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A method for the analysis of the take-off and the flight start in the long jump

O metodă de analiză a desprinderii și a debutului fazei de zbor din proba de săritură în lungime

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Abstract

Background. In order to improve the technique of the long jump, aimed at achieving performance, a detailed analysis of each phase of the jump is done.

Aims. In this paper, a method of analysing from a mechanical point of view the moment of the take-off (both take-off velocity and take-off angle) and the beginning of the flight phase is presented.

Methods. The used method is based on the video data processing for some athletes during the performance test, records obtained with a high-speed video camera.

Results. Using the Adobe After Effects code, the markers' trajectory was analysed, and the main coordinates of these markers were obtained. Through the MATLAB code, calculations for both the take-off velocity and the take-off angle were completed.

Conclusions. The jumper's take-off velocity with its two components (vertical and horizontal) and the take-off angle have a major influence on the length of the jump.

Keywords: biomechanics, movement analysis, long jump, take-off velocity, take-off angle

Rezumat

Premize. În vederea îmbunătățirii tehnicii de executare a săriturii în lungime, care are ca scop obținerea performanței, se realizează o analiză, cât mai detaliată, a fiecarei faze a săriturii.

Obiective. În acest articol este prezentată o metodă de analiză a fazei de desprindere, cât și a debutului fazei de zbor, din punct de vedere mecanic (viteza de desprindere, unghiul de desprindere).

Metode. Metoda de analiză are la bază prelucrarea înregistrărilor video ale unor atleţi în timpul executării probei, înregistrări obținute cu o cameră video de mare viteză.

Rezultate. Cu programul Adobe After Effects a fost urmărită traiectoria markerilor, ulterior obţinându-se coordonatele acestor markeri. Prin intermediul programului MATLAB s-a realizat calculul vitezei de desprindere și a unghiului de desprindere.

Concluzii. Viteza de desprindere a atletului, cu cele două componente ale sale, componenta verticală si cea orizontală, cât și unghiul de deprindere au o influență majoră asupra lungimii săriturii.

Cuvinte cheie: biomecanică, analiza mişcării, săritura în lungime, viteza de desprindere, unghiul de desprindere.

Introduction

The subject of this paper is based on the interest in the human ability to set new records in athletic tests. The aim of exercise biomechanics is to improve the mechanical efficiency of the human body forces and to indicate practical methods to increase performance, depending on the purpose of training. The athletic trial selected in the present work is the long jump test, including a very important stage of it, which is thoroughly analysed, especially from a mechanical point of view. The long jump phases, in the order of their succession, are as follows (Burcă et al., 2010; Hay et al., 1990; Ionescu-Bondoc, 2007; Mihăilă et al., 2008): the run-up, the take-off, the flight, and the landing.

The take-off is considered an essential phase in the long jump test, being at the same time the most difficult one because during the execution of this phase the entire system of forces is recovered, especially at the time of getting vertical speed and keeping as much as possible horizontal speed, and these components require a high performance level. From a biomechanical point of view, the take-off is very difficult to perform. This difficulty is given by the driving actions at the time of the contact with the ground, by the switch to the flight phase, resulting in

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the ground run-up of the athlete.

A segmentation of this phase into successive moments includes:

- the moment of placing the take-off foot on the board;
- the moment of shock taking up;
- the moment of active take-off.

At the time of the take-off, the horizontal velocity developed in the run-up phase decreases by 1-2 m/s, which represents 9.5-14% of the take-off velocity. The high value of the correlation coefficient (r = 0.66) between the decreasing horizontal velocity and the increasing vertical velocity indicates the fact that specific decrease is higher when both the projection angle of the athlete's mass centre (MC) and the height of the jump (trajectory) increase (Popov, 1971; Tiupa et al., 1982).

In the case of research performed on a sample of elite athletes, it appears that the distance of the jump is mainly influenced by horizontal speed, the value of the correlation between horizontal speed and the jumping distance being D = 0.79, and that of the correlation between vertical speed and the jumping distance D = 0.68 (Nigg, 1974).

Research carried out on a diversified group of long jumpers (in terms of performance) showed that the jump distance is influenced by the dominant vertical speed (Ballreich et al., 1986; Kollath, 1982).

According to Popov, it is better to obtain a projection angle of the detachment around 20-22º; a higher value than the above mentioned involves a higher influence of the take-off velocity, and a lower value of the angle influences the ground run-up force (Popov, 1971).

From a mechanical point of view, the ideal take-off angle is 45º, but this statement is based on the assumption that the speed issue is a constant that is independent of the projection angle; in reality, however, neither the speed nor the take-off angle is independent. Depending on both the take-off speed and the processing power of the upward force, take-off angles between 22-28º are found.

One way of calculating the optimum take-off angle is given by Tsuboi. The proposed model of the take-off includes three parameters: horizontal velocity of the mass centre, speed and angle of the take-off. The optimum take-off angle is determined as a function of these parameters. Fig. 1 illustrates the take-off model characterised by three parameters V, w and ψ. The V parameter defines the horizontal velocity of the athlete's mass centre, which before represents the run-up velocity. The w parameter is the take-off speed generated by the foot jump, and Ψ is the take-off angle that represents the angle between the horizontal velocity of the mass centre and the take-off speed (Tsuboi, 2010).

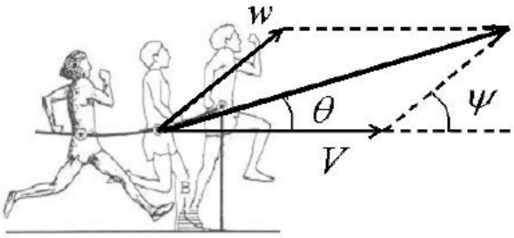


Fig. 1 – The take-off model (Tsuboi, 2010).

Considering the model described above, one can find the take-off speed component (u_i, v_i):

$$u_i = V + w\cos\psi \tag{1}$$

$$v_i = w\sin\psi \tag{2}$$

from which the angle of the resultant velocity θ is obtained (Fig. 1):

$$\tan\theta = \frac{v_i}{u_i} = \frac{w\sin\psi}{V + w\cos\psi} \tag{3}$$

Based on Fig. 1 and relations (1) - (3), the optimum take-off angle relation is obtained (Tsuboi, 2010):

$$\cos\psi_{opt} = \frac{1}{3}\left(\frac{V}{w}\right)\left\{\frac{1}{2} + \left(\frac{w}{V}\right)^2 + \frac{gh}{V^2}\right\}\left(2\cos\frac{\varphi}{3} - 1\right) \tag{4}$$

where

$$\cos\varphi = -1 + \frac{27}{2}\left(\frac{w}{V}\right)^2\left\{\frac{1}{2} + \left(\frac{w}{V}\right)^2 + \frac{gh}{V^2}\right\} \Big/ \left(\frac{1}{2} + \left(\frac{w}{V}\right)^2 + \frac{gh}{V^2}\right)^3 \tag{5}$$

and h is the vertical displacement of the mass centre (MC).

Long jumpers during the flight phase move due to inertia. From the take-off moment, the jumper's MC is influenced by gravity and an accelerated motion follows with a uniform downward acceleration that is the acceleration of gravity. In terms of vertical motion, in the first half of the jump, the jumper's MC has a uniform slowed rise, and in the second half, it falls uniformly accelerated (Mihăilă et al., 2008). The proposed model of the jumper's body was validated by an experimental test consisting of video data recording with a high speed camera (AOS X - PRI).

Hypothesis

The aim of this paper is to develop a method, based on a mechanical concept, which can offer the possibility to analyse the take-off phase from the moment of ground run-up and the flight phase.

Material and methods

The following aspects were presented to each athlete: the nature of the research, the fact that the obtained data will be strictly used for research purposes, and at the end of the tests, each athlete and each coach signed an informed consent regarding their involvement in experimental research. The records were done during training, without any disturbance of the athletes' activity.

Research protocol

a) Period and place of the research

The experimental records were done during training in a summer camp conducted by the Athletics Squad at the National Sports Complex located in Poiana Brasov. The tests were performed during a period of two weeks in July, 2014.

b) Subjects and groups

The research included four international long jump athletes with high level competition performance: two females and two males. All of them were members of the

Romanian National Athletic Team and they had different jump techniques.

c) Tests applied

The data were obtained based on the trajectory of special coloured markers that were attached on each athlete's body (Fig. 2). The positions of the markers were established considering both the mechanical model and the suggestions and acceptance of the trainers. The position of each marker was chosen on the same side as the video camera, at a proper distance. The video recorded data were later used to analyse the motion trajectory (Mihălcică et al., 2014a).

Fig. 2 – Attachment of markers.

d) Statistical processing

All four jumpers performed 10 jumps. The jumpers' trajectories were recorded with a video camera that had a resolution of 800x600 pixels at 500 frames/s.

Using the recorded images of the markers, based on inverse kinetics, accelerations and velocities can be found. Also, considering the video records of the markers, the geometrical dimensions of the body segments and the angles between them can be established.

Results

The recorded data were processed with the Adobe After Effects code. The code allows obtaining the main motion trajectory and can be used in professional video editing and visual effects creation (Christiansen, 2007). Fig. 3 shows the trajectory of the jumper's mass centre.

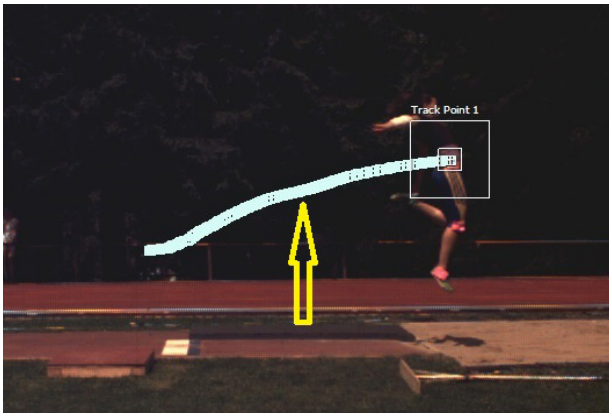
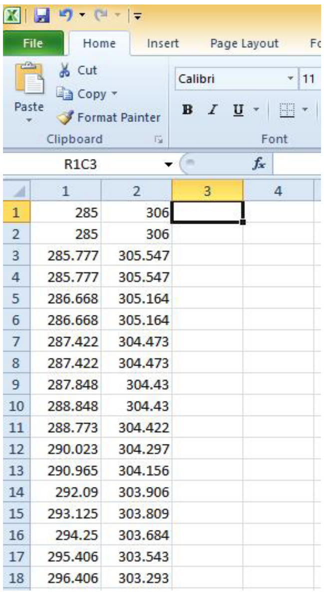


Fig. 3 – Marker position-based trajectory (Adobe After Effects).

The Adobe After Effects code is not specially designed for direct motion analysis. The code does not achieve export of automatic marker coordinates. As a result, it is necessary to copy the recorded data in a desired format to be processed with a specialised program (Mihălcică et al., 2014b). The specialised code used was EXCEL (Fig. 4).



	1	2	3	4
1	285	306		
2	285	306		
3	285.777	305.547		
4	285.777	305.547		
5	286.668	305.164		
6	286.668	305.164		
7	287.422	304.473		
8	287.422	304.473		
9	287.848	304.43		
10	288.848	304.43		
11	288.773	304.422		
12	290.023	304.297		
13	290.965	304.156		
14	292.09	303.906		
15	293.125	303.809		
16	294.25	303.684		
17	295.406	303.543		
18	296.406	303.293		

Fig. 4 – Marker position exported in EXCEL.

Based on converted data in EXCEL, the facilities of the MATLAB code were used for the analysis of some important phases of the long jump: the last stride of the approach run-up, the take-off, and the start of flying through the air (Mihălcică et al., 2014b; Guiman et al., 2014).

Considering the measured data, a graphical representation of the real motion could be completed. From a mechanical point of view, it was useful to find, considering experimental data, an approximate equation of the jumper's trajectory within an acceptable range.

Polynomial approximations were performed. Trajectory approximation considering the path markers by this method is beneficial as multiplication coefficients are determined, based on which other parameters such as speed or acceleration can be derived.

Considering the case of a second degree polynomial function approximation, the shape of the trajectory should be given by:

$$y = a_0 + a_1 x + a_2 x^2 \qquad (6)$$

which by first derivative leads to the velocity relation:

$$\dot{y} = 2a_2 x + a_1 \qquad (7)$$

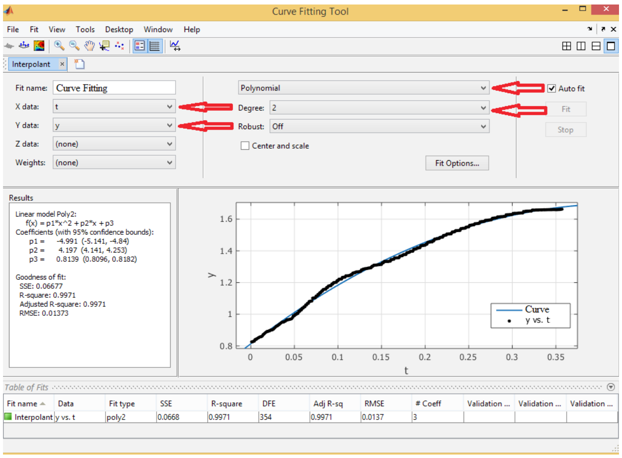
and by second derivative leads to acceleration:

$$\ddot{y} = 2a_2 \qquad (8)$$

Using the routine *cftool* of the MATLAB code, in the *Curve Fitting Tool* window (Fig. 5) (Mihălcică et al., 2014c), the following were obtained:

- abscissa data - time, in this case;
- ordinate data - jump height;
- degree of the polynomial function (second degree in this case).

The code allowed determining the coefficients of the relation (6). Based on the coefficients found, the graph of the equation (6) and the graph obtained from the considered experimental data could be compared. At the same time, the regression coefficient could be found for an image of the accuracy of the approximation that was performed (Fig. 5).



Fit name: Curve Fitting

X data: t

Y data: y

Z data: (none)

Weights: (none)

Polynomial

Degree: 2

Robust: Off

☐ Center and scale

☑ Auto fit

```
Linear model Poly2:
    f(x) = p1*x^2 + p2*x + p3
Coefficients (with 95% confidence bounds):
      p1 =     -4.991  (-5.141, -4.84)
      p2 =      4.197  (4.141, 4.253)
      p3 =     0.8139  (0.8096, 0.8182)

Goodness of fit:
  SSE: 0.06677
  R-square: 0.9971
  Adjusted R-square: 0.9971
  RMSE: 0.01373
```

Fit name	Data	Fit type	SSE	R-square	DFE	Adj R-sq	RMSE	# Coeff	Validation ...	Validation ...	Validation ...
🟩 Interpolant	y vs. t	poly2	0.0668	0.9971	354	0.9971	0.0137	3			

Fig. 5 – Selected options in the *Curve Fitting Tool* window.

Considering the facilities of the code (*File->Print to Figure->Edit->Figure Properties*) (Fig. 6), the comparison between the recorded data and polynomial function approximation is highlighted.

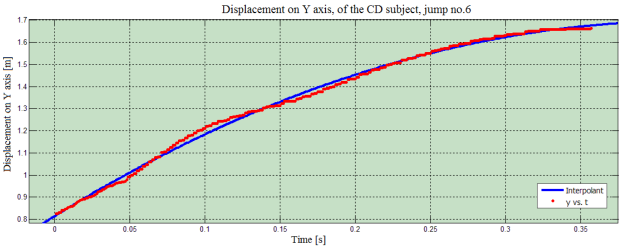


Fig. 6 – Jump height vs. time.

Another representation refers to the length of the jump. Based on the *Curve Fitting Tool* (Fig. 5), the following data were found:

- abscissa data - time, in this case;
- ordinate data - jump length;
- degree of the polynomial function (first degree in this case).

Again, a comparison between the recorded data and polynomial function approximation was made (Fig. 7).

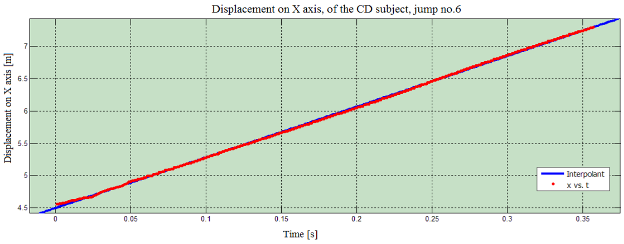


Fig. 7 - Jump length vs. time.

Denoting with V_x the horizontal velocity of the mass centre (MC) at the take-off and with V_y the vertical velocity of the mass centre (MC) at the same moment, the take-off angle of the mass centre relative to the horizontal direction is given by the relation:

$$tg\,\theta = \frac{V_y}{V_x} \tag{9}$$

and the angle value results:

$$\theta = arctg\left(\frac{V_y}{V_x}\right) \tag{10}$$

Considering the relations (9) and (10), the angle of the mass centre relative to the horizontal direction can be obtained.

Discussions

From an experimental point of view, the presented method provides some facilities. The system used is an integrated one, allowing its application to similar research. At the same time, data recording requires a laptop and a high speed video camera, both with batteries. Experimental data regarding the long jump trial can be obtained indoors or outdoors. The ideal recording environment is outdoors (e.g. stadiums), where there is natural light, while indoors, additional light sources are needed.

From the point of view of processing, the proposed method is a simple one and involves the use of a code that has special data processing and curve fitting facilities. The obtained data were processed using a video code and a specialised mathematical code. At the end, based on measurements, different approximation curves as well as polynomial approximations could be defined.

Conclusions

1. Generally, the parameters that influence the quality of the long jump are: the length of the run-up, the run-up velocity, the moment of the take-off, the angles between different parts of the athlete's body, the take-off angle of the mass centre in relation to the horizontal direction, the take-off velocity of the mass centre with its two components (horizontal and vertical).
2. The main parameters that can increase the athlete's performance are the take-off velocity and the take-off angle.
3. The above model can be applied to increase and optimise the performance of jumpers considering their human driving forces.

Conflicts of interests

There are no conflicts of interests.

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