed for the study. The analysis on each attempt was done using Kinovea motion analysis software. All the linear kinematics variables of three phases were measured using Kinovea motion analysis software. Hop distance, Step distance, and Jump distance were obtained by measuring the displacement from the first touchdown point of each phases to the next touchdown point after the flight during the attempt of the Jump. Hop Flight Time, Step Flight Time, Jump Flight Time were measured in seconds from the point of projection to the point of next touchdown of each phases, with the help of time frame given by kinovea motion analysis software. Average Velocity of Hop, Step and Jump was calculated by dividing the displacement of each phase with the flight time. Take off velocity of Hop, Step and Jump was measured by dividing displacement of the CG from the point of first touchdown to the point of take off with the time taken to cover the displacement in each phases. The angular kinematics (Angle of takeoff of Hop, Step and Jump) was the upward shifting angle of the CG between the points of last touchdown and the takeoff of each phase, with the help of kinovea motion analysis software. The data pertaining to the selected biomechanical variables of Triple Jump phases were tested using Descriptive statistics, Univariate Analyses of Variance (ANOVA), and LSD post hoc. The level of significance was set at. 05 for testing the hypotheses.

Results of the study

The Kinematic variables of three phases (hop, step, and jump) of triple jump are presented in Table 1.

Table 1: Analysis of the variables of different phases of Triple Jump

Variable	Phases	N	Mean	Std. Deviation
Distance	Hop	20	5.45	0.40
	Step	20	4.53	0.29
	Jump	20	5.39	0.26
Flight Time	Hop	20	0.54	0.05
	Step	20	0.44	0.07
	Jump	20	0.69	0.09
Average Velocity	Hop	20	10.20	1.13
	Step	20	10.44	1.77
	Jump	20	7.99	1.16
Takeoff Velocity	Hop	20	8.84	0.41
	Step	20	7.75	0.45
	Jump	20	7.01	0.39
Angle of Takeoff	Hop	20	12.85	2.52
	Step	20	13.00	2.81
	Jump	20	18.85	2.96

The Hop phase showed a mean Distance of 5.45m with a standard deviation of 0.40m, Step phase showed a mean Distance of 4.53m with a standard deviation of 0.29m and Jump phase showed a mean Distance of 5.39m with a standard deviation of 0.26m respectively. The mean Flight Time and standard deviation of Hop, Step and Jump phases were recorded as 0.54s and 0.05s, 0.44s and 0.07s and 0.69s and 0.09s respectively. The results of mean Average Velocity and standard deviation of Hop, Step and Jump phases of the subjects were 10.20m/s and 1.13m/s, 10.44m/s and 1.77m/s and 7.99m/s and 1.16m/s respectively. The mean Take off Velocity and standard deviation of Hop were recorded as 8.84m/s and 0.41m/s, that of Step as 7.75m/s and 0.45m/s and that of Jump as 7.01m/s and 0.39m/s respectively. The results of mean Angle of takeoff and standard deviation of the three phases such as Hop, Step and Jump were 12.85 degree and 2.52 degree, 13.00 degree and 2.81 degree, 18.85 degree and 2.96 degree respectively.

Table 2: Univariate ANOVA on effect of phases with dependent variables of triple jump

Source	Variable	Sum of Squares		DF	Mean Square	F	Sig.
Phases	Distance	Between Groups	10.59	2.00	5.29	50.57	0.000
		Within Groups	5.97	57.00	0.10		
		Total	16.55	59.00			
	Flight Time	Between Groups	0.60	2.00	0.30	54.08	0.000
		Within Groups	0.31	57.00	0.01		
		Total	0.91	59.00			
	Average Velocity	Between Groups	73.03	2.00	36.51	19.02	0.000
		Within Groups	109.44	57.00	1.92		
		Total	182.47	59.00			
	Takeoff Velocity	Between Groups	33.81	2.00	16.91	96.80	0.000
		Within Groups	9.96	57.00	0.17		
		Total	43.77	59.00			
	Angle of Takeoff	Between Groups	468.30	2.00	234.15	30.53	0.000
		Within Groups	437.10	57.00	7.67		
		Total	905.40	59.00			

The ANOVA results of the independent variable phases reveal that the dependent variables, Distance (F=50.57, P=0.000), Flight Time (F=54.08, P=0.000), Average Velocity (F=19.02, P=0.000), Takeoff Velocity (F=96.80, P<0.000), and Angle of Takeoff (F=30.53, P=0.000) differ significantly with the independent variables, Phases (Hop, Step, Jump). Pair-wise comparison and post hoc test (LSD) performed on the following dependent variables found significant (Distance, Flight Time, Average Velocity, Take off Velocity, and Angle of Takeoff) effect on the independent variable phases (Hop, Step, Jump) presented in table 3.

Table 3: Pair-wise Comparison of means of significant dependent variables on Phases (LSD)

Dependent Variable	Phases		Mean Difference (I-J)	Std. Error	Sig.
Distance	Hop (5.45)	Step	.92050*	.10232	.000
		Jump	.06200	.10232	.547
	Step (4.53)	Hop	-.92050*	.10232	.000
		Jump	-.85850*	.10232	.000
	Jump (5.39)	Hop	-.06200	.10232	.547
		Step	.85850*	.10232	.000
Flight Time	Hop (0.54)	Step	.09385*	.02351	.000
		Jump	-.14855*	.02351	.000
	Step (0.44)	Hop	-.09385*	.02351	.000
		Jump	-.24240*	.02351	.000
	Jump (0.69)	Hop	.14855*	.02351	.000
		Step	.24240*	.02351	.000
Average Velocity	Hop (10.20)	Step	-.24100	.43818	.584
		Jump	2.21050*	.43818	.000
	Step (10.44)	Hop	.24100	.43818	.584
		Jump	2.45150*	.43818	.000
	Jump (7.99)	Hop	-2.21050*	.43818	.000
		Step	-2.45150*	.43818	.000
Takeoff Velocity	Hop (8.84)	Step	1.09025*	.13216	.000
		Jump	1.82755*	.13216	.000
	Step (7.75)	Hop	-1.09025*	.13216	.000
		Jump	.73730*	.13216	.000
	Jump (7.01)	Hop	-1.82755*	.13216	.000
		Step	-.73730*	.13216	.000
Angle of Takeoff	Hop (12.85)	Step	-.15000	.87570	.865
		Jump	-6.00000*	.87570	.000
	Step (13.00)	Hop	.15000	.87570	.865
		Jump	-5.85000*	.87570	.000
	Jump (18.85)	Hop	6.00000*	.87570	.000
		Step	5.85000*	.87570	.000

The pair-wise comparison of Distance results indicated that Hop phase has the highest mean score of 5.45 and differ significantly with the Step phase (Mean = 4.53) with a mean difference of 0.92. It is also found that Jump phase with a mean score of 5.39 differ significantly with the Step phase (Mean = 4.53) with a mean difference of 0.86. All these differences are found significant at 0.05 levels. The pair-wise comparison of Flight Time results indicated that the Jump phase has the highest mean score of 0.69 and differ significantly with the Hop (Mean = 0.54) and Step (Mean = 0.44) with a mean difference of 0.15 and 0.24. It is also found that the Hop phase also differ significantly with the Step phase with a mean difference of 0.09. All these differences are found significant at 0.05 levels. The pair-wise comparison of Average Velocity results indicated that the Step phase has the highest mean score of 10.44 and differ significantly with the Jump phase (Mean = 7.99) with a mean difference of 2.45. It is also found that Hop phase (Mean=10.20) differ significantly with the Jump phase with a mean difference of 2.21. All these differences are found significant at 0.05 levels. The pair-wise comparison of Takeoff Velocity results indicated that the Hop phase has the highest mean score of 8.84 and differ significantly with the Step (Mean = 7.75) and Jump (Mean = 7.01) phases with a mean difference of 1.09 and 1.83. It is also found that Step phase differ significantly with the Jump phase with a mean difference of 0.74. All these differences are found significant at 0.05 levels. The pair-wise comparison of Angle of takeoff results indicated that the Step phase has the highest mean score of 18.85 and differ significantly with the Hop (Mean = 12.85) and Step (Mean = 13.00) phases with a mean difference of 6.00 and 5.85. All these differences are found significant at 0.05 levels.

Conclusions

1. The kinematic analysis of selected biomechanical variable of different phases in triple jump revealed that there is significant difference in the selected biomechanical variables among three phases of triple jump.
2. The highest mean value for Distance of Triple Jump was found in the Hop phase and it differs significantly with Step phase. It was also found that the Distance of Jump phase differ significantly with step phase. Larger phase distance of Hop is inveigled by the consequential variables such as Angle of Takeoff, Maximum Height of Center of Gravity at Takeoff, Take off Velocity, Duration of Support phase, Horizontal Velocity and Vertical Velocity. The values shown by the above said variables influence the optimal trajectory which contributes to a larger phase distance.
3. The highest mean value for the Flight Time was observed in the Jump phase and found that it differs significantly with the Hop and Step phases. It was also found that significant difference exists between Hop and Step Flight Time. Longer Flight Time in the jump phase is influenced by the variables such as Angle of Takeoff, Vertical Velocity, and Maximum Height of Center of Gravity at Takeoff which increases the flight curve which in turn increases the flight time.
4. The highest mean value for the Average Velocity among the three phases of Triple Jump was observed in the step phase and found that it significantly differs with the hop phase. It was also found that the Average Velocity of Hop phase differ significantly with the Jump phase. Average Velocity of the step phase is influenced by the variables such as distance and flight time. Since the

distance is moderate and the flight time shows the lowest value the average velocity of the step phase finds the highest

5. The highest mean value for Takeoff Velocity was found in the Hop phase and it differs significantly with Step and Jump phases. It was also found that the Takeoff Velocity of Step phase differ significantly with Jump phase. The Horizontal Velocity achieved along the approach run is transferred at the time of takeoff and the athlete takes off with a moderate Angle of Takeoff which enhances the Takeoff Velocity of the Hop phase.
6. The highest mean value for the Angle of Takeoff among the three phases was observed in the Jump phase and found that it differs significantly with the Hop and Step phases. Consciously to prepare the athlete for safer landing, the athlete has to linger in the air for longer duration in the Jump phase. Accordingly, the athlete has to take off at a greater Angle of Takeoff, breaking the Horizontal Velocity component more into the Vertical Velocity by shifting the Maximum Height of Center of Gravity at Take off with a high Duration of Support phase in the short –stretching cycle which enhances the flight curve as well as Flight Time. On that account, the Jump phase Angle of Takeoff finds the highest.

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