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Original article

ELEMENTS OF MATHEMATICAL MODEL FOR STEP IN RACEWALKING

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Abstract

Aim. The aim of the experiment is to realize a simulation based on a mathematical model and to presents a biomechanical model of human body whichever there are studied mechanical work, charts variance on different muscles quarters which training legs and arms, which make more efficient the displacement during the racewalking.

Method. Mathematical and biomechanical models were used by applying specific calculation formulas when calcuating the friction energy created in the lower and upper limbs. The data obtained was processed and illustrated in MATCAD.

Results. The optimal values of the moving angles of the upper and lower limbs were set, in order to generate the most efficient movement while racewalking, and the energy consumed while making these movements to be minimum. The obtained values were used in the simulation training program in C. D.'s case, and led to an improvement in her technique, her arms movement trajectory and the technique of rolling the foot against the ground were improved.

Conclusions. The biomechanical model is able to provide information regarding the proper rotation angles in order to reduce the muscular effort, as well as to perform correct movements technically speaking.

Key words: biodynamics, (friction) energy, efficiency, force systems, rotation angles.

Introduction

The biomechanics of human movement can be defined as the interdisciplinary science which describes, analyzes, and evaluates human motion. The body movements present in human motion are highly complex: from the ordinary strolling to a worker lifting a heavy weight or an athlete's performance. The physical and biological principles involved in various movements are the same. It is just the specificity of the movement and the necessary details that are being changed. (according to Gagea, 2002) Specialists from various fields are interested in the aspect of human body motion: orthopaedists, surgeons, trainers, athletes, engineers in the biomedical field, orthosis and prosthesis specialists, athletic outfits designers and users.

Fig. 1 illustrates segments lengths l1,..., l6, segments weights G1,..., G6, rotation angles in articulations Θ1,..., Θ6, and the xOy axis system in which the movement takes place.

Methods

Biodynamically, the human body is a deformable body subject to various internal or external demands. Due to its soft tissues, bones, joints, internal organs, and also due to its configuration characteristics, generally the human body is a complex vibrating system (according to Gheorghe, 2002).

Starting from the idea of italian trainer Perez (1994), that the correct execution of the racewalking step is very important, as it ensures not only the athlete's presence in the race but it also helps saving energy and getting important performances, we thought it necessary to create *the biomechanical model* of the racewalker. It must be mentioned that this is a theoretical model and the data can afterwards be used on the simulator.

For a complete analysis of walking step, are requires some technical clarifications on this. Alexei (2005) says that the race walking, like running, consists of cyclical movements in the two consecutive steps, simple forms a double step, which constitutes the basic cyclic unit in the technical description of the sample. Perez (1994), gives a definition of art, meaning by this „total psycho-physiological adjustments that allow the engine to adapt their behavior characteristics of the environment, respecting the principle of rationalization and efficiency, and in compliance with the rules imposed by regulation sample."

In this section of the paper we are not set to approach the complex vibratory movements of the human body, but, as a beginning of a series of studies on human body, we are setting a few work variation

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diagrams, work (energy) that needs to be created by the muscle groups which activate the upper and the lower limbs during half the time (limb motion in racewalking).

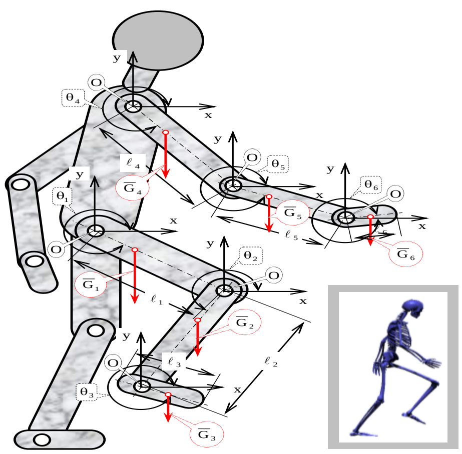


Fig. 1 Mechanic model of the human body used to determine the energy create

Data Analysis.

Results.

Mathematical relations (1) and (2) of the work for each of the two cases, depending on the geometrical parameters described in fig. 1, are set according to the equivalence of the force systems (reduction torque) and from the defining relations of the work in the case of a resulting moment, in relation to the hip joint – for the lower limb, and the shoulder joint – for the upper limb (according to Gheorghe, 2008)

Thus, mayhematically, the work for the lower limb is represented by the following relation:

$$L_{Oz}(\theta_1)=\left[\theta_1\cdot G_1\cdot\frac{1}{3}\cdot\ell_1\cdot\sin\theta_1+\theta_1\cdot G_2\cdot\left(\ell_1\cdot\sin\theta_1-\frac{1}{3}\cdot\ell_2\cdot\sin\theta_2\right)\right]+$$
$$+\theta_1\cdot G_3\cdot\left(\ell_1\cdot\sin\theta_1-\ell_2\cdot\sin\theta_2+\frac{1}{3}\cdot\ell_3\cdot\sin\theta_3\right)$$

(1)

The following mathematical relation corresponds to the work of the upper limb:

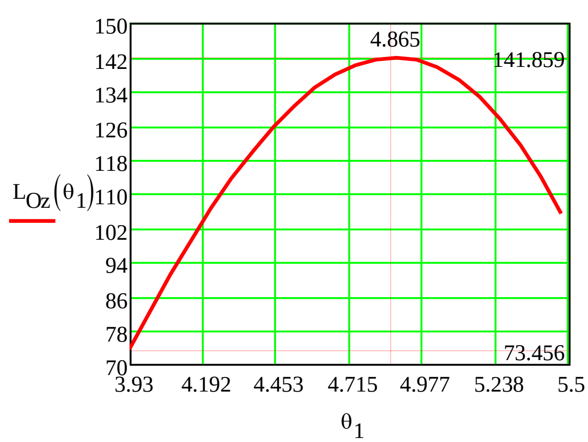
Through complex mathematical relations, described further on, the work from the lower and the upper limbs was calculated and the data was processed and analyzed in MATCAD.

$$L_{Oz}(\theta_4)=\left[\theta_4\cdot G_4\cdot\frac{2}{5}\cdot\ell_4\cdot\sin\theta_4+\theta_4\cdot G_5\cdot\left(\ell_4\cdot\sin\theta_4-\frac{1}{2}\cdot\ell_5\cdot\sin\theta_5\right)\right]+$$
$$+\theta_4\cdot G_6\cdot\left(\ell_4\cdot\sin\theta_4-\ell_5\cdot\sin\theta_5+\frac{1}{2}\cdot\ell_6\cdot\sin\theta_6\right)$$

(2)

The charts for formulas 1 and 2 are presented in figures 2 and 3. Thus, graphical representations (charts) resulted and they highlight the optimal rotation angles inside the upper and lower limbs joints, in order to reduce muscular effort.

Figure 2 a, b, c, d, e, f represent the optimal angles of legs motion. For the sake of exemplification, one can notice the method of determining the optimal angle of rotation for the knee. Thus, for the L (work) created by the lower limb muscle system (fig. 2) the angular position of the knee (*Θ*2) was divided into 6 intervals, and the parameter from the horizontal axis (the rotation angle inside the hip joint - *Θ*1) has values between 3.93 şi 5.5 radians. After the calculations, the results indicated that L (work) has minimum value for *Θ* 2 (knee rotation angle) = 4,68 radians (fig. 2c).



a) $\Theta_2 = 3.93$

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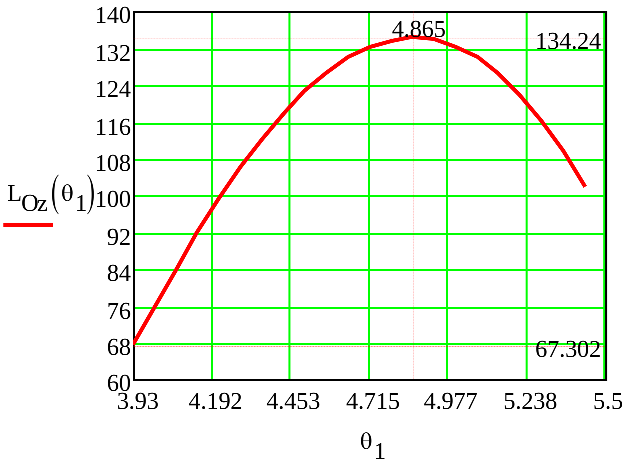
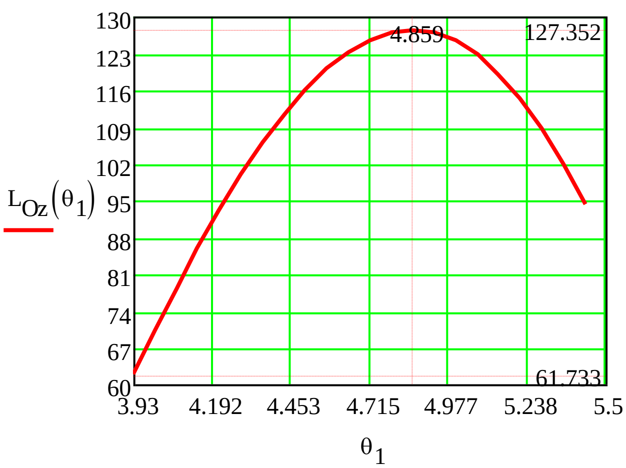
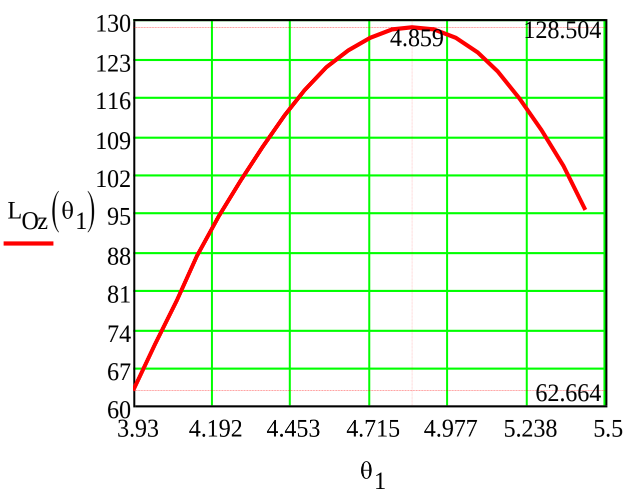


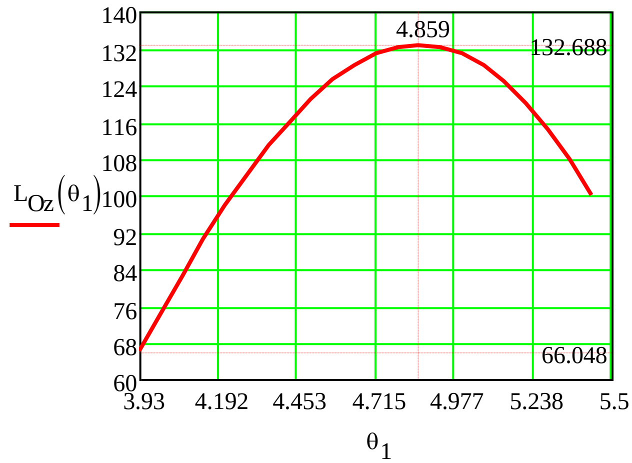
b) $\Theta_2 = 4.18$



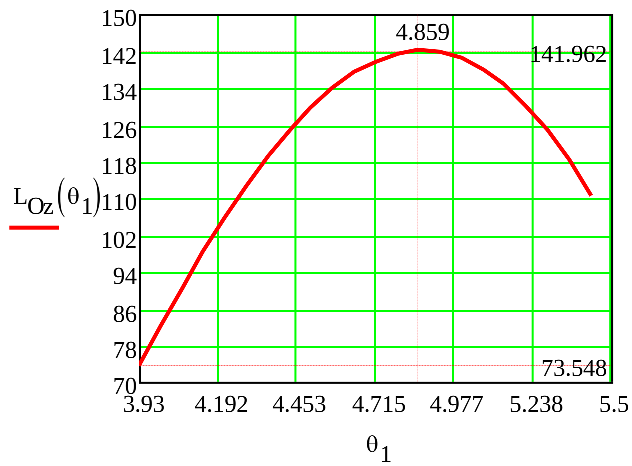
c) $\Theta_2 = 4.68$



d) $\Theta_2 = 4.93$



e) $\Theta_2 = 5.18$



f) $\Theta_2 = 5.498$

Fig. 2. The variation of the lower limb muscle system work (aggregate), depending on the position (Θ_1=3,93 ÷5,498 rad), for the following/previous step, imposing for Θ_2 the fix values in charts a, b, c, d, e and f.

The functioning of the upper limb is presented similarly, case in which graphical charts were made according to the same model (fig. 3 a,b, c, d, e, f).

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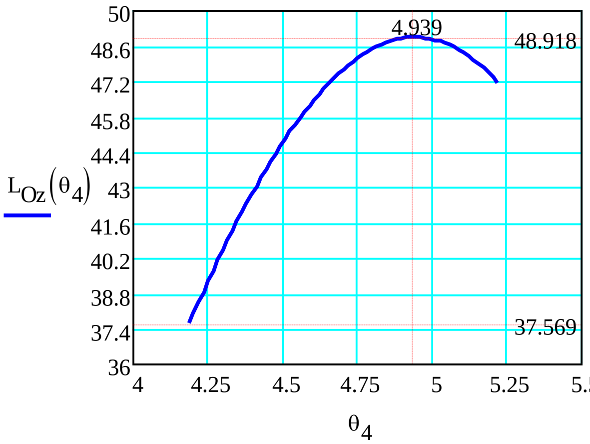
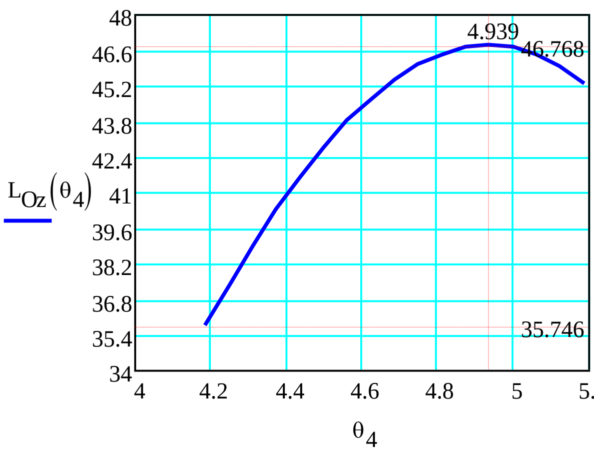
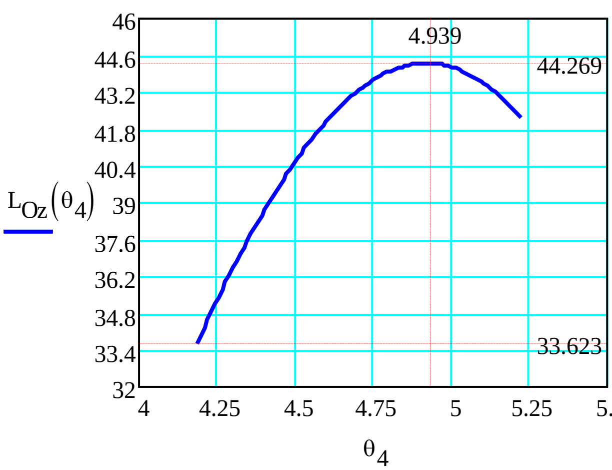


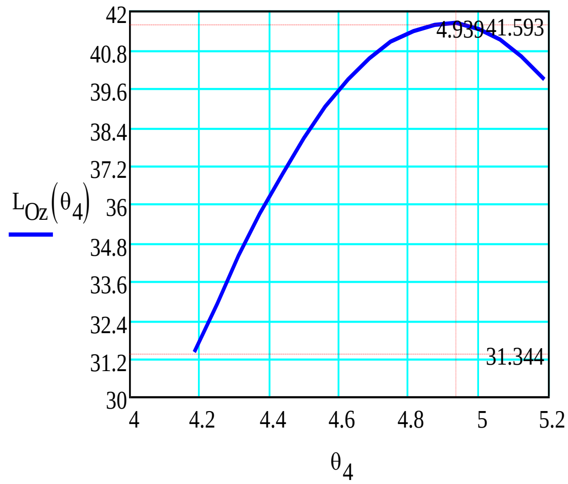
a) $\Theta_5 = 2.356$



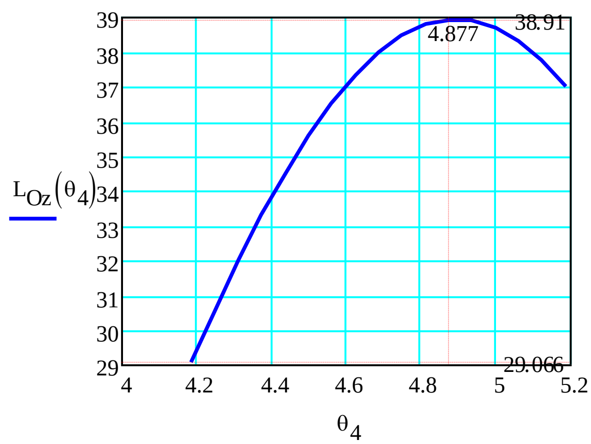
b) $\Theta_5 = 2.618$



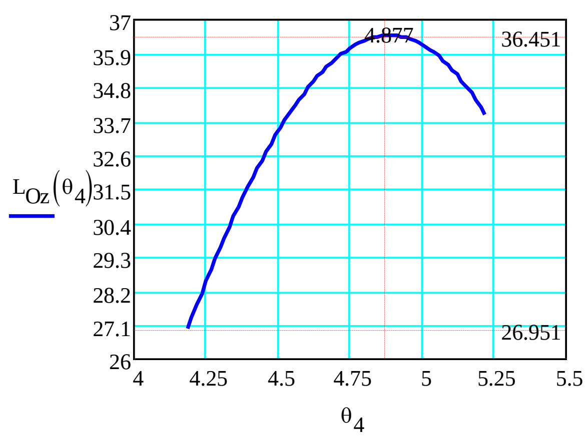
c) $\Theta_5 = 2.88$



d) $\Theta_5 = 3.142$



e) $\Theta_5 = 3.404$



f) $\Theta_5 = 3.666$

Fig. 3. The variation of the upper limb muscle system work (aggregate), depending on the

position (Θ_4=3,93 ÷5,498 rad), for the posterior/anterior step, imposing for Θ_5 the fix values in charts a, b, c, d, e and f.

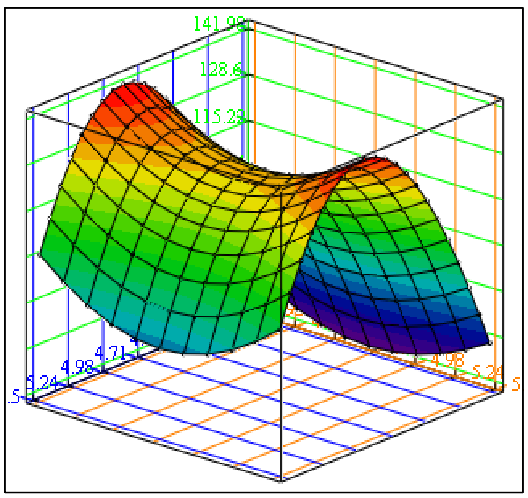
These data are represented spatially in the following charts (fig. 4a and 4b), consequently the work executed for half the period is represented vertically, and the variation of two angular parameters, hip-knee (Θ 1şi Θ 2), respectively shoulder-elbow (Θ 4şi Θ 5) is represented horizontally.

Fig. 4. Charts for the work performed by the muscle system while carrying out the posterior/anterior step:

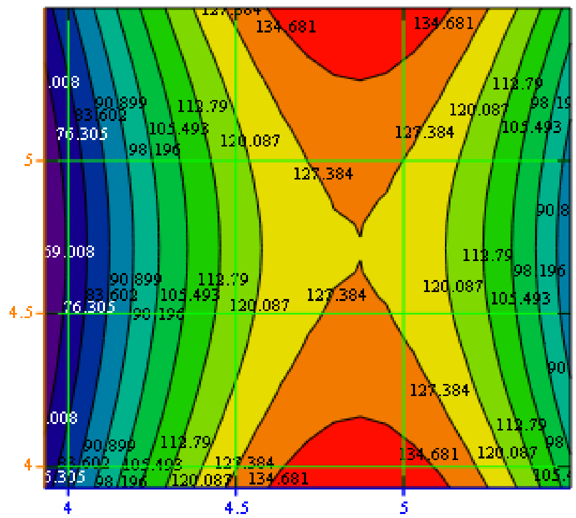
a) spatially for the lower limb, two parameter function (θ_1; θ_2);

b) frame-chart for the lower limb, two parameter function (θ_1; θ_2);

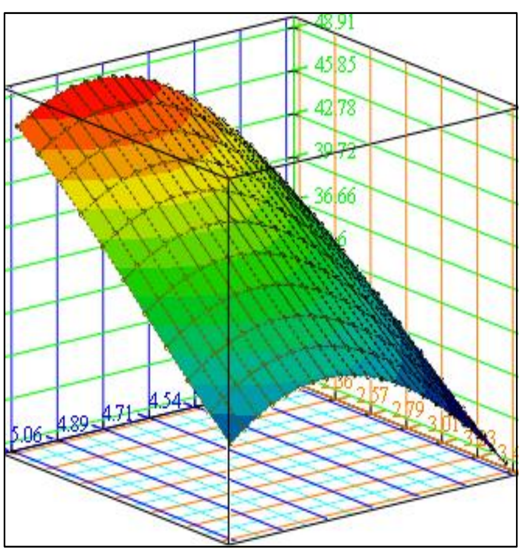
Figures 4c and 4d contain the same representations but in map shape**.**



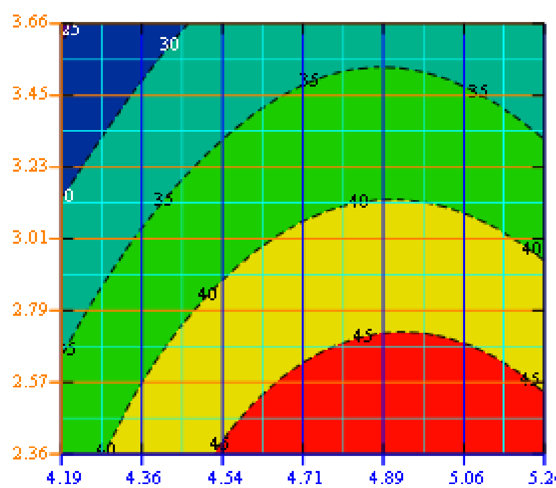
a) L_{Oz}



L_{Oz}



L_{Oz}



L_{Oz}

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Fig.4. Charts for the work performed by the muscle system while carrying out the posterior/anterior step:

c) *spatially for the upper limb, two parameter function (θ_4; θ_5);*
d) *frame-chart for the lower limb, two parameter function (θ_4; θ_5)*

Discussion

When analyzing the charts the debates were carried between engineers specialized in mechanics and dynamics, engineers from the Engineering Faculty in Sibiu, trainers of the national team of race walking, orthopaedists, and mathematicians. Perez (1994), said "movements and events that occur between successive contact with the ground the heel of the same foot."

Gennady quoted Mârza (2005) defines optimization in sports training as a process of "efficient operating model relative to the generalized model (increasing the efficiency of the model)".Compare with those point of view, it justifies as permanent concern to optimize technique, because it assumes the decisive role in determining performance.

It was noticed that:

- where lower limbs are concerned (fig. 2) the necessary work for crossing a half period, during race walking, has maximum values for Θ_2=3,93 rad and 5,498 rad respectively, and minimum value for Θ_2=4,68 rad; the observation suggests that the Θ_2 angle chosen optimally reduces the muscle effort of the lower limb;
- where upper limbs are concerned (fig. 3) the necessary work for crossing a half period, during race walking, has maximum values for Θ_5=2,356 rad and minimum value for Θ_5=36,451 rad; the observation suggests that the Θ_5 angle chosen optimally reduces the muscle effort of the upper limb;
- the space charts in figure 4 (surface and frame) allow the values of the two angular parameters (Θ_1 and Θ_2, Θ_4 and Θ_5 respectively) to pair for the optimal work (minimal)
- the issue may be approached from other points of view also. It is possible to start from a consumed work, a minimum one, and to reach the determining of the optimal sizes of the bone segments for race walking. Thus the optimal height for a race walker can be mentioned, with possible influences even on the selection process;
- various muscle groups can be worked, in the sense of decreasing or increasing the weight of some segments of the athlete's body with the purpose of improving the motion (decreasing the work in performing the motion);
- research in the field of creating biomechanical models can be widely extended through a much more complex dynamic analysis, using differential equation systems which take into account the speeds and accelerations of different segments of the racewalker's body. For this method special software is needed which can solve differential equation sustems, and also specialized personnel (in dynamics, biomechanics, mathematics)

Conclusions:

- the biomechanical model can offer information on optimal rotation angles for minimizing the muscular effort and also for performing correct movements from the technical point of view;
- the information obtained was used within the simulation training program for C. D., (after a model presented by Schor, (1997) and led to an improvement in her technique in the sense of the optimization of her arm motion trajectory and feet rolling technique;
- mathematical simulation does not imply experimenting, therefore the informational and the financial methods are not very special. Other advantages of this method are:
- a large number of simulations (exercises) can be performed in a very short period of time; biomechanically, a better understanding of certain mechanisms which trigger its motion and optimization can be achieved;
- the space is being occupied by the computer, the desk, and the operator;
- it is interactive alteration of input information which interfere with various phases of the process and the correlated identification of the output alterations;
- we are not dealing with any accidents where the athlete is concerned because he/she does not have to be present thus he/she is not affected in any way;
- the equipment necessary for investigations conducted in real conditions can not be deteriorated;
- the athletic system can be better studied in full effort. A complex investigation of the athlete is being conducted much easier: biomotive, biochemical, physiological, psychological; (INCS, 2003),
- the athlete is not tired physically and psychologically as he/she would have been if the study were conducted directly on him/her. The fear of

having his/her training, diet, and performance changed may inhibit the athlete when being directly studied and may affect the correct conclusions drawn if the simulations were used;

- the athlete has the possibility to perform the same movements as if he/she were in a race, but he/she can control every move, being fully aware of the progress he/she made;

- the computer is a much more accurate measurement instrument than any timer and can provide information from inside the motion interactively, on time and leads to an increase in the athlete's self-control;

- all the information can be recorded for further studying;

- for the younger athletes raised in the IT era it is possible that training became more pleasant as the monotony is no longer an issue.

It is worth mentioning that mathematical model, the simulation method, and the use of simulators will never substitute live training. They will only complete it, because the model will never be able to take into consideration the many factors which define the real context in which the athlete's training takes place, the influence of the environment on it.

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