A 3D KINEMATICAL ANALYSIS OF LONG JUMP IN THE "GOLD MEETING RIO OF ATHLETICS 2007"

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This study was based on the 3D kinematical analysis of long jump in an official competition of the International Association of Athletics Federation. A six camera kinematical analysis system was used to reconstruct the 3D coordinates of eighteen points, modeling the athlete's body with the follow segments: head, trunk, arms, forearms, thighs, calves and feet. Several performance variables concerning the center of mass trajectories and velocities were used to characterize and compare the individual jumps. Descriptive statistics was used to compare the results obtained with those found in the literature.

KEY WORDS: biomechanics, sport, kinematical analysis, long jump.

INTRODUCTION:

The biomechanical analysis of long jump has been conducted with many different purposes. Ballreich and Brüggemann (1986) presented the principles of analysis and researched the best variables to explain the success of the athletes. Alexander (1990) identified the principles that govern optimum speed and leg angle for the take-off of long jumping and concluded that a faster run-up is desirable in long jumping to allow a great horizontal component of velocity at take-off. Bridgett and Linthorne (2006) analyzed an experienced male athlete using a single high speed camera and they concluded that the athletes should use a maximal run-up speed and place the take-off leg at about 61° to the horizontal with a minimum of knee flexion.

Graham-Smith and Lees (2005) have performed a three-dimensional analysis of the touch-down to take-off phase in the long jump. They studied fourteen male high level long jumpers and found that performance in the long jump is dependent not only on speed but also on technique and strength. According to these authors, many three dimensional studies of long jump exist, but the only studies to have reported detailed data on the touch-down to takeoff phase were two-dimensional.

The purpose of this study was to present data on high level male long jumpers who participated in the GOLD MEETING RIO OF ATHLETICS 2007 and to analyze the 3D kinematical variables related to their performances, in the takeoff, touchdown on board and landing phases.

METHOD:

The "GOLD MEETING RIO OF ATHLETICS 2007" was a competition included in the calendar of the International Association of Athletics Federation (IAAF) and the winner was the first in the IAAF mean's long jump ranking, in May 2007. There were analyzed the two best jumps of the winner (Irving Saladino, 8.53m and 8.20m), the second best jump of the 2nd placed (Bashir Ramzy, 7.75m), the second best jump of the third placed (Trevell Quinley, 7.40m), the two best jumps of the 4th placed (Louis Tristán, 7.75m and 7.38m) and the best jump of the 5th placed (Erivaldo Vieira, 7.70m). The best jumps of the second and third placed were lost due to problems of occlusion.

The DVideo kinematic analysis system (Figueroa, Leite & Barros, 2003) was used for the 3D kinematical analysis. Four video cameras (60 Hz) were positioned in one size along the runaway and used two-by-two to reconstruct the movement from the two last steps to the takeoff. Two more cameras were located in front of the runaway. These cameras were used

for the 3D reconstruction of the flying phase. The angles between the optical axes of the cameras used to reconstruct coordinates were approximately 90 degrees. The camera registers were synchronized as described in Barros et al. (2006).
Eighteen points were manually digitized in the image sequences, modeling the athlete's body with the follow segments: head, trunk, arms, forearms, thighs, calves and feet. These 3D data were smoothed with a zero-phase forward and reverse Butterworth digital filter of 3th order with a 6 Hz cut-off frequency. The body center of mass was calculated based on the anthropometric model proposed in Zatsiorsky and Seluyanov (1990).
Several performance variables concerning the center of mass trajectories and velocities were used to characterize and compare the individual jumps. Descriptive statistics was used to compare the results obtained with those found in the literature.
The definition of touchdown on the board was taken as the first clear frame in which the foot was in contact with the ground and the takeoff was taken as the first frame in which the foot was clear of the ground (Lees et al., 1994). The landing on sand was defined as the first frame in which the foot was in contact with the sand.
In order to evaluate the accuracy of the measures obtained with the kinematical analysis system used in actual conditions, the following test was conducted. The procedures of measurements accomplished by the referees after each jump were recorded. Three-dimensional positions of two points on the extremity of the jump board were reconstructed in order to define a straight line corresponding to the board extremity. The contact point of the laser-based electronic distance measurement device and the sand was also reconstructed and the distance from the board extremity to the contact point was calculated. These measures were compared with the official distances contained in the official report.

RESULTS AND DISCUSSION:

Table 1 presents the official distances and the distances measured by the kinematical analysis system after each of five jumps. The official results were reported with two numbers after the decimal point (centimeters). The test shows that the video based measures were such accurate as the official measures.

Table 1. Comparison of official measures and those obtained by the kinematical system.

Athlete	**D (m)**	**D_{video} (m)**
Saladino, I.	8.20	8.198
Ramzy, B.	7.75	7.748
Tristán, L.	7.75	7.754
Quinley, T.	7.40	7.398
Tristán, L.	7.38	7.378

Table 2 presents the official distances (**D**) and biomechanical variables used to describe the individual jumps of the athletes. The variables were calculated from the three-dimensional reconstruction of the whole-body center of mass trajectory and velocity curves. The variables measured at the touchdown on board were the components of the vector velocity in the progression ($\mathbf{V_{TX}}$), latero-lateral ($\mathbf{V_{TY}}$) and vertical directions ($\mathbf{V_{TZ}}$). The variable α_T corresponds to the angle defined by the vertical line passing through the **CM** and the line defined by the **CM** and the point at the calcaneous (attack angle). The follow variables were measured at the takeoff. $\boldsymbol{\alpha_0}$ is the angle between the vector velocity of the **CM** and the horizontal plane. $\mathbf{h_0}$ is the height of CM. $\mathbf{V_{0X}}$, $\mathbf{V_{0Y}}$ and $\mathbf{V_{0Z}}$ are, respectively, the components of the vector velocity in the progression, latero-lateral and vertical directions. Δ_x/Δ_z is the ratio between the loss in horizontal velocity and the gain in the vertical velocity. Higher values mean better transfer from horizontal to vertical velocities.

Table 2. Performance variables at touchdown and takeoff on board of men's long jump in the GOLD MEETING RIO OF ATHLETICS 2007.

Athlete	D (m)	V_{TX} (m.s^{-1})	V_{TY} (m.s^{-1})	V_{TZ} (m.s^{-1})	α_T (º)	α_0 (º)	h_0 (m)	V_{0X} (m.s^{-1})	V_{0Y} (m.s^{-1})	V_{0Z} (m.s^{-1})	Δ_x/Δ_z
Saladino, I	8.53	10.15	0.28	0.10	29.7	23.6	1.21	8.66	-0.11	3.79	0.40
Saladino, I.	8.20	9.88	0.32	0.24	27.5	25.6	1.20	8.38	-0.05	4.02	0.40
Ramzy, B.	7.75	9.12	0.24	0.45	20.1	19.9	1.41	8.11	-0.02	2.94	0.41
Tristán, L.	7.75	10.23	0.25	-0.39	30.2	20.0	1.26	8.77	0.49	3.19	0.41
Vieira, E.	7.70	9.41	0.25	0.48	25.4	24.9	1.28	8.19	0.01	3.80	0.37
Quinley, T.	7.40	9.37	0.18	0.22	24.7	25.5	1.33	7.99	0.09	3.81	0.38
Tristán, L.	7.38	9.80	0.15	-0.26	31.2	22.0	1.13	8.45	0.61	3.43	0.37
Mean	**7.82**	**9.71**	**0.24**	**0.12**	**27.0**	**23.1**	**1.26**	**8.36**	**0.15**	**3.57**	**0.39**
SD	0.42	0.42	0.06	0.33	3.9	2.47	0.09	0.29	0.29	0.34	0.02
Mean (Lees et al., 2005)		**9.93**	**0.13**	**-0.18**	**32.2**		**1.27**	**8.55**	**0.18**	**3.37**	**0.39**
SD (Lees et al., 2005)		0.37	0.24	0.21	2.2		0.04	0.35	0.32	0.32	

Table 3: Results of the stride length and distances of mean's long jump in the GOLD MEETING RIO OF ATHLETICS 2007.

Athlete	**NLS** (m)	**LS** (m)	D_1 (m)	D_2 (m)	D_3 (m)	D_4 (m)	D_{T2H} (m)	D_{T2B} (m)	D_{Land} (m)
Saladino, I	2.40	---	0.23	6.69	1.17	0.59	8.88	0.20	0.12
Saladino, I.	2.30	---	0.27	6.81	0.85	0.56	8.62	0.14	0.28
Ramzy, B.	2.47	2.15	0.37	5.89	1.30	0.45	8.08	0.09	0.24
Tristán, L.	2.70	2.08	0.33	6.30	0.90	0.68	8.25	0.03	0.47
Vieira, E.	2.29	---	0.17	6.15	1.23	0.56	8.33	0.21	0.42
Quinley, T.	2.60	1.64	0.40	5.67	1.20	0.26	7.74	0.21	0.13
Tristán, L.	2.52	1.92	0.13	5.58	1.28	0.61	7.67	0.07	0.22
Mean	2.47	1.95	0.27	6.16	1.13	0.53	8.22	0.14	0.27
STD	0.15	0.23	0.10	0.48	0.18	0.14	0.43	0.07	0.13

Table 3 presents the variables related to the distances covered during the jump phases. **NLS** is the length of the next to the last stride. **LS** is the length of the last stride. $\mathbf{D_1}$ is distance from the extremity of the board to the center of mass projection on the ground at the takeoff. $\mathbf{D_2}$ is the distance traveled by the **CM** from the instant of takeoff to the instant in which the **CM** reached the same height of takeoff. $\mathbf{D_3}$ is the distance from the end point of $\mathbf{D_2}$ to **CM** projection at the landing in sand. $\mathbf{D_4}$ is the distance from the end point of $\mathbf{D_3}$ to the foot landing on sand.

$\mathbf{D_{T2H}}$ consists of the distance from the toe contact at the takeoff to the heel contact on sand in landing. This distance measures the effective distance traveled by the jumper and reveals the athlete's potential jump in case of a jump without any waste in takeoff or landing ($\mathbf{D_{T2B}}$ and $\mathbf{D_{Land}}$). $\mathbf{D_{T2B}}$ quantifies the distance from the athlete's toe at the touchdown to the board extremity (the greater the worst). $\mathbf{D_{Land}}$ is the distance lost during landing by the contact of any part of the body with the sand behind the heel. In this study, this variable was calculated as follow: $\mathbf{D_{Land}}=\mathbf{D_{T2H}} - (\mathbf{D_{T2B}} + \mathbf{D})$.

The results of mean values and standard deviations were also presented in Table 2 and Table 3. The comparable results obtained by Lees et al. (2005) in a similar 3D kinematical analysis were included at the end of Table 2. The comparison of means and standard deviations revealed very coherent results.

The result of an individual jump is determined by multiple factors and none of them can alone explain the better performance. Despite this, some aspects can be highlighted from the analysis of Table 2 and 3. In order to exemplify the analysis, the two Saladino's best jumps (**J1**=8.53m and **J2**=8.20m) were compared. The results show that in **J1** the approach happened with higher horizontal velocity at the touchdown ($\mathbf{V_{TX}}$=10.51 x $\mathbf{V_{TX}}$=9.88 $m.s^{-1}$) and takeoff ($\mathbf{V_{0X}}$=8.66 x $\mathbf{V_{0X}}$=8.38 $m.s^{-1}$) and smaller vertical velocity at the takeoff ($\mathbf{V_{0Z}}$=3.79 x $\mathbf{V_{0Z}}$=4.02 $m.s^{-1}$). Similar values were found in $\mathbf{V_{0Y}}$, $\mathbf{h_0}$, Δ_x/Δ_z, $\mathbf{D_1}$ and $\mathbf{D_4}$.

Besides the difference in the velocities, the main differences appeared comparing **J1** and **J2** in terms of $\mathbf{D_2}$ and $\mathbf{D_3}$ and the variables related to the distances lost during the jump, $\mathbf{D_{T2B}}$ and $\mathbf{D_{Land}}$. $\mathbf{D_2}$ was 0.12 m smaller in **J1**, but $\mathbf{D_3}$ was 0.32 m greater. In **J1**, the distances lost were 0.10 m less than in **J2**.

In the best jump, the horizontal velocity was greater despite the smaller vertical velocities producing a two degrees smaller takeoff angle. This decreased the flying time compared to **J2** and consequently $\mathbf{D_2}$. However, this flatter angle makes possible the landing with a lower center of mass position, increasing substantially $\mathbf{D_3}$ (0.32m). These associated facts seem to be the main reasons to explain the better performance in the first jump.

CONCLUSION:

Three-dimensional analyses of high level long jumpers in an official competition were reported in this study. Individual and statistical analyses were provided and the results compared with the data available in the literature.

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