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THEORETICAL AND EXPERIMENTAL ASPECTS CONCERNING THE LONG JUMP TRIAL

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Abstract: *The aim of the present paper is to present the main theoretical aspect of the long jump trial and some experimental results considering the data recorded during athletes training. The used data were obtained using a video record based on image processing. Using special markers attached on athletes it was obtained the trajectory of the jumpers and some important parameters as horizontal and vertical velocities in the moment of the take-off. There were defined two mathematical function of calculating the length of the jump considering the recorded above velocities.*

Key words: *biomechanics, motion analysis, long jump, imagine processing.*

1. Introduction

Biomechanics is a special scientific domain useful in different special activities as: sports, special activities at the work place, physical disabilities etc.

The roots of biomechanics are situated in the ancient times but the basics of a scientific study were done beginning with the Middle Age.

Leonardo da Vinci who analysed the muscle forces, the joints between bones and realised some very accurate drawings of the human parts made the first known studies. Another important study was done by Galileo Galilei who applied principles of mechanics to the bone structure doing a so-called “hydrostatic balance” to find the specific body weight.

Isaac Newton defined the scientific basics of classical mechanics and implicitly of biomechanics. He posited the bodies motion axioms that express the connections between forces and their effects. Practically all the athletes’ mechanical behaviour is based on Newton’s laws.

James Keill who calculated the number of muscle fibres in a muscle and defined the stress developed on each fibre did another important step in biomechanics. In the 19th century, Samuel Haughton developed biomechanics studies on different animals.

P.F. Leshaft founded the sports biomechanics. He did the first course about the theory of human body motion for sports. The course contents data about the proportions of the human body parts, about motion and positions in different sport trials.

Currently the studies are more accurate and are based on experimental data and the facilities offered by the simulation codes.

In the present paper it is done a study about the main models used in long jump

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trial and it is done a comparison with studies done on some athletes.

2. The Long Jump Trial

One of the oldest athletic trials is the long jump. During the last century the Olympic Games had a continuous development and new records were established in any athletic game. The first word record recognised by the International Athletics Federation (IAAF) was done by Peter O'Connor on 5th of August 1901, at Dublin, and was about 7.61 m. Since that moment the results obtained by jumpers were better and better. In the last 30 years, along with the biomechanics development, it was seen an improvement of the sports results, in particular in long jump trial.

In case of the long jump trial there are defined four distinguishing phases: run-up, take-off, aerial and landing.

All these phases considered separately or combined are important in performances and have to be balanced with the physical performances of the long jumper.

2.1. The Run-Up

A good result obtained by a long jumper depends on the qualities as sprinter in the first phase, the developed force in legs in the take-off moment, flight and landing.

Description of all these phases can be found in different specific papers [3], [9], [12], [13], [21] and [23].

About the run-up phase the length is established according with both speed potential and acceleration capacity of the jumper. In [9] there are mentioned as values about 37...50 m (19...24 steps) for men and 33...40 m (18...21 steps) for women. In [4] and [17] for the same phase it is considered a length about 30...45 m (18...22 steps) for men and 25...35 m (16...20 steps) for women. The world-class long jumpers during the run-up phase did approximately the same number of steps: Bob Beamon - 20 steps, Carl Lewis - 23 steps and Mike Powell - 23 steps. It was found for the men long jumpers a so-called "correct run-up length" as function of the obtained time for the two different lengths 30 m and 100 m (Table 1) [22].

Correct run-up length [22] Table 1

Time [s] for 30 m	**Time [s] for 100 m**	**Run-up steps**
4.7	13.0	12
4.5	12.5	14
4.3	12.0	16
4.1	11.5	18
3.9	10.9	20
3.7	10.4	22

As is mentioned in different papers [5], [8], [10], [18] the length of the jump is strongly influenced by the final velocity at the run-up phase and is correlated with the horizontal component of the take-off velocity [8], [24].

Values of the maximum velocities of some world-class jumpers and jumps' length are presented in Table 2 [20].

Table 2
World class jumpers performances [19]

Long jump athlete	**Velocity [m/s]**	**Length [m]**
Carl LEWIS	10.9	8.55
Heike DAUTE	9.7	7.27
Volker MAI	9.9	7.99
Sofia BOSANOVA	8.8	6.68
Dietmar HAAF	10.4	7.93

Concluding, for a large jump distance the jumper must have at the end of the run-up a maximum horizontal velocity.

2.2. The Take-Off

The take-off is considered the hardest moment of the long jump trial.

During the take-off phase it is used the entire force system to obtain an adequate vertical velocity and to preserve the horizontal velocity.

The moment of the take-off is discussed in many papers [7-9], [14-16] and [19] where are detailed presented the parameters that has directly influence on it and there are presented models of long jump.

The target of the take-off is to maximize the flight distance of the athlete body considering both optimum take-off angle and optimum take-off velocity.

In the take-off moment the horizontal velocity (forward velocity) is diminished with 1...2 m/s that represents 9.5...14% from the run-up velocity.

After the moment of the take-off the athlete must generate a large vertical velocity combined with minimizing the horizontal velocity loss.

As is presented in literature [1], [11] the length of the jump is strongly influenced by the vertical component of the velocity.

In [8] it is mentioned that the take-off maximum vertical component of the velocity is has to be around 3...4 m/s and the horizontal component is about 8...10 m/s. Another important parameter that describes the take-off is the take-off angle.

The optimum angle is found based on the maximization problem of the flight distance considering a model with three parameters: the horizontal speed of the centre of mass, the take-off speed and the take-off angle.

The value of the take-off angle is necessary to be smaller than 45° and, based on video records it was predicted that the great majority of the world-class long jumpers give a take-off angle around 21°.

In [9] it is mentioned that the most of the jumpers use for the take-off an angle in the range of 20°...30° while in [10] the jumper is assumed as a projectile in free flight, and it is concluded that the optimum take-off angle can be predicted considering the motion equation combined with the take-off speed, take-off height.

2.3. The Aerial Phase

Another important aspect of the athlete technique is represented by the flight phase when it is necessary to be developed self-control of the forward rotation produced at the take-off moment.

After the take-off moment the jumper will start the third phase, the flight.

Since the detachment moment of the jumper the whole motion is influenced by the gravity and thus a vertical downwards oriented motion component is developed.

In the first half of the flight, the jumper rises evenly slowed and in the second half has a uniformly accelerated falls [19].

From a theoretical point of view, during the flight air resistance decreases the speed of the running movement and makes that the downward trajectory to be steeper.

Practically, in normal atmospheric conditions, the air resistance can be neglected and the decreasing of the jumper speed is minimised.

However, the windy conditions change the flight and can have both influences: to accelerate the jump or to break it.

In the same time, during the flight, there developed compensatory spins [6].

These spins are divided in two classes: on a hand spins that involves the angular momentum conserving (balance of the body) and on the other hand spins that generate a real rotation motion around the mass centre [25].

2.4. The Landing Phase

The landing is the last phase of the trial. The main aim is to enhance the trajectory of mass centre of the jumper in a manner that the obtained distance is maximized. From a biological point of view, the joints are loaded at a maximum dynamic level in the sock developed in the moment of the legs contact with the ground.

3. Case of Study

Based on the theoretical aspects, briefly above mentioned there were done studies on a four jumpers. The four considered subjects were jumpers with high-level competition performances. Two of them were females and the other two were males.

All the four athletes were members of the Romania National Athletic Team and having different jump techniques.

3.1. Experimental Set-Up

The main objective of the experimental study was to record their jumps and to analyse them to determine some mathematical correlations.

The considered place of experiments was the summer camp conducted by Athletics Squad in the Romanian National Sports Complex (Poiana Braşov). The record considered period was about two weeks while the subjects did a number of ten workouts.

The motion of the jumpers was recorded using special coloured markers and a high-speed camera (AOS X - PRI) done with a resolution of 800x600 pixels at 500 frames/s directly connected to Laptop (Figure 1).

Fig. 1. *Camera AOS X-PRI and recording data system*

The markers were fixed in different points previously established considering two aspects: the mathematical model of the jumper and the suggestions given by the trainers. The markers were posted on the bodies on the same side with the video camera.

The video camera was installed at a distance about 5.20 meters from the jump path on normal direction on the jumpers manly focused on the take-off point (Figure 2).

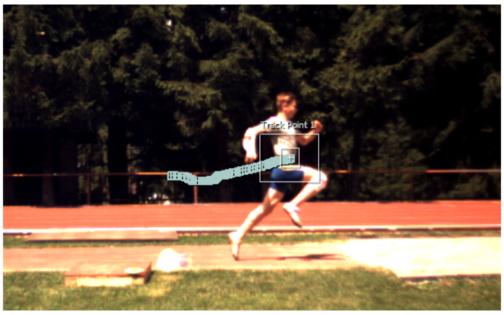

Fig. 2. *The trajectory visualised with markers*

The obtained images were processed in order to obtain the needed data for jumper performances analysis. The markers trajectory was recorded in image files and then it was converted in position coordinates. Image analysis was done using the code Adobe After Effects and it was calculated the pixels-meter conversion to be obtained the ride in meters. The time was obtained considering the range of video recording (500 frames/second).

3.2. The Take-Off Velocities Analysis

One of the most important targets of a trainer work is to obtain the best performances from an athlete. In case of long jump each phase is an important one and a useful help for trainers is to find a mathematical relation that can describe the correlation between different parameters of each jumper. As was mentioned above one of the most important moments is the end of the run-up where it is needed to be obtained

In §2.2 it was mentioned that the performances are directed tied with the horizontal and vertical velocities, v_x and v_y, developed by the jumper in the take-off moment.

Based on the recorded velocities measured for all four athletes there were established some correlation functions between the length of jump and the two velocity components (vertical and horizontal). According with the measurements there were found data presented in Table 3 for one of the jumper.

Table 3

Velocities vs. measured jumped length

No.	Horizontal velocity v_x [m/s]	Vertical velocity v_y [m/s]	Jumped length L [m]
1	9.90	2.893	5.27
2	9.62	3.357	5.36
3	9.49	3.530	5.39
4	9.40	3.518	6.59
5	9.28	3.086	6.43

The considered jumper is member of the Junior Romania Athletic team. The athlete is 1.78 m tall and has a weight about 67 kg. The main values of the long jump are around 7.25 m. There were considered the first five best jumps.

Considering the presented data there were found two interpolation curves velocity vs. jump length. The interpolation function were found using MATLAB code.

The first relation refers to the jump length L approximation as function of the horizontal velocity v_x (Figure 3):

$$L(v_x) = 0.5504 v_x^2 - 90.22 v_x + 53.14 . \quad (1)$$

The regression coefficient for the Relation (1) is $R^2 = 0.9302$.

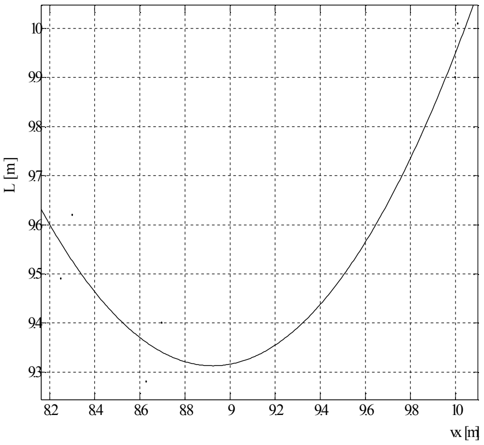

Fig. 3. *The curve interpolation for horizontal velocity* v_x *vs. jump length*

The second relation refers to the jump length L approximation as function of the vertical velocity v_y (Figure 4):

$$L(v_y) = -22.82 v_y^3 + 222.5 v_y^2 - 721.5 v_y + 787.5 . \quad (2)$$

The regression coefficient for the Relation (2) is $R^2 = 0.9611$.

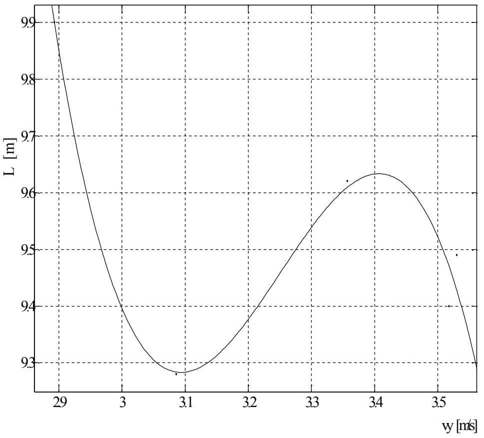

Fig. 4. *The curve interpolation for vertical velocity* v_y *vs. jump length*

As it can be seen from Relations (1) and (2) the mathematical approximation is given by polynomial functions.

In the same time, for two different values of velocities it is obtained the same jump length. There were used other types of interpolation functions but the best results were obtained using the two polynomial functions above presented.

3.3. The Take-Off Resultant Velocity Analysis

Considering the resultant v of the velocity in the take-off moment:

$$v = \sqrt{v_x^2 + v_y^2}\ , \tag{3}$$

there were obtained the variation of the jump length according with the resultant velocity (Table 4).

Table 4

Jump length vs. resultant velocity

No.	Jumped length L [m]	v [m/s]
1	5.27	10.408
2	5.36	8.954
3	5.39	8.973
4	6.59	9.383
5	6.43	9.163

Based on data from Table 4 it was found as correlation function (Figure 5):

$$L(v) = 0.7248v^2 - 13.78v + 74.82\,. \tag{4}$$

The regression coefficient for the Relation (4) is $R^2 = 0.8759$.

As in the previous analysis of correlation the best value for regression coefficient was found for a polynomial approximation function.

As it can be seen in Figure 5 there are velocities that correspond to two different values of the jump length.

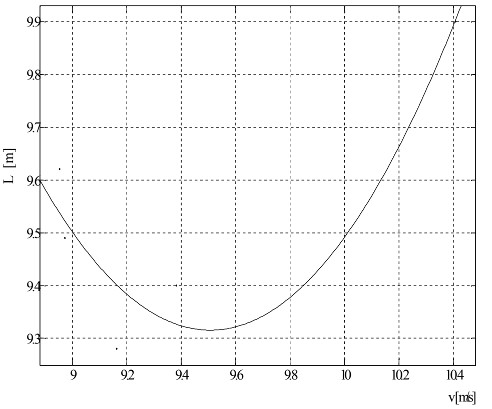

Fig. 5. *The curve interpolation for resultant velocity vs. jump length*

3.4. The Take-Off Angle Analysis

Another important element that has to be taken into the consideration in long jump is the angle of the take-off.

This angle can be calculated considering the two velocity vectors v_x and v_y.

In Table 5 there are presented the values of the take-off angle for the considered athlete.

Table 5

Jump length vs. take-off angle

No.	Jumped length L [m]	Angle θ [°]
1	5.27	16.15
2	5.36	22.03
3	5.39	23.18
4	6.59	22.03
5	6.43	19.69

Considering the above data, using the MATLAB code, can be found a function of correlation between the angle and the jump length (Figure 6):

$$\begin{aligned} L(\theta) = {} & -0.017\theta^3 + 1.057\theta^2 \\ & - 21.46\theta + 153.2. \end{aligned} \tag{5}$$

The regression coefficient for the Relation (5) is $R^2 = 0.9025$.

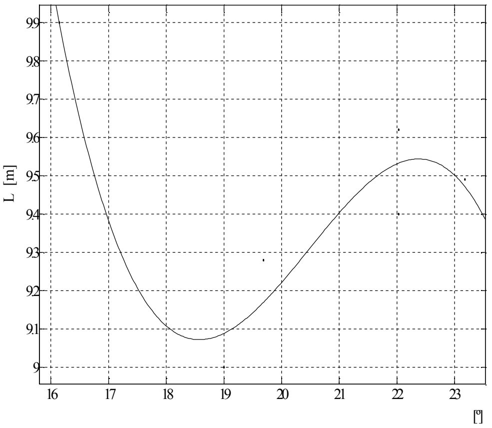

Fig. 6. *The curve interpolation for resultant angle vs. jump length*

The realised simulations lead to a polynomial approximation.

4. Conclusions

The long jump consists of four phases that have their role in a good performance. As is mentioned in many papers the moment of take-off has a key role established by the two velocities of the athlete: the horizontal v_x and the vertical v_y.

The aim of this paper was to present the theoretical concepts of the long jump trial and to find mathematical equations, which can make an approximation of the jump length according with the two velocities. Based on data measurements made in situ there were obtained the Relations (1) and (2).

As it can be seen from Figures 3 and 4 these approximations give for two different velocities the same value of the jump length.

These incongruities are mainly caused by the variable behaviour of the athlete. The considered athlete was a junior one that has not defined yet a good technique of jumping.

In the same time another cause of differences is considered to be the difference behaviour between the beginning and the end of the training. The values presented in Table 3 were the best values from the same training considering the whole period of two weeks of training.

The values that have to be used for the functions described by relations (1)...(5) are limited to the range of the abscissa.

As it can be seen in different papers [2] and [25], the best approximation of the long jump is to consider the jumper as a projectile but this assumption is a proper one only in the case of a world-class long jumper.

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