THE OPTIMIZATION OF TRAINING LOADS IN HIGH CLASS HURDLERS

by

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The application of mathematical techniques of optimization allows for the improvement of steering and controlling of the training process. Until recently all attempts of steering the training process were based on data that included motor test results and the volume of particular exercises.

This paper included the method of optimal steering to evaluate the current and optimal training loads for particular hurdlers.

The research included 18 high hurdlers (110 HH) possessing at least a first sports class. The analysis included six, 3 month training periods, during which an improvement of results was achieved ($p \leq 0,001$). Seven variables were chosen to describe the training process while 22 specific exercises were used in the steering process. The application of optimization allowed for a comparison of the currently used training loads with those that were calculated as optimal. This method allows for the identification of mistakes in planing of the training process and gives the possibility for corrections in successive training periods.

Key words: hurdling, training loads, optimization, optimal control

Introduction

Earlier analysis of training programs of elite hurdlers indicate that the improvement in results is not always related to the increase in volume and intensity of training loads (Iskra 1998). Research indicates that excessive training loads or improper proportions of training means are a cause of stagnation or decrement in sport results.

The 110 m hurdle race is a track event which is evenly dependent on both, the level of motor abilities and technique (McFarlane 1988, Otrubiannikow i Razumowski 1988, Iskra 1997). The necessity of developing speed, endurance

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and specific strength as well as technical skills justifies the application of varied training means in training programs of high hurdlers.

Each attempt of evaluating the influence of training loads on sport results in the hurdle race must consider a proper classification of annual training means. Previous attempts at classifying training means for this event were usually simplified (Bowerman and Freeman 1988, Otrubiannikow and Razumowski 1988, Rubin and Ilin 1988, Brejzer 1991). Developing a precise yet simple classification of exercises used in 110 m HH training is of high importance in the application of computer programs for training load analysis. The classification of training means presented in this paper is based on the basic methods of teaching hurdle racing (McFarlane 1988, Otrubiannikow and Razumowski 1988, König 1989, Iskta 1999b, 1999d), physiological aspects of hurdling (Winckler and Gambetta 1987, Hautier at al. 1994, Ward-Smith 1997) and biomechanical aspects of hurdling technique (Grimshaw 1995).

Until now the analysis of training means in hurdle racing has been done in two ways. One method included the presentation of the volume and intensity of work of the top athlete, in the so called "champion model" (Iskra and Kosmol 1994, Iskra 1999c). The second procedure included the average value of exercises performed by several top class hurdlers (ten or more). This allowed for the development of certain norms of performed exercises for hurdlers representing different sport levels (Kawierin and Schustin 1981, Otrubiannikow and Razumowski 1988, König 1989). Both procedures had many vices, among which the most important included the impossibility to copy the "champion model" training concept and the omitance of individual predispositions. First attempts to optimilize training loads in hurdle racing over 110 m were undertaken by Rubin and Ilin (1978) and Brejzer (1991). These authors attempted to create mathematical training models for high class athletes using a minimal amount of exercises (2-4). These analysis considered only the final state of development (results of 110 m HH races), without specific motor tests applied in annual training periods.

The aim of this research was the attempt of determining the best possible structure of training loads for elite hurdlers (110 m) with the application of mathematical optimization techniques. The following research questions were created:

- which training means have the greatest impact on sport results in the 110 m HH ?
- to what degree is the individualisation of training loads possible in elite hurdlers ?

Material and methods

The research material included top polish high hurdlers, members of the national team as well as the best hurdlers of AZS Katowice competing between 1988 and 1999.

Among them were participants of the Olympic Games, World and European Championships in different age categories. The analysis included 18, two year training cycles. During this training period the average improvement of results was close to 0,30 s, from 14,18 ± 0,55 to 13,91 ± 0,41 ($p \leq 0,001$).

All annual training cycles were divided into 3 subperiods; general preparation (October – January), specific preparation (February – May) and competitive period (June – September). In all, six 3 months training periods were analysed. The main research procedure included the method of mathematical modelling.

MATHEMATICAL MODEL

Describing the variables for the model

In continuation an example of construction and analysis of a optimal training model based on high hurdle racing will be presented. The following variables were chosen for each athlete playing the role of state variables:

x_1 – 60 m HH results
x_2 – 150 m sprint
x_3 – standing triple jump
x_4 – overhead shot put throw (4 kg)
x_5 – squat (free weights)
x_6 – olympic clean (free weights)
x_7 – 30 m sprint

It must be noticed that the consequence of choosing x_1 as one of the variables of the model is an increase in sport results with a simultaneous increase in its value.

The following training means were considered as decision variables:

u_1 – maximal speed (m)
u_2 – technical speed (m)
u_3 – technical and speed exercises (m)
u_4 – speed endurance (m)
u_5 – specific hurdle endurance (m)
u_6 – pace runs (m)
u_7 – aerobic endurance (m)
u_8 – strength endurance I(m)
u_9 – strength endurance II (m)
u_{10} – general strength of lower limbs (kg)
u_{11} – directed strength of lower limbs (kg)
u_{12} – specific strength of lower limbs (kg)
u_{13} – trunk strength (amount)
u_{14} – upper body strength (kg)
u_{15} – explosive strength of lower limbs (amount)
u_{16} – explosive strength of upper limbs (amount)
u_{17} – technical exercises – walking pace (min)
u_{18} – technical exercises running pace (min)
u_{19} – runs over 1-3 hurdles (amount)
u_{20} – runs over 4-7 hurdles (amount)
u_{21} – runs over 8-12 hurdles (amount)
u_{22} – hurdle runs in varied rhythm (amount)

In optimisation process we use it as a 10 s – x_1 result.

Creating the model

The collected data includes 2 training cycles composed of 3 training periods for 18 elite hurdlers. Because of different time schedules for competitive and postcompetitive periods, individual cycles were treated separately. In this manner an analysis of 36 athletes in one cycle composed of 3 periods was performed. According to earlier makings we have the following variables: n = 7, m = 22, z = 36, N = 3.

This indicates that the equation is not filed and the model for these athletes is completed. According to the mathematical procedures presented before, the values of coefficients included in the equation were expressed.

Table 2 presents indicators of the changes in variables on the state of the result, while table 2-a shows the influence of interaction of the training state on the increment of particular variables.

Table 1

Training means for 110 m HH

Training means	Exercises
u_1	Sprints over 20-80 m (max. intensity)
u_2	Sprint over 20-80 m (submax. intensity)
u_3	Skiping and speed bounding over 20-80 m
u_4	Runs over 80-150 m (submax. and max. intensity); interval and repetitive method
u_5	Runs over 150-500 m (submax. and max. intensity); interval and repetitive method
u_6	Runs over 150-800 m (moderate to high intensity); interval and repetitive method
u_7	Continuous runs, mountain hiking, extensive interval.
u_8	Uphill runs, skiping above 80 m, resistance runs
u_9	Bounding above 30 m (70 or more hops)
u_{10}	Squats, step ups
u_{11}	Half – squats
u_{12}	Barbell jumps
u_{13}	Abdominal and back exercises
u_{14}	Bench pressing, clean and jerk, snatch
u_{15}	Plyometrics – bounding and hoping, below 30 m
u_{16}	Medicine ball throws
u_{17}	Special hurdling exercises at walking pace
u_{18}	Special hurdling exercises at running pace
u_{19}	Runs over 1-3 hurdles under competition conditions
u_{20}	Runs over 4-7 hurdles under competition conditions
u_{21}	Runs over 8-12 hurdles under competition conditions
u_{22}	Hurdle runs at non competition conditions (varied hurdle height and distance)

Table 2 and 2a indicates that the results of 60 m HH are influenced to the highest degree by explosive strength (overhead shot put throw – x_4, olympic clean – x_6) and most of all by maximal speed – x_7. This is confirmed by the explosive, speed character of the 60 m HH race. It is commonly accepted that strongly build athletes with good results over the 60 m flat distance are well suited for high hurdling (Rubin and Ilin 1978, Iskra 1998).

The improvement of results in speed endurance (150 m sprint), standing triple jump (x_3) as well as maximal strength evaluated by the squat have no significant influence on 60 m hurdle results.

It is assumed that speed endurance (150 m) has more influence on the results over 110 m HH because of its glycolytic character (Ward-Smith 1997).

In light of the obtained results the prognosis of 60 m HH results upon the level of speed endurance (x_2) and maximal strength of the lower limbs (x_5) are not justified.

It also seems that the application of the standing triple jump (x_3) as a typical test of explosive strength for sprinters should be verified (Arakelian and Mirzojew 1997).

The greatest expectations of methods of mathematical optimization in sports are related to the steering process of basic training variables which include volume and intensity of work in the annual cycle. Taking into consideration the 60 m HH result as the main variable the influence of particular training means on sport results was analysed.

Table 2

The values of coefficients a_{ij} (i,j=1,...,7) in equations (1)

Equation for variable	State variable						
	X1	X2	X3	X4	X5	X6	X7
X1	0.56	0.35	-0.49	0.06	-0.01	0.01	-0.62
X2	-5.70	-0.79	1.58	-0.06	0.08	-0.06	1.24
X3	7.67	1.95	-2.48	0.20	-0.22	0.21	-4.57
X4	-19.33	-4.47	5.20	-0.24	0.51	-0.37	9.09
X5	265.92	55.91	-73.06	-4.79	-4.74	6.17	-154.45
X6	32.01	11.99	-15.99	-3.59	-0.71	0.81	-5.56
X7	1.65	0.51	-0.54	-0.00	-0.04	0.05	-1.40

Table 2a

Values of expression

Equation For variable	State variable						
	X1	X2	X3	X4	X5	X6	X7
X1	1.15	5.76	-4.56	1.17	-1.28	0.72	-1.98
X2	-11.69	-13.00	14.71	-1.17	10.27	-4.29	3.96
X3	15.72	32.08	-23.09	3.90	-28.24	15.03	-14.58
X4	-39.63	-73.53	48.41	-4.68	65.47	-26.48	29.00
X5	545.14	919.72	-680.19	-93.50	-608.52	441.59	-492.70
X6	65.62	197.24	-148.87	-70.08	-91.15	57.97	-17.74
X7	3.38	8.39	-5.03	0.00	-5.14	3.58	-4.47

Optimal control

The greatest benefit of applying the mathematical model is the optimal control (training leading to best sport results) for intial conditions (particular athlete). At first optimal steering must be pin-pointed for maximalizing x_1, which means reaching the best results at 60 m HH. Table 3 presents the results obtained by particular athletes and theoretical, optimal results for each hurdler. The results of athletes for which it was impossible to pin-point loads that would improve results are marked in italics. For those hurdlers that optimal control increased results data is presented in bold print. The greatest improvement occurred in hurdlers marked as nr 12,14,15. The data confirms that in case of 4 athletes during the first annual training cycle and in 9, during the second cycle the actual result was in accordance with the optimal, calculated value (table 3).

This confirms that in relation to those athletes the training process was conducted properly, omitting mistakes with improper selection of training means. Worth considering are the results of athlete nr 1 (K.M.) who became a semi-finalist at the Olympic Games during his second annual training cycle. During this period of time his actual result at 60 m HH equalled to the optimal one. The greater, proper solutions (from the standpoint of optimal training loads) is most likely related to searching for new, more affective training concepts.

The application of optimization techniques seems highly justified in track and field as shows that in case of 15, of the 18 considered hurdlers, the predicted results were better than the actual ones.

The main objective of optimal steering is on individual analysis of training loads in a extended period of time. Information on the discrepancies between the actual and optimal (theoretical) realisation of the training process allow for changes and modifications of training plans. Those programs relate to training means as well as volume and intensity of work.

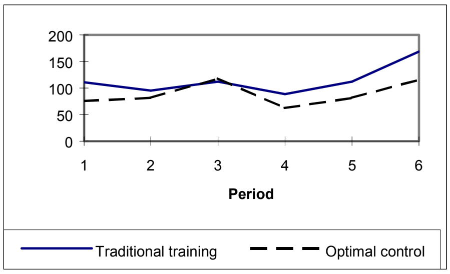
Table 3

Actual and optimal results in 60 m H runs.

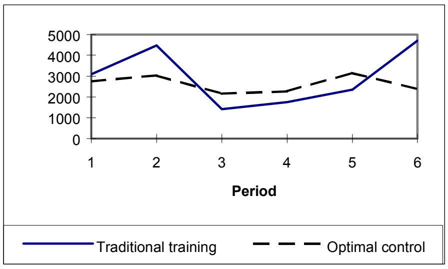
Number of athlete	60 m H time [s] – 1st cycle			60 m H time [s] – 2nd cycle		
	actual	optimal	%	actual	optimal	[%]
1	7.62	7.43	2.5	7.57	7.57	0.0
2	*7.70*	*7.70*	*0.0*	*7.62*	*7.62*	*0.0*
3	*7.81*	*7.81*	*0.0*	*7.70*	*7.70*	*0.0*
4	8.08	8.07	0.1	7.81	7.81	0.0
5	*8.04*	*8.04*	*0.0*	*7.91*	*7.91*	*0.0*
6	7.91	7.91	0.0	7.83	7.78	0.6
7	7.83	7.76	0.9	7.68	7.68	0.0
8	**7.63**	**7.50**	**1.7**	**7.59**	**7.44**	**2.0**
9	**8.42**	**8.27**	**1.8**	**8.17**	**8.13**	**0.5**
10	8.17	8.10	0.9	7.99	7.99	0.0
11	**8.17**	**7.90**	**3.3**	**8.02**	**7.82**	**2.5**
12	**8.02**	**7.82**	**2.5**	**7.83**	**7.35**	**6.1**
13	**8.42**	**8.08**	**4.0**	**8.19**	**8.04**	**1.8**
14	**8.19**	**7.95**	**2.9**	**8.02**	**7.72**	**3.7**
15	**8.48**	**8.00**	**5.7**	**8.12**	**7.95**	**2.1**
16	7.65	7.40	3.3	7.60	7.60	0.0
17	**7.68**	**7.58**	**1.3**	**7.74**	**7.64**	**1.3**
18	7.76	7.55	2.7	7.64	7.64	0.0

To present the differences in actual and optimal training procedures a two year training cycle was analysed of two international class hurdlers (athlete nr 8 – with PR of 13,44 s and athlete nr 14 with a PR of 14,27 s). The actual result over 60 m HH for athlete nr 8 was 0,13 s slower (1,7%) during the first annual cycle from the optimal result (diag. 1). In accordance with the procedures of optimization techniques the hurdler performed a to low volume of speed endurance (U_4), specific strength of lower limbs (U_{12}), runs over 1-3 hurdles (U_{19}) and technical exercises (U_{18}).

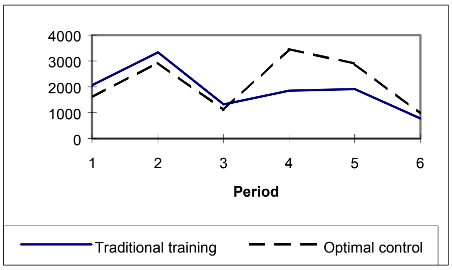
Diagram 1. Actual and optimal control of hurdler NR 8 (personal best 13,44 s)



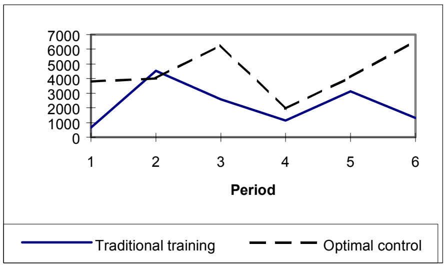
u_1 - maximal speed (m)



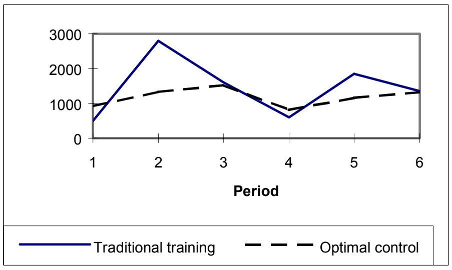
u_2 - technical speed (m)



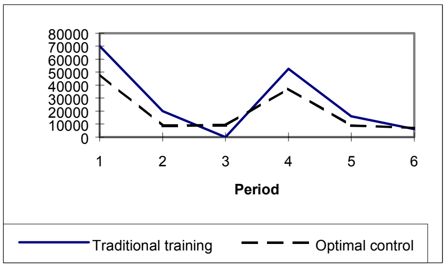
u_3 - technical and speed exercises (m)



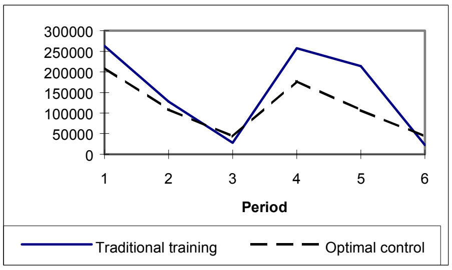
u_4 - speed endurance



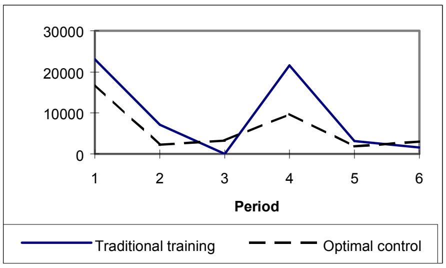
u_5 - specific hurdle endurance (m)



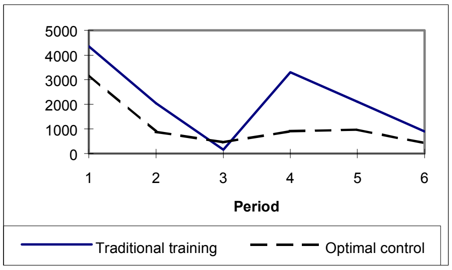
u_6 - pace runs (m)



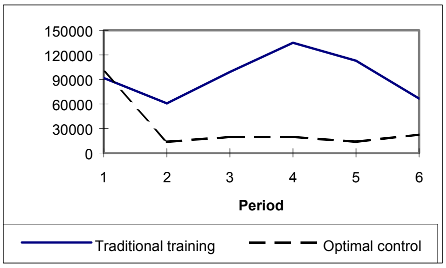
u_7 - aerobic endurance (m)



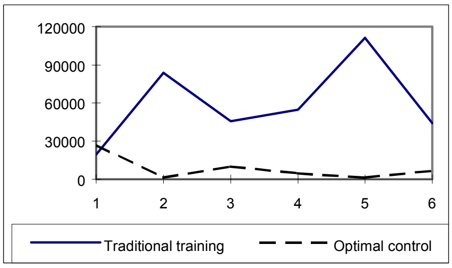
u_8 - strength endurance I (m)



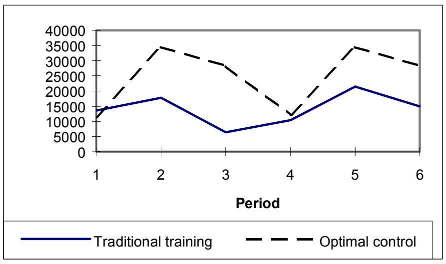
u_9 - strength endurance II (m)



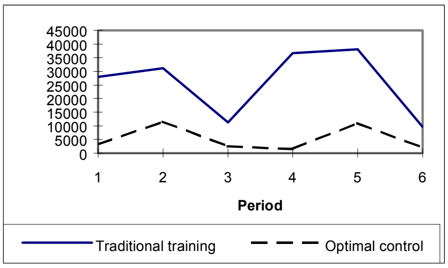
u_{10} - general strength of lower limbs (kg)



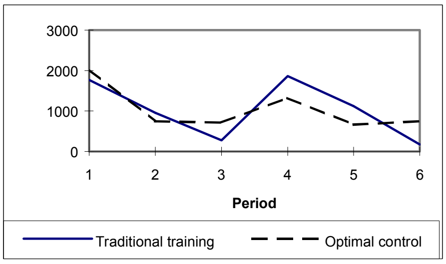
u_{11} - directed strength of lower limbs (kg)



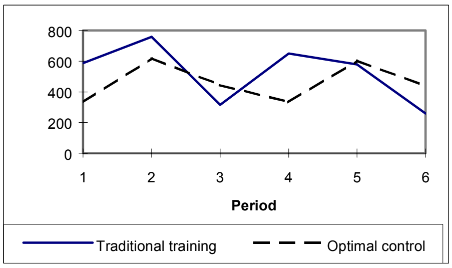
u_{12} - specific strength of lower limbs (kg)



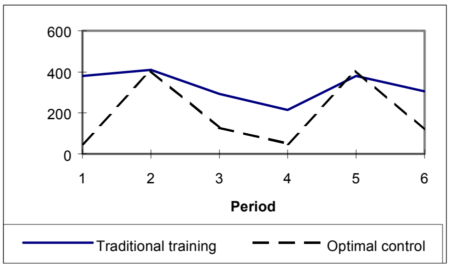
u_{13} - trunk strength (amount)



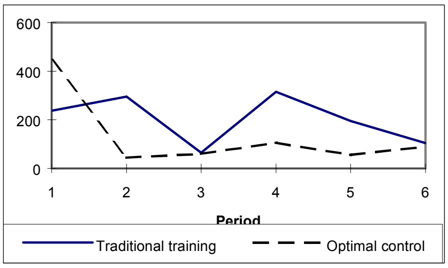
u_{14} - upper body strength (kg)



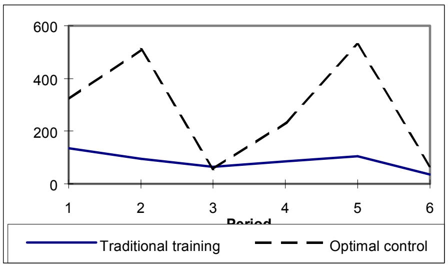
u_{15} - explosive strength of lower limbs



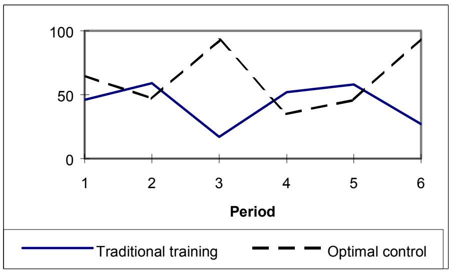
u_{16} - explosive strength of upper limbs



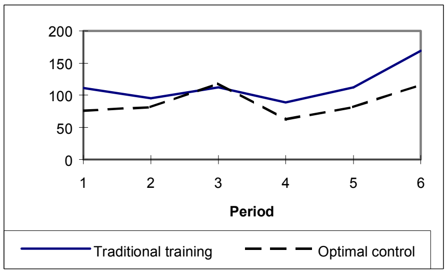
u_{17} - technical exercises - walking pace (min)



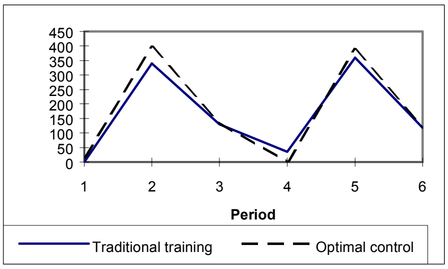
u_{18} - technical exercises running pace (min)



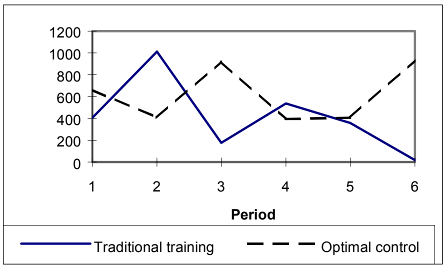
u_{19} - runs 1-3 hurdles (amount)



u_{20} - runs over 4-7 hurdles (amount)



u_{21} - runs over 8-12 hurdles (amount)



u_{22} - hurdle runs in varied rhythm (amount)

An excess of exercises directed at the development of speed (U_1), specific hurdle endurance (U_5), as well as general and directed strength (U_{10} and U_{11}). A high amount of exercises stimulating trunk muscles (U_{13}) seemed necessary because of repeated spine injuries.

During the next training cycle, in which the athlete presented a higher sports level it seems that aerobic endurance (U_7), strength endurance (U_8, U_9) and strength exercises of general and directed character (U_{10}, U_{11}) were overused. It is assumed that the excess of the last two training means restricted further improvement. According to the optimal data the result in the 60 m HH could have been better by 0,15 s (2,0%).

For athlete nr 14 during both cycles the result could have been better by: 2,9% (0,24 s) in the first year and by 3,7% (0,30 s) during the second year of analysis (diag 2).

The main mistakes in training procedures related to the disproportions in strength training of the lower limbs (U_{10} – U_{12}), explosive strength exercises (U_{15} – U_{16}) and most of all to the use of specific hurdling exercises (U_{17} – U_{22}). An excess of running exercises without hurdles (U_6, U_7) did not fully compensate the small amount of runs over hurdles. On the other side an excess of endurance exercises could not compensate the lack of general and directed strength exercises (U_{10}, U_{11}). The above presented results indicate, that mathematical optimization, backed up by proper analysis may interfere in a creative way in the construction and correction of training plans. It must by considered that in the majority of cases the prognosed optimal steering lead to better results. On this basis, it may be concluded that individualisation of training procedures is possible and necessary in hurdle racing.

Conclussions

1. The methods of mathematical modelling may improve the training process, especially in relation to the optimal choice of training volume and intensity.
2. The analysis proved that in the group of 18 elite hurdlers, only in case of 3 athletes the training process was conducted properly.
3. The differences between the actual and optimal hurdle results were the effect of great discrepancies between the volume of chosen training means. The accepted method allowed for an individual evaluation of training mistakes during the two year training cycle.

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