OPTIMIZATION OF TRAINING LOADS DEVELOPING STRENGTH IN 400-METRES HURDLES

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- optimization of training loads,
- 400-metres hurdles,
- artificial neural network.

Abstract:

This paper presents planning training loads using artificial neural networks. Calculated models perform the task of generating optimal training loads for competitors practising for the 400-metres hurdles. All models are calculated based on the training data of 21 Polish National Team athletes aged 22.25 ± 1.96 years, starting in competitions between 1989 and 2012. The analysis included 48 training plans that represent the annual training cycle. In the process of calculating the optimization models 12 variables were used. The following methods were used: artificial neural networks (ANN) with radial basis function (RBF). For the error analysis of the calculated models the method of leave-one-out cross-validation was used in which the error $NRMSE_{CV}$ (Normalized Root Mean Squared Error) was calculated. The analysis shows that generated loads have relatively small errors. Additional analysis of variation showed non-linear character of most strength training loads over the whole competition time. Calculated models can be used as a tool to assist the coach in planning strength training.

INTRODUCTION

The contemporary competitive sports pose an enormous challenge for the coach. The still rising and even level of athletes' sports skills forces the coach to look for and apply modern and sometimes innovative solutions. In many sport events, the planning of training process is conducted based on the practical experience of the coach and it lacks scientific background. Therefore it is very important to find and verify different ways of training plan optimization. Those ways include without doubt all kinds of methods that apply advanced mathematic models. Thanks to the advanced computational methods, the expected level of athlete's development can be modelled and the optimal training load can be generated, so that the athlete can achieve the desired result. Selection of a suitable training load taking into account the intensity and amount of work to be done should also include the individual capabilities of athlete's body, as well as its reaction on the applied load. If this principle is not followed, the body can be overloaded, "overtrained" and the further development of athlete's abilities can be inhibited.

A very important factor determining the best results in athletics is the selection of optimal training loads. The 400-metres hurdle race is one of the complex athletic events. In this event, the result involves among others coordinative abilities, technique of jumping over the hurdles and specific hurdling rhythm [4, 5, 8, 9].

Optimization of training process includes among others prediction of results development, choice and selection of athletes and training system. Optimization means determination of such solution of the given problem that would be the best with regard to the chosen criterion and meet the necessary restrictions. In training, optimization involves looking for such training loads thanks to those the athlete achieves the best result [11, 12, 14, 15]. In this case it will be the result in 400-metres hurdle race.

An important part in training load optimization or in results prediction play artificial intelligence methods. The most popular artificial intelligence methods are artificial neural networks. Neural models are widely used in modelling, prediction and optimization. Ryguła applied in his study [11] SSN for result prediction, where the network, based on the data featuring the athlete predicted the level of his future development. For model development purposes a set of 26 features was used, out of which only 14 were applied at the final stage. In other studies by Ryguła [12, 13] a neural model was presented; it was aimed at optimal training load generation so that the sprinters could achieve the possibly best results. The system was developed based on the data of 20 female 100 m race sprinters aged 16–17 years.. In the next study [10], a complex neural system optimizing the training loads in race walking was demonstrated. The system performed the task of result prediction and that of training load generation. The obtained neural networks predicted the result with prediction error of 150 sec. over the distance of 5 km and generated a two-week-training with average error of 25% of the average training load value.

The main objective of this study was to review the effectiveness of artificial neural networks in planning the training loads developing strength. The verification was carried out based on the training data of high-level 400-metres hurdlers.

MATERIAL AND METHODS

The analysis included 21 Polish hurdlers aged 22.25±1.96 years participating in competitions from 1989 to 2011. The athletes had a high sport level (the result over 400-metres hurdles: 51.26±1.24 s). They were the part of the Polish National Athletic Team Association representing Poland at the Olympic Games, World and European Championships in junior, youth and senior age categories. The best result over 400-metres hurdles in the examined group amounted to 48.19 s. The collected material allowed for the analysis of 48 annual training plans.

Table 1. The variables and their basic statistics (n=48)

	Descrioption	$\bar{x}$	x_{min}	x_{max}	SD	$V[\%]$
x_1	Expected result on 400m hurdles (s)	51.26	48.19	53.60	1.21	2.4
x_2	Age (years)	22.3	19.0	27.0	2.0	8.8
x_3	Body height (cm)	185.04	177	192	4.70	2.5
x_4	Body weight (cm)	74.29	69	82	2.71	3.6
x_5	Current result on 400m hurdles (s)	51.91	48.70	54.70	1.37	2.6
y_1	General strength of lower limbs (kg)	124060.4	40100	318610	70776.5	57.1
y_2	Directed strength of lower limbs (kg)	58379.2	8240	134400	25912.3	44.4
y_3	Specific strength of lower limbs (kg)	41659.9	7810	272750	40685.1	97.7
y_4	Trunk strength (amount)	46438.7	6100	233680	44496.7	95.8
y_5	Upper body strength (kg)	3305.8	760	29610	4151.1	125.6
y_6	Explosive strength of lower limbs (amount)	824.0	282	2138	350.9	42.6
y_7	Explosive strength of upper limbs (amount)	443.7	60	1360	277.9	62.6

Table 1 contains an accurate description of the variables considered and their basic statistics, i.e. the arithmetic mean of $\bar{x}$, the minimum value x_{min}, the maximum value x_{max}, standard deviation SD and the coefficient of variation V. Variables represent selected training loads.

Optimization of training loads within the annual training cycle concerns optimization of training loads regarded as the sum of the given training means used during the whole annual cycle. In the optimization of the annual cycle, 12 variables were used; 5 of them describe the athlete, and seven variables represent the strength training loads.

To calculate the optimal values of training loads artificial neural network was used. The study used artificial neural networks of RBF (Radial Basis Function) type. The feature of RBF network is the fact that the hidden neuron performs a basis function function that changes radially around the selected center. Radial neural network acts as a multidimensional interpolation which replicates the input vectors into the set of real numbers. All the analysed networks have only one hidden layer [2].

For the implementation of artificial neural networks methods StatSoft STATISTICA software [15] was used. Owing to the fact that this software does not have cross-validation it was implemented using Visual Basic language. To validate the model cross-validation was used. While constructing the model a normalized mean square error was applied expressed by the formula:

$$NRMSE_{CV} = \frac{1}{r}\sum_{j=1}^{r}\frac{\sqrt{\frac{1}{n}\sum_{i=1}^{n}(y_{ij}-\hat{y}_{-ij})^2}}{y_{j_{max}}-y_{j_{min}}} * 100\%$$

where r – number of outputs, n – total number of paterns, y_{ij} – real (measured) value, $\hat{y}_{-ij}$ – the output value constructed in i-th step of cross-validation based on a data set containing no testing pair (x_i, y_i).

RESULTS AND DISCUSION

The optimal RBF network generating an optimal training loads has 5 hidden neurons and *NRMSE*$_{CV}$=18.98%. Therefore, as the optimal method for generating training loads RBF network with five hidden neurons was used.

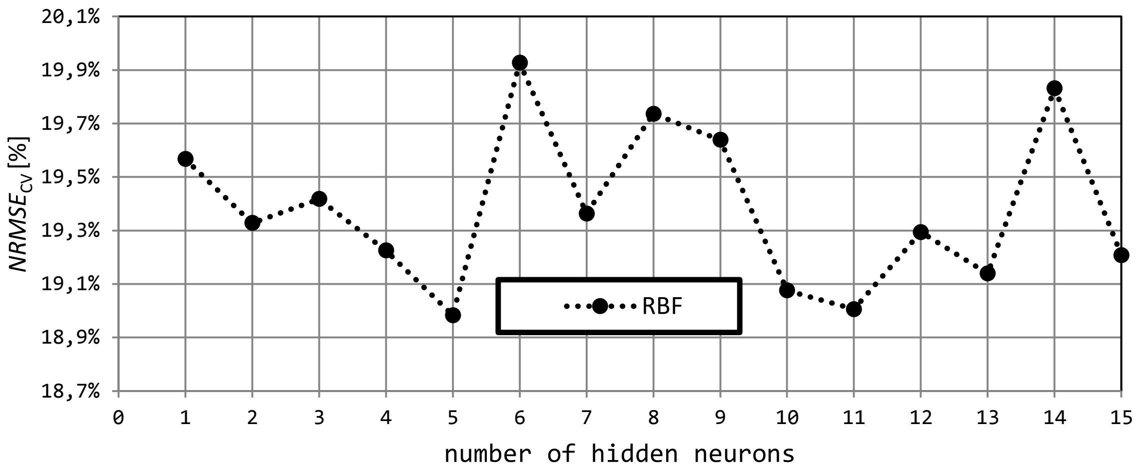

Figure 1. Normalized prediction error for artificial neural networks

A trained neural network was used to generate the optimal values of training loads for a hypothetical athlete (age: 21 years, body height: 185 cm, weight 75 kg). The generated training loads concern the strength preparation and include a one-year training plan.

Table 2. Optimal training loads for hypothesis competitor

		56	55	54	53	52	51	50	49
	current result (400m hurdles)	**56**	**55**	**54**	**53**	**52**	**51**	**50**	**49**
	expected result (400m hurdles)	**55**	**54**	**53**	**52**	**51**	**50**	**49**	**48**
y_1	General strength of lower limbs (kg) (Przysiady, wspięcia, wejścia na skrzynię)	33244	28308	54861	99572	135131	146188	142402	140582
y_2	Directed strength of lower limbs (kg) (Półprzysiady)	31116	33801	42908	54157	61099	61394	58424	55885
y_3	Specific strength of lower limbs (kg) (Wyskoki ze sztangą)	48923	47031	47244	47557	44768	38967	35585	39447
y_4	Trunk strength (amount) (Ćwiczenia mięśni brzucha i grzbietu)	8481	24041	48366	70052	76165	64391	44687	28377
y_5	Upper body strength (kg) (Wyciskanie leżąc, rwanie, podrzut, zarzut)	3587	2680	2175	2200	2564	3000	3538	4339
y_6	Explosive strength of lower limbs (amount) (Wieloskoki do 30 m (do 10 skoków), skoki obunóż przez płotki)	699	692	701	736	798	868	903	880
y_7	Explosive strength of upper limbs (amount) (Rzuty kulami lub piłkami lekarskimi)	376	380	379	382	401	432	450	437

In order to visualize the dynamics of the training loads change, training programs improving the results by 1 sec. (Tab. 2) were generated. The training programs included improvement of result within the range from 56 to 48 s over the distance of 400-metres hurdles. In the table, an example of strength training improving the result from 56 to 52 was marked in green. In the generated values of training load, no negative loads were observed; moreover, all loads meet the substantive criteria relating to sport training [3].

The suggested training loads developing strength in 400-metres hurdles include the entire career of an athlete. The variability of individual loads at all stages of athlete's career was analyzed. To give a picture of the dynamics of the individual loads, the values were standardized by dividing them by the maximal load (maximal value appearing during the whole athlete's career).

From the conducted research, it follows that the load value is determined by the athlete's sports level (result in 400-metres hurdles). A similar dynamics present the following loads: general strength of lower limbs, directed strength of lower limbs and explosive strength of upper limbs, the values of which systematically increase up to the moment in which the athlete achieves the intermediate level (approx. 50s in 400-metres hurdles). At the very high training level, those loads remain on a constant and very high level. The characteristics of the specific strength of lower limbs is different, because the value of that load remains at a high level for a very long time, and only at the champion stage, the value of that load slightly decreases.

An interesting dynamics was also observed in the category of the trunk strength, in which the systematic increase of the given load value can be noted, up to the moment in which the athlete achieves the result at the level of 51; after that the load value decreases along with the increase of the athlete's sports level.

The comparison of the obtained results with other studies is at least difficult. Studies, concerning training loads of athletes specializing in hurdle races that have been published so far [1, 5], were not focused on the issue of optimal training loads generation by neural networks, what makes the presented solution an innovative one.

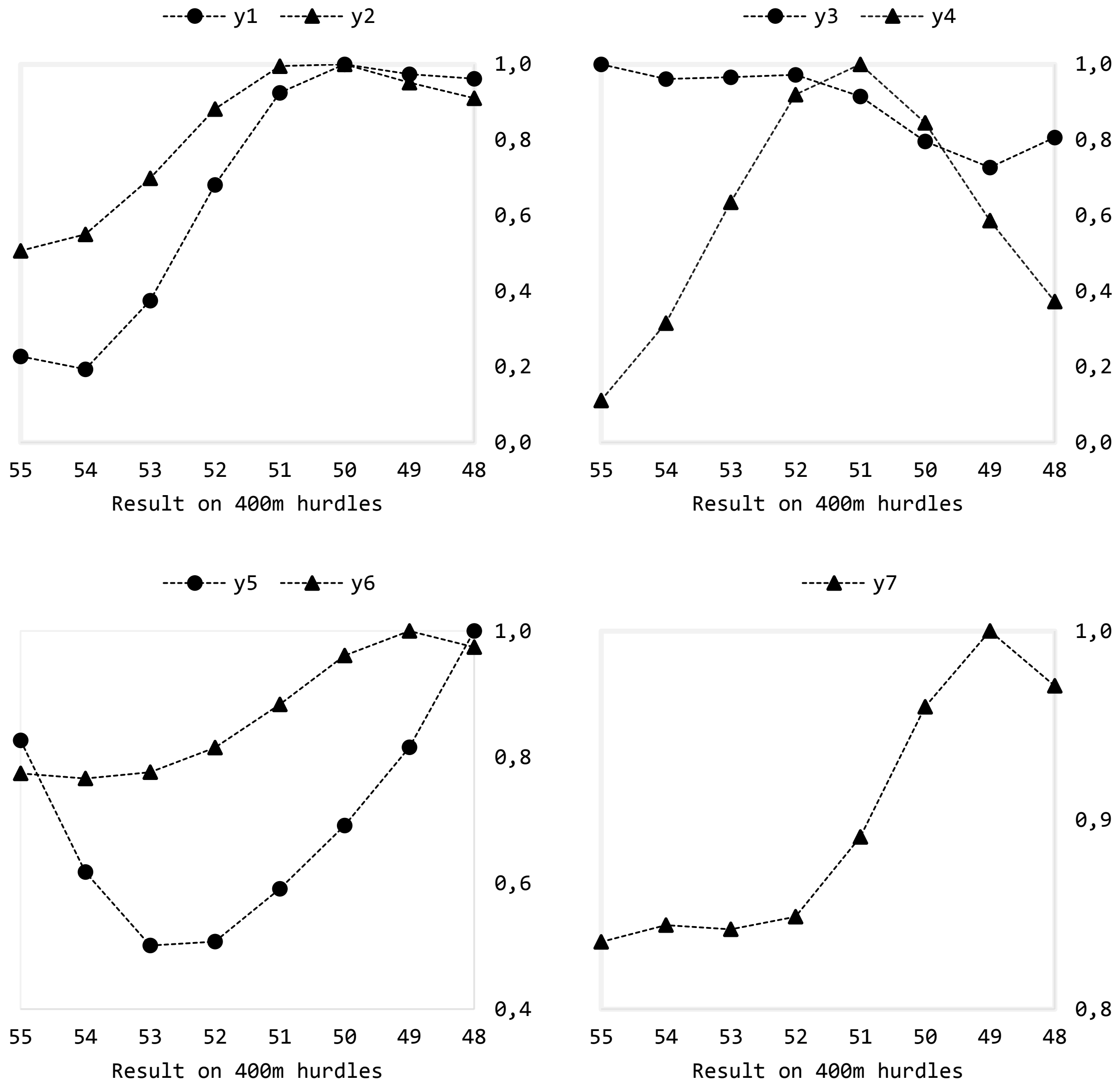

Figure 2. Normalized values of optimal training loads

In the study of Iskra [7], a detailed characteristics of hurdles strength training was presented. Strength training in 400-metres hurdles is the issue that is continually discussed by coaches. There is no uniform scheme according to which strength training loads are planned. In this study, training loads dynamics classified in accordance with Iskra [6], are presented. The obtained results can be regarded as suggestions to be used while planning those loads.

CONCLUSION

The study allowed us to draw the following conclusions:

1. Implementation of artificial neural networks in training loads analysis makes it possible to support the hurdles training process.
2. The obtained results can be regarded as suggestions to be used while planning those loads.
3. The vast majority of the analyzed training loads changes non-linearly over the whole athlete's career; as an example can serve here the training component developing the **explosive strength of upper limbs.** Its value increases systematically up to the

moment when the athlete achieves the intermediate level (approx. 50s in 400-metres hurdles), and after that it remains at a constant level.

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