BIOMECHANICAL STUDY ATHLETES' MOVEMENT TECHNIQUES IN THE HURDLES (ON EXAMPLE OF PHASE OF FLIGHT)

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Annotation. _Purpose:_ To design a theoretical biomechanical model of athletes' movement techniques in the hurdles and then check there movements on real athletes. _Material_: In the practical part of the study participated 10 smortsmen. _Results_: Showing the possibility of constructing a theoretical model of hurdling technique. The basis of constructing a model using the known approaches in theoretical mechanics. Shows the calculated and actual performance movement of the athlete. _Conclusions_: The developed model provides a good theoretical understanding of the interactions of individual elements of movement and the ability to simulate different situations and to determine the optimal values of the kinematic and dynamic characteristics of the movement of the athlete. The model allows the individual elements of motion correction directly in the process of training. When analyzing art movement should consider specific features of physical development and anthropometric characteristics of the athlete's body.
Keywords: model, biomechanics, hurdling, flight, phase.

Introduction

Simulation of different movements in sport functioning is an important element of analysis of its structure and its components, such as speed, acceleration, kinematic and dynamic characteristics. Alongside with it, with building of model itself it is necessary to know kind of sport and its characteristic features. Also it is important to correctly understand interconnections between separate elements of movement. All these in complex permit to create certain mechanical copy of actual movement. One of obstacles for creation of reliable model can be absence of possibility of its workability practical testing. However, even theoretical model creates good preconditions to constructing of real movement ot to correction of its separate elements. That is why, bio-mechanical simulation is one of components of training and perfection of movements of both" beginners and experienced sportsmen.

In this context solution of practical tasks of sportsmen's preparation can be found on example of hurdling, whose important component is flight phase. It is known that sport result in hurdling is determined, mainly, by rational bio-mechanical characteristics, which a sportsman is able to realize at stages of smooth run and in flight phases. In flight phase such characteristics are determined by speed of pushing off, angle of take off, distance from barrier to center of sportsman's body mass (CBM), sportsman's CBM position in phases of pushing off and overcoming barrier, considering resistance of air.

Problems of creation of bio-mechanical models have been sufficiently elucidated in different works, oriented on solution of both general and approximated to certain kinds of sports tasks. It is necessary to specify fundamental works of such scientists like N.A. Bernstein [4], A.N. Laputin [15], D.D. Donskoy [11], S.V. Dmitriyev [10], who actually determined general direction of bio-mechanical models' creation and, thus, made basis and permitted building of certain sportsmen's movements.

Among other works, we can mark out the, works, oriented on certain kinds of sports: outdoor games (N.A. Nosko) [19]; S.V. Stroganov [26]), arm wrestling (L.V. Podrigalo, M.N. Galashko, N.I. Galashko [22]), run and walking (S.S. Yermakov, V.M. Adashevskiy [12]; V.M. Adashevskiy, S.S. Yermakov, Ye. Ziyelinskiy [2]; G.P. Shepelenko, Kr. Prusik, K. Prusik, S.S. Yermakov [33]), thae-quan do (V.M. Adashevskiy, S.S. Yermakov [1]), weight lifting (S.V. Sulim, K.N. Sergiyenko, A.V. Bakum [27]), track and fields (R.F. Akhmetov [3]; Leite Werlayne [39]), gymnastics (V.A. Potop, R. Grad, V.N. Boloban [23]; V.A. Potop, R. Grad, V.N. Boloban, A.P. Otsupok [24]). Besides, a number of researches of hurdling is reflected in publications of domestic and foreign authors: problems of technical training of junior hurdlers [16], women [17], general problems of sportsmen's trainings [20, 25, 35]. Bio-mechanical [3, 6, 12, 34, 36-38, 40-42] and other problems of sportsmen's training in track and fields and hurdling were reflected in some works [7-9, 14, 18, 28-32]. Among researches of hurdling bio-mechanical parameters the work by V.V. Mekhrikadze, V.V. Cherenev of 2008 [5] is of special interest. The authors note that technical level of hurdling step is conditioned by continued fulfillment of all five phases by the most flat trajectory of GCBM movement, the highest point of which is in front of barrier.

Alongside with it problems of hurdling technique still require more profound study, considering new conditions of sportsmen's training, moder equipment and technical devices.

Purpose, tasks of the work, material and methods

The purpose of the work is to build theoretical, bio-mechanical model of sportsman's movements with its further testing by real sportsmen's movements.

The tasks of the research:

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- to compose calculation schema for determination of influence on efficiency of push off speed, sportsman's center of body mass take off angle, air resistance, position of sportsman's center of body mass in phase of pushing off and barrier's overcoming.
- to compose physical-mathematical model and solve the task of body flight dynamic.

In the research students-sportsmen of National technical university "Kharkov polytechnical institute" participated. Calculations were fulfilled with the help of program complex "KIDIM", which was worked out at theoretical mechanics department of NTU "KhPI".

Results of the research

Theoretical model of sportsman's movements permitted to mark out characteristics of body flight trajectory depending on the following: initial speed of sportsman's center of body mass take off; CBM take off angle; air resistance; distance from barrier to sportsmen's center of body mass.

At first stage of the research we composed calculation schema for determination of rational parameters in hurdling depending on initial take off speed, take off angle, height of take off and sportsman's center of sody mass (see fig.1).

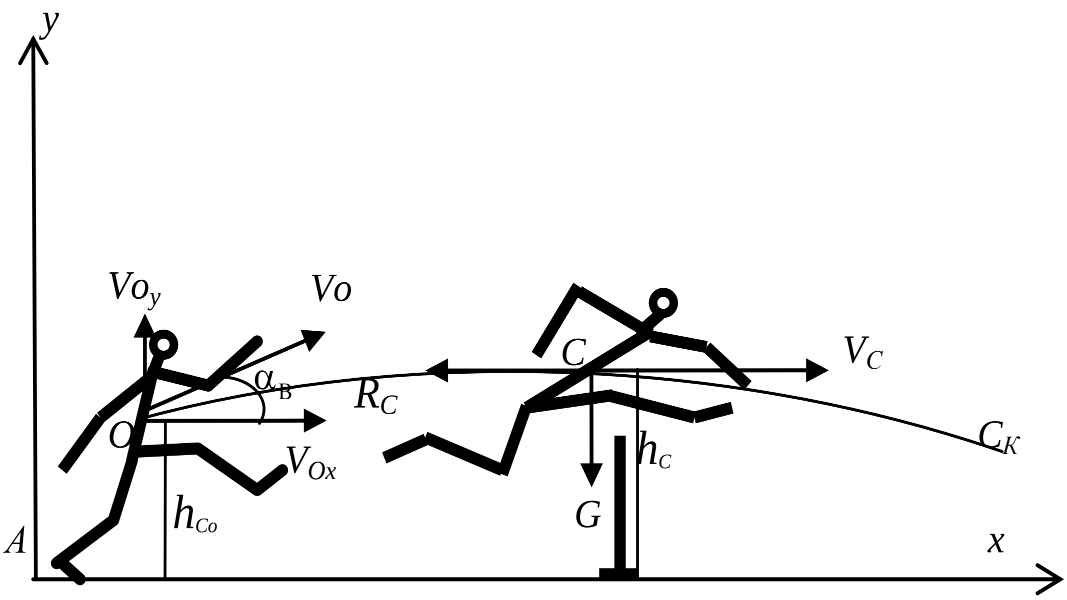


Fig.1. Calculation schema for determination of initial take off speed, take off angle, CMB take off height in front of barrier

V_0 = Vc_0- initial speed of center of mass body, Vo_X – projection of take off of body mass center on axis Ox, Vo_Y – projection of take off speed of body mass center on axis Oy, V - current speed of body mass center.

Now let us regard influence of initial speed of take off, take off angle, height of take off and flight of body mass center, considering variable values of air resistance depending on sportsman's mid-section.

In projections on axes of Descartes absolute coordinates system:

$$v_{Ox} = v_0 \cos\alpha_0; \quad v_{Oy} = v_0 \sin\alpha_0$$

Absolute initial speed of body mass center's take off:

$$v_0 = \sqrt{v_{0x}^2 + v_{0y}^2}$$

h_{Co} = h_0 – height of body mass center's take off at initial moment of take off,

α_0=α_{C0} – take off angle of body mass center,

G – force of gravity of body,

Rc – force of air resistance.

For solution of this task force of air-dynamic resistance *Rc* for bodies, moving in air medium with density ρ, is

$$R_c = 0.5 \cdot c_\tau \rho s V^2 ; \; R_c = kV^2 .$$

With calculation of these forces non-dimensional coefficients of frontal resistance c_τ are determined depending on form of body and its orientation in medium. Value S (mid section) is determined by value of projection of cross section's area on plane, perpendicular to axis of movement.

V – absolute speed of body.

Air density - $\rho \approx 1.3 кг/м^3$.

Owing to the fact that sportsman's body changes position in flight, value of mid-section S also changes. With solution of this task we assume averaged variable values of mid-section S and coefficient of frontal resistance C_τ, and, accordingly, coefficients (к) for 6- intervals of flight time.

First let us determine (position) of coordinate of body mass center in the moment of barrier's overcoming for its rational posture, which, in chosen system of calculation, are to be determined by the following formulas:

$$x_C = \frac{\sum_{k=1}^{n} m_k x_k}{\sum_{k=1}^{n} m_k}; \quad y_C = \frac{\sum_{k=1}^{n} m_k y_k}{\sum_{k=1}^{n} m_k}$$

$\sum_{k=1}^{n} m_k$ = m – mass of bio-mechanical system,

$x_к$, $y_к$ – coordinated of center of body mass segments.

We obtain x_c = 0,0013m, y_c =0,14m, for system of Descartes coordinates OXY, which is rigidly connected with human body, with starting of counting in anthropometrical point, belonging to top of spine of fifth lumbar vertebra.

Considering position of lower limbs in the moment of barrier's overcoming, minimal rational height of body mass center above barrier in average shall be within 0.3-0.4m.

Because of sportsman body's moving in one of anatomical planes – sagittal, we can compose equations of dynamics in projections on two axes of coordinates: Так как тело спортсмена

$$m\ddot{x}_c = P_x^e; \quad m\ddot{y}_c = P_y^e .$$

Here m - mass of body, $\ddot{X}_c, \ddot{Y}_c$ - correspond to projections of acceleration of body mass center, P_x^e, P_y^e - projections of resultant, acting on body

With moving in plane *xAy*, system of equations can be written in the following way:

$$m\ddot{x} = -R_{c_X}; \quad m\ddot{y} = -G - R_{c_Y};$$

$$m\ddot{x} = -R_c \cos\alpha; \quad m\ddot{y} = -mg - R_c \sin\alpha;$$

$$\cos\alpha = \dot{x}/v; \quad \sin\alpha = \dot{y}/v; \quad v = \sqrt{v_x^2 + v_y^2} = \sqrt{\dot{x}^2 + \dot{y}^2}$$

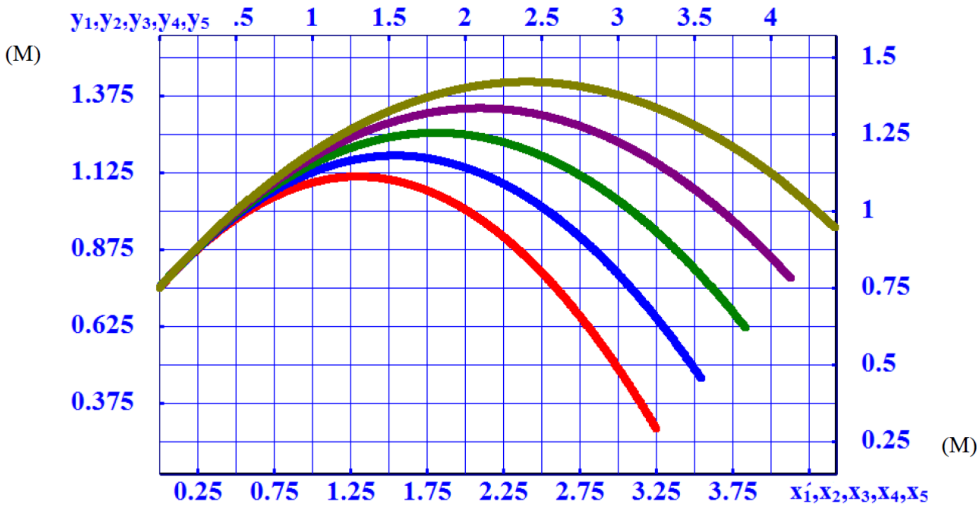
α – angle between projections, speed of body mass center and vector of its speed, determining signs of projections of forces' vectors on coordinates' axes.

Solution of this task requires integrating of differential equations of movement.

We obtain graph dependences of parameters of hurdling trajectories:

- on absolute initial take off speed of body mass center in front of barrier with assumed take off angle and body mass center's height (see fig.2);
- on take off angle of body mass center with assumed value of initial take off speed (see fig. 3);
- on initial height of body mass center with assumed values of initial take off speed and take off angle (see fig. 4);
- on air resistance forces (see fig. 5);
- on horizontal distances of body mass center's take off from barrier (see fig. 6).

trajectories: $y_1(x_1)$, $y_2(x_2)$, $y_3(x_3)$, $y_4(x_4)$, $y_5(x_5)$



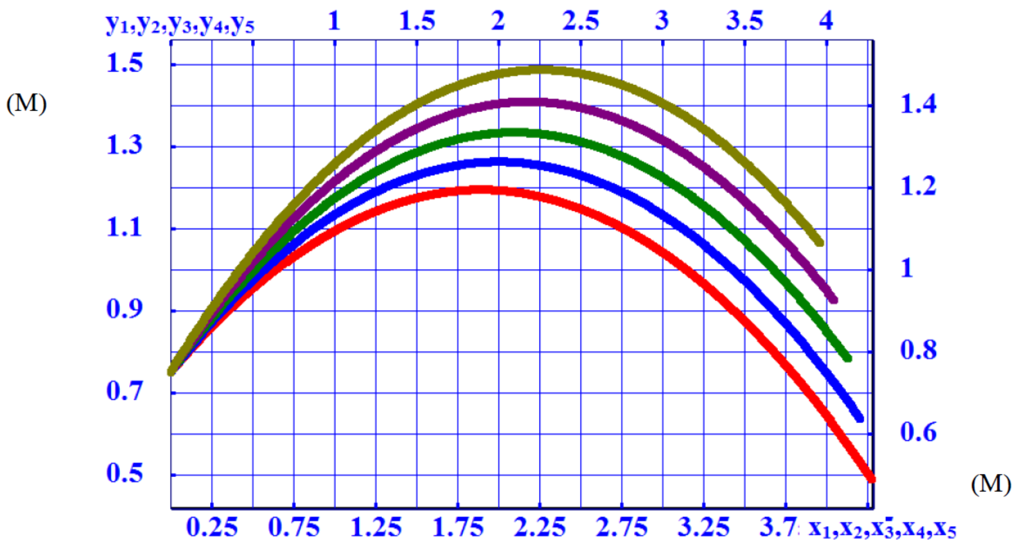
V_0=7.5 м/с; V_0=7. 0м/с; $_0$=6.5м/с; V_0=6.0 м/с; V_0=5.5 м/с.

$k_1 - k_5$=0.25-0.18-0.12-0.15-0.2 кг/м; $\alpha_0=\alpha_{C0}=29^0$; h_{C0}=0.7 5м; t=0.68с.

Fig 2. Comparative curve characteristics of trajectories in flight phase, depending on initial speeds of body mass center's take off

Analysis of comparative graphs of trajectories in flight phase, depending on initial speeds of body mass center's take off shows that sportsmen with higher initial take off speed V_0 =7.5 m/sec; contact with track after overcoming of barrier at greater distance from barrier that, accordingly, improves results of run. Sportsmen with little initial take off speed V_0 =5.5 m/sec; contact with track after overcoming of barrier at less distance that, in some cases can pull off barriers owing to critical height of body mass center above barrier that, accordingly worsens results of run.

trajectories: $y_1(x_1)$, $y_2(x_2)$, $y_3(x_3)$, $y_4(x_4)$, $y_5(x_5)$



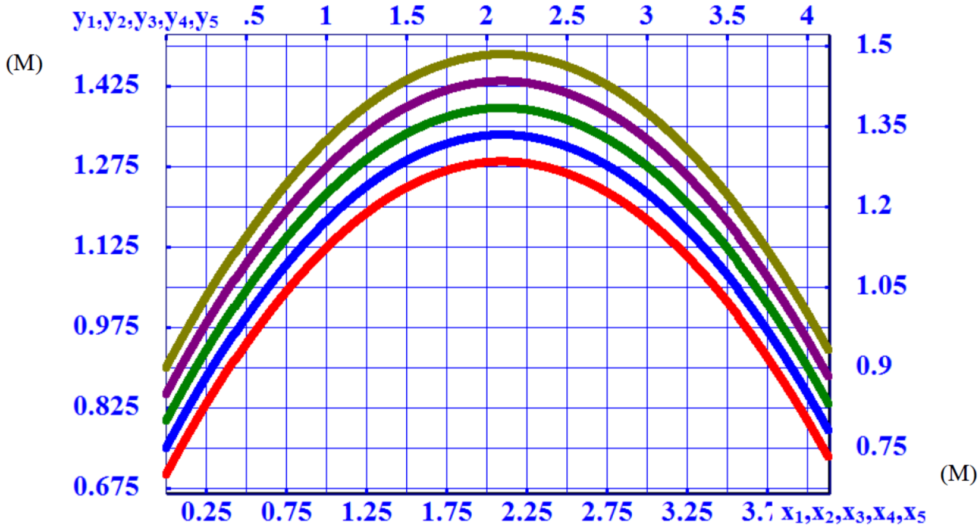
$\alpha_0 = 33^0$; $\alpha_0 = 31^0$; $\alpha_0 = 29^0$; $\alpha_0 = 27^0$; $\alpha_0 = 25^0$

$k_1 - k_5$=0.25-0.18-0.12-0.15-0.2 кг/м; V0 =7.0 м/с; h_{C0}=0.7 5м; t=0.68с.

Fig 3. Comparative curve characteristics of trajectories in flight phase, depending on take off angles of body mass center

Analysis of comparative graphs of trajectories in flight phase, depending on take off angles of body mass center shows that choice of the least rational take off angles ($\alpha_0 = 29^0$), also significantly improves results. It should be noted that with little take off angles ($\alpha_0 = 25^0$) sportsman can not overcome barrier. That means that take off angles shall be chosen in compliance with physical parameters of certain sportsman and initial parameters of take off.

trajectories: $y_1(x_1)$, $y_2(x_2)$, $y_3(x_3)$, $y_4(x_4)$, $y_5(x_5)$



h_{C0}=0.90м; h_{C0}=0.85м; h_{C0}=0.80м; h_{C0}=0.75м; h_{C0}=0.70м

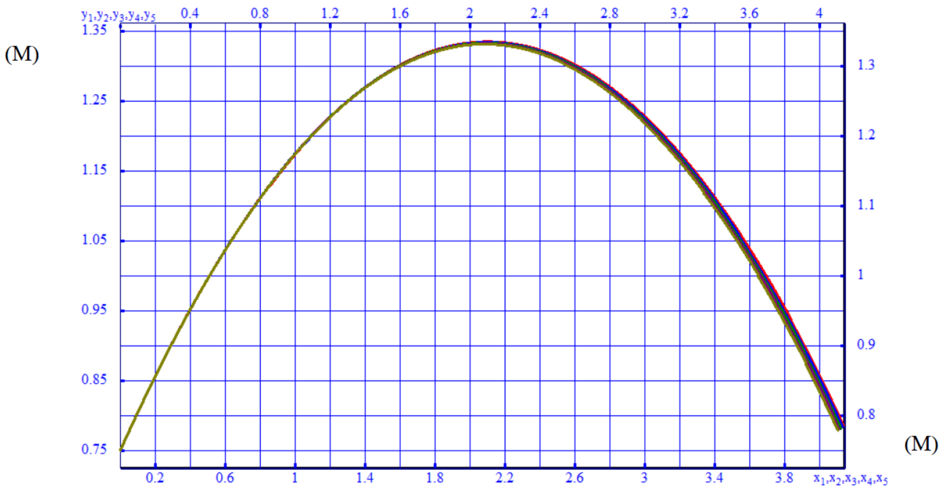
$k_1 - k_5$=0.25-0.18-0.12-0.15-0.2 кг/м; V0 =7.0 м/с; $\alpha_0=\alpha_{C0}=29^0$; t=0.68с.

Fig 4.

Comparative curve characteristics of trajectories in flight phase, depending on take off heights of body mass center

Analysis of comparative graphs of trajectories in flight phase, depending on take off height of body mass center with other constant kinematic and geometric characteristics shows that result changes a little.

trajectories: $y_1(x_1)$, $y_2(x_2)$, $y_3(x_3)$, $y_4(x_4)$, $y_5(x_5)$



$k_1 - k_5$=0.25-0.18-0.12-0.15-0.2 кг/м; k1 – k_5=0.5-0.36-0.24-0.3-0.4 кг/м.

V_0 =7.0 м/с; $\alpha_0=\alpha_{C0}=29^0$; h_{C0}=0.7 5м; t=0.68с.

Fig 5. Comparative curve characteristics of trajectories in flight phase, depending on air resistance forces

Analysis of comparative graphs of trajectories in flight phase, depending on air resistance showed that for considered speeds of flight above barriers, air resistance forces influence insignificantly on efficiency. In othwer cases, for example with frontal wind, this influence can be significant.

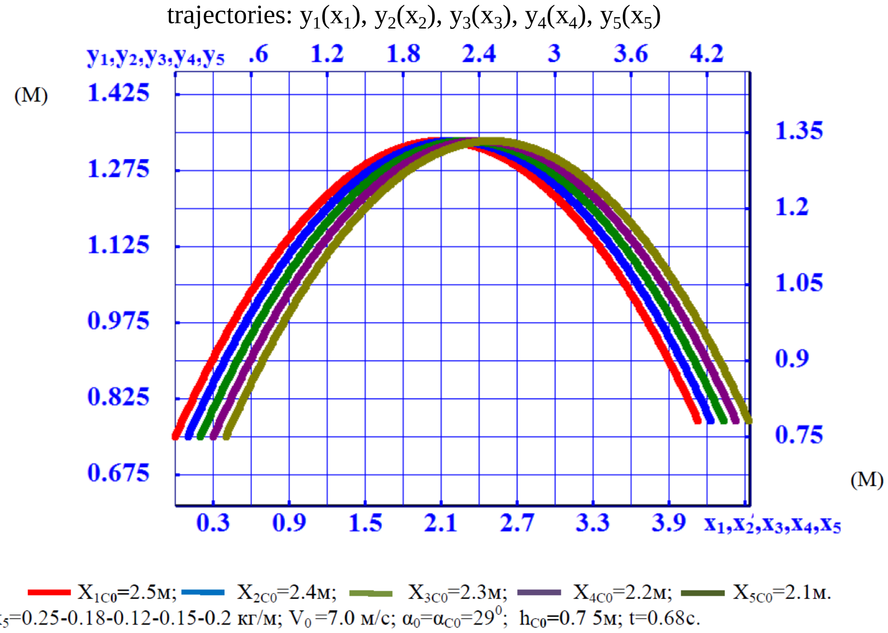
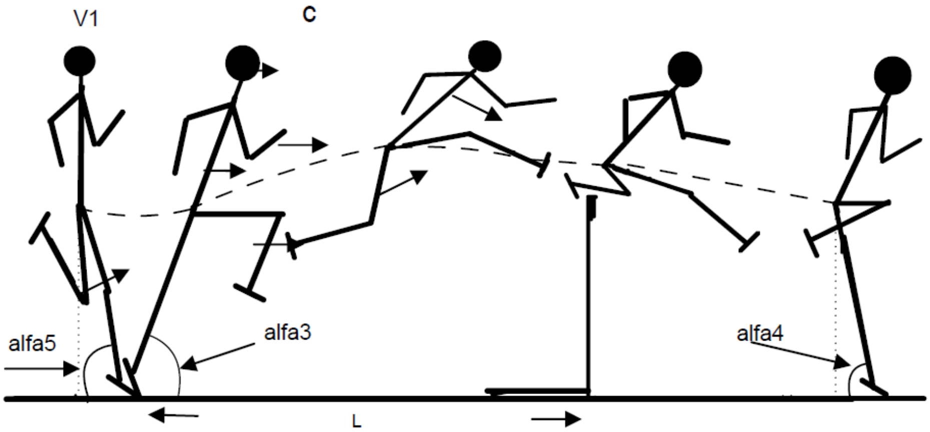


Fig 6. Comparative curve characteristics of trajectories in flight phase, depending on horizontal distance of body mass center take off from barrier

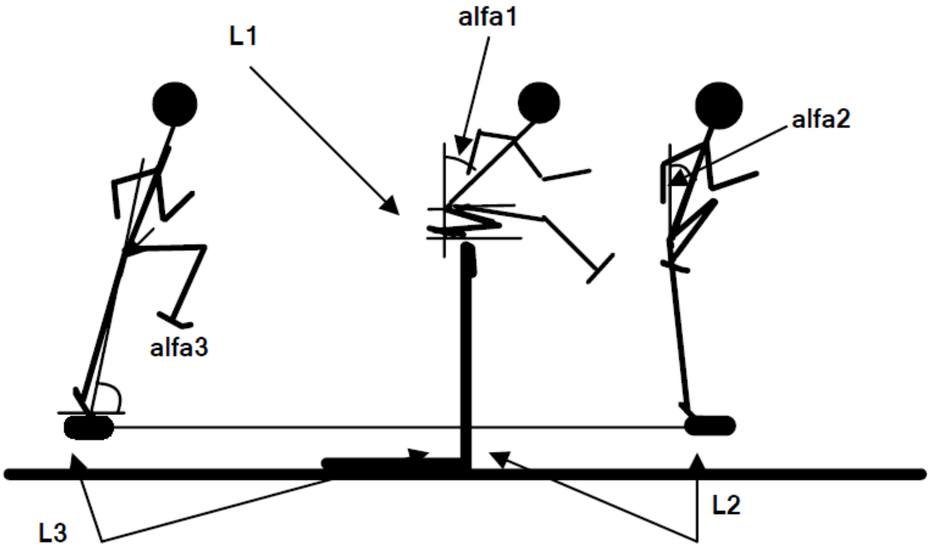
Analysis of comparative graphs of trajectories in flight phase, depending on horizontal distance of body mass center take off from barrier with other constant kinematic and geometric characteristics shows that place of contact with track after flight phase is in reverse proportion to distance of body mass center's take off from barrier. The height of trajectory above barrier also is in reverse proportion to these distances and an have minimal values, with which barriers can be pushed down. with other constant kinematic and geometric characteristics

Thus, using of graph characteristics for determination of hurdling parameters depending on take off speed, take off angle and height it is possible, with its analysis, to correct sportsmen's actions in initial phase and improve result, considering physical parameters and potentials of a sportsman.

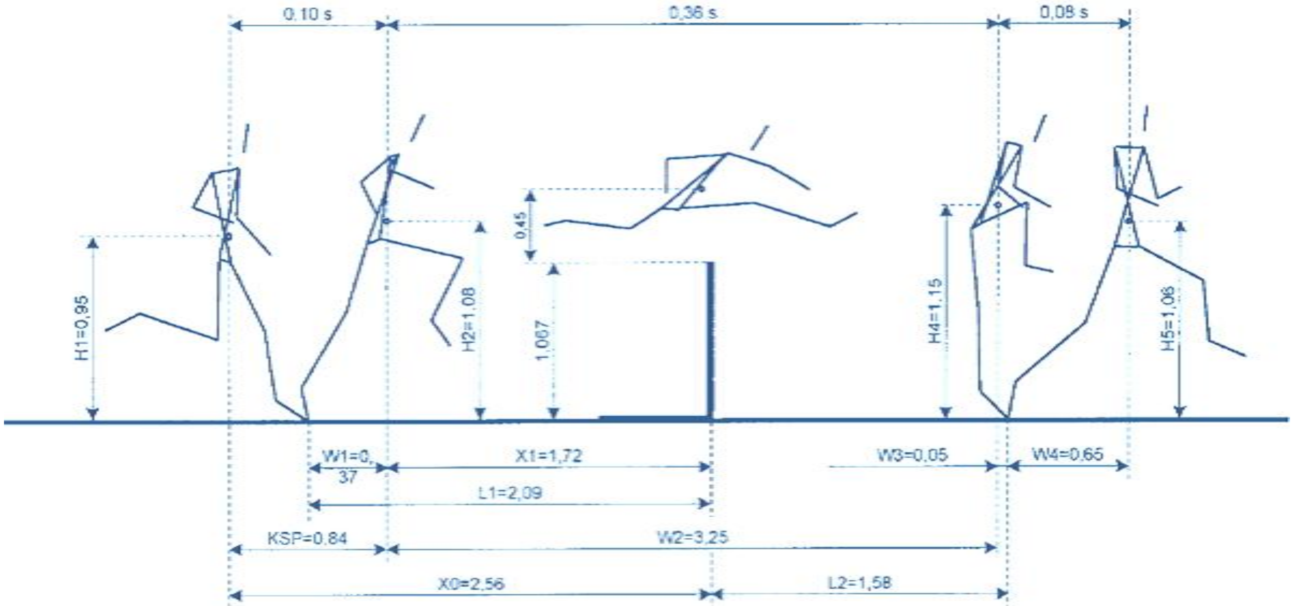
Results of theoretical researches to large extent characterize theoretical aspect of barrier step's fulfillment at distance of 100, 110 and 400 meters for men and women (see fig. 7).



A



B



C

Fig. 7. Kinematic parameters of barrier step (A, B – by data of V.V. Mekhrikadze, L.A. Cherenev , 2008, C – by data of Milan Coh, 2003):

L_1 – distance (cm) from barrier to highest point of GCBM 110 m =14; 100 m = 37; 400 m, men = 38, women = 39; alfa1 – angle of torso bent over barrier: 110 m = 42°, 100 m = 40°, 400, men = 32°, women = 30°; alfa2 – angle of torso bent at landing: 110 m = 27°, 100 m = 24°, 400 m, men = 24°, women = 23°; alfa3 – angle of pushing off; L_2 – distance (cm) from barrier to place of landing 1/3 of barrier step or 110 m = 140, 100 m = 100, 400 m, men = 140, women = 115; L_3 – distance (cm) from place of pushing off to barrier 2/3 of barrier step or 110 m = 209, 100 m = 200, 400 m, men = 225, women = 200; V1 – speed of run before pushing off; C – position of CBM at moment of pushing off; L – distance from place of pushing off to barrier; alfa4 – angle of landing; alfa5 – angle of leg's positioning.

Parameters of hurdling are characterized by high position of CBM before pushing off, high speed and relatively far place of pushing off that permit: 1- push off under more acute angle and land quicker; 2 – fulfill entering barrier in bent position; 3- prevent from jumping acting. In the proves of barrier step separate parts of body – arms, legs, torso come closer to CBM trajectory and facilitate straight and continuous manner of movement [5]. Such approach permits to create optimal parameters in real movements of a sportsman.

Conclusions:

Thus, the worked out model gives sufficient theoretical understanding of interconnections of movements' different elements, as well as permit to simulate different situations and determine optimal values of kinematic and dynamic characteristics of sportsman's movements. The model permits to correct separate elements of movement directly in the process of training. In analysis of movements' technique it is necessary to consider individual physical condition and anthropometrical characteristics of sportsman's body.

The prospects imply improvement of this model on the base of existing systems of movements' video-analysis.

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