

Modelling analysis and prediction of women javelin throw results in the years 1946 – 2013

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ABSTRACT: The main goals of our study of the women's javelin throw were twofold: first, to analyse the dynamics of female javelin throw results variability as a function of time (time period 1946-2014), second, to create a predictive model of the results during the upcoming 4 years. The study material consisted of databases covering the female track and field events obtained from the International Association of Athletics Federations. Prior to predicting the magnitude of results change dynamics in the time to follow, the adjustment of trend function to empirical data was tested using the coefficients of convergence. Phase II of the investigation consisted of the construction of predictive models. The greatest decreases in result indexes were noted in 2000 (9.4%), 2005-2006 (8.7%) and 2009 (7.4%). The trend increase was only noted in the years 2006-2008. In general, until 1998 the mean result improved by 54.6% (100% - results of 1946) whereas from 1999 through 2011 the result only increased by 1.3%. Based on data and results variability analysis it might be presumed that, in the nearest future (2015-2018), results variability will increase by approximately 9.7%. Percent improvement of javelin throw distance calculated on the basis of the 1999 raw input data is 1.4% (end of 2014).

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INTRODUCTION

Athletics encompasses four sporting events including competitive running, jumping, throwing, and walking. In the modern era, its roots can be traced back to the second half of the XIXth century. Originally, athletics comprised a very limited number of events and was meant for men only. In subsequent years several new events were added and female athletes were allowed to participate. In the 1980s, five new events were introduced and one was withdrawn, while in the 1990s, one was added and one withdrawn. The women's 20 kilometre race-walk became an Olympic event at the end of the XXth century. This delay in the introduction of women's events in the athletics program has significantly affected the dynamics of women's athletics development. It has also caused difficulties in the analysis of sports results over time and in predicting the outcome of particular events [1, 2].

Technological progress is another factor that has an impact on the dynamics of sports results variability. Technology can easily be perceived as a set of instruments and associated rules, and it should be deemed an important factor to drive the developments in sport. Considering the evolution in sport, a hypothesis could also be formulated that the overwhelming majority (if not all) of changes has

resulted from exogenous processes related to advances in technology. Sport, initially understood as play and competition, has been redefined as a result of technological innovations and broadening of the knowledge in this rapidly growing field. Changes have mainly affected sports equipment, upgrading of which continuously increases the level of sports achievements, thus altering sport itself. All technological innovations have had a significant and direct influence on sports results and variability thereof. Sports equipment, devices and facilities have evolved noticeably through the several hundred years of athletics history, which remains an ongoing process.

The javelin throw is an event which places both physical and technical demands on the athlete. It was first time held for women at the 1932 Olympic Games. The distance of the javelin throw mainly depends on the initial velocity and angle of release; it is calculated using the following formula:

$$S = \frac{v^2 \cdot \sin 2\alpha}{g} \quad (1)$$

The average length of the run-up for female athletes is 20 to 25 meters. A fast and well-coordinated run-up, exactly along the throw-

ing line, guarantees a good result. Correct work of the legs, trunk and arms is of considerable importance at the delivery. The optimum body position of a thrower is the position of a tense arch. The explosive power-velocity effect of this system ensures maximum javelin acceleration at delivery. Since that moment, throw distance depends on the initial javelin velocity and optimum angle of release [3, 4, 5]. Javelin female and male throwers belong to the mesomorphic somatotype.

The main goals of our study of the women's javelin throw were twofold: first, to analyse the dynamics of female javelin throw results variability as a function of time (time period 1946-2014), second, to create a predictive model of the results during the upcoming 4 years. The most important component of the first part of the investigation was the determination of the strength and direction of results variability in the above mentioned time period. It should be emphasized that we did not mean to establish the causes of the variability (which cannot be done without analysing all predictors for a given event), but to present the dynamics of results variability and, based on the findings obtained, calculate predictive values.

MATERIALS AND METHODS

Material. The study material consisted of databases covering the female track and field events obtained from the International Association of Athletics Federations (IAAF). Since the data available on the IAAF website only refer to the period starting from the year 1990, the previous rankings were collected from the Internet, athletics statistics yearbooks and reviews [6]. Data of the Association of Track and Field Statisticians (ATFS) in the form of annual yearbooks, i.e., the International Athletic Annual 1951-2014 (currently published under the title: Athletics: The International Track and Field Annual) were also used. Since 1985, the annuals have been edited by Peter Matthews [7]. The missing results (1946-1950) were obtained from the latest publications of Brant and Waśko [8], and Quercetani [2]. The accuracy of the collected data was verified and confirmed by comparison to the information available on the website [9] as well as the information obtained from the Canadian The-sports.org in the form of database records.

Study material preparation

The majority of researchers analysed the dynamics of sports results on the basis of setting world or European records, as vector time series or by separate consideration of World Championships and Olympic Games [10, 11]. Due to a wide variety of accidental and incommensurable factors affecting sports records, more precise trends can be determined by investigating best results series calculated as arithmetic means of the best achievements in several successive years. Our analyses were based on the means of 10 best annual results presented in world listings starting from the year 1953 (year by year).

Since IAAF started standardized scoring tables as late as in 1952, the statistics for the years 1946-1952 comprises each year's eight

top athletes and their results. Starting from 1953 all events are listed year by year with the names and results of 100 best competitors in each event. Hence our analysis is based on the arithmetic means of 8 best athletes' results in the years 1946-1952 and 10 best athletes' results starting from 1953. Scoring tables and databases of sports records prompted us to consider annual statistics. Prediction models were verified using mean values of sports results achieved during the 2012 Summer Olympics.

The enormous amount of data resulted in the so called 'information surplus' and hampered correct graph reading. We therefore decided to present comparisons of empirical data with linear or broken trends using 10-year intervals.

Statistics

The basic features of study data were described using descriptive statistics. The results and input data were presented as means. During the first phase of the empirical investigation, the dynamics of results change was examined based on the time-series; the levels of the variable (i.e. sports results) were analysed as a function of time. Time units were numbered $t=0$ to $t=n-1$ and assigned the observed levels of the result change; thus, the stochastic process was modelled as time-series [12, 13, 14, 15, 16, 17]. The analysis of dynamics of results change was based on chained or fixed-base indexes. The magnitude and direction of trends were determined using a moving average.

Due to a relationship between throw results and changes in javelin construction, results variability and trends in the years 1949 through 2011 are presented as a broken trend line. The predictive models, on the other hand, correspond to the period after changes of the centre of gravity of the javelin, i.e., the year 1999.

Trend function was determined and selected based on a moving average:

$$f(t) = a + b \cdot t \quad (2)$$

where:

a – trend value at time 0,

b – average trend increase ($b>0$) or decrease ($b<0$),

t - time variable.

Prior to predicting the magnitude of results change dynamics in the time to follow, the adjustment of trend function to empirical data was tested using the coefficients of convergence calculated from the formula:

$$\varphi^2 = \frac{\sum [x_i - f(t)]^2}{\sum (x_i - \bar{x})^2} \quad (3)$$

Sport results prediction was based on time-series modelling.

Phase II of the investigation consisted of the construction of predictive models based on the obtained data starting with time-series of periods under consideration. Prognoses were made using a moving average model. The values of the coefficient of convergence (φ^2) were each time checked. Nonlinear regression models were then constructed using Microsoft Excel 2013 spreadsheet software. Re-

gression predicting was based on the power method and exponential smoothing. Thus, regression models were set using regression function and array formulas. The most important part of Phase II was building neural network models and prognoses made with the use thereof. The models were constructed based on the approximation framework – reconstruction of hypersurface to best fit the training data, i.e., Radial Basis Functions (RBF) Neural Networks. Thus, it might be presumed that the dynamics of the phenomenon (associated with short time vectors) was efficiently eliminated and did not have any significant effect on predictive values. RBF show better approximation to nonlinear values of time function in short time vectors. Time-series predicting based on artificial neural networks was developed using the network with the minimum validation error. The analyses and neural networks construction were carried out with STATISTICA 9.1.

This project was approved by the Bioethics Committee for Scientific Research at the Jerzy Kukuczka Academy of Physical Education in Katowice in Poland. The authors declare that they have no conflict of interest.

RESULTS AND DISCUSSION

The dynamics of javelin throw result variability. The results of female javelin throwers (since 1946 to 2014) are presented in Table 1. Graph analysis of results variability (in the years 1946-1998 and 1999-2014) is shown in Figures 1, 2 and 3; empirical data are compared to broken trend lines. Trend line breaks are seen in the years of the centre of gravity change in the women's javelin.

For female javelin throwers, the critical point occurred at throw distance of 70.18 m. Dynamic growth of the results was observed until 1985 with the greatest increases in the years 1949 (9%), 1952 (3.7%), 1958 (4.9%), 1960 (6.8%), 1964 (4.4%), 1972 (4.8%), 1976 (4%), 2001 (3%), 2007 (7.5%), 2008 (3%) and 2012 (4.5%). The greatest decreases in result indexes were noted in 2000 (9.4%), 2005-2006 (8.7%) and 2009 (7.4%).

Our analysis reveals that, until the end of 1980s, the results of female javelin throwers showed an increasing tendency. Curves' inclination angles indicate considerable dynamics of results variability.

Trend analysis revealed previously unobserved results decreases in the years 1999-2001. Researchers agree that the change was a result of athletes' adaptation to new javelin parameters [1, 4]. It might be supposed that the fact of women's results remaining over the trend line following a break in the 'old trend' was a consequence of training strategies previously developed by male athletes. This seems to indirectly confirm that the change from the strength-speed-technique to technique-speed-strength training strategies had positive effects and caused results improvement starting in the year 2000 [1, 5].

It might be interesting to emphasize that a simulation of trend index based on 'old' javelin parameters demonstrated a statistically significant results increase after 1984 (up to 110 meters) and after 1999 (up to 80 meters). However, the present trend is almost constant (Figure 3). When comparing independent trends determined in our investigations, it might be presumed that broken trend lines are, to some extent, influenced by the results from the years 1946-1984 and 1999 as the observed result variability is not that signifi-

TABLE I. Arithmetic means of ten top results in women's javelin throw in the years 1946 through 2013.

Event	Place	1946	1954	1964	1974	1984	1994	2003	2004	2005
Javelin throw	1-10	44.03	50.50	58.32	62.51	70.64	67.06	64.29	65.02	65.62
Event	Place	2006	2007	2008	2009	2010	2011	2012	2013	2014
Javelin throw	1-10	65.09	65.28	66.72	65.88	66.52	66.76	66.39	65.81	66.79

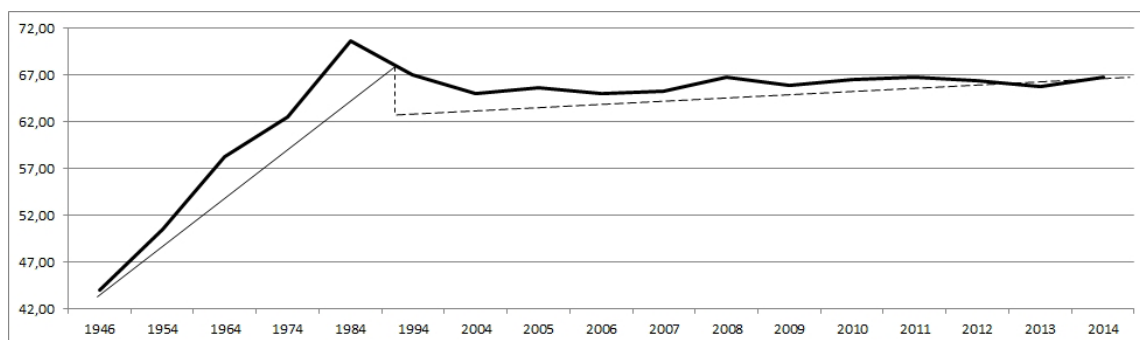


FIG. I. Female javelin throwers' results (empirical data) and broken trend lines in the years 1946 through 2014.

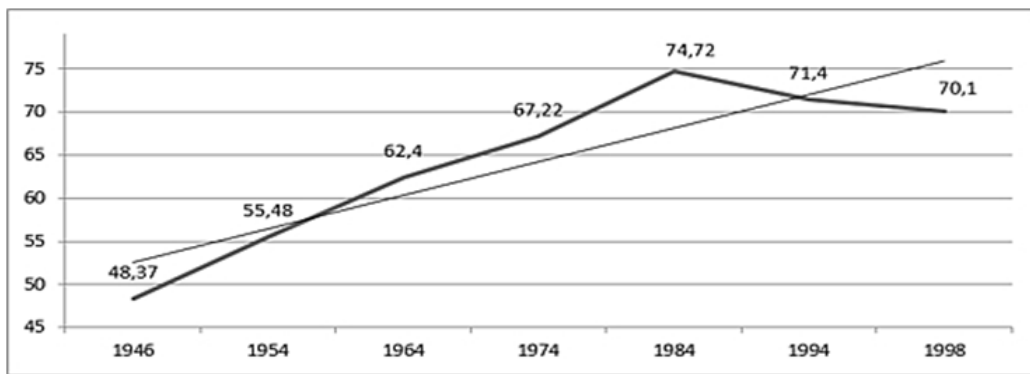


FIG. 2. Female javelin throwers' results variability (empirical data) and linear trend determined for the years 1946 through 1998.

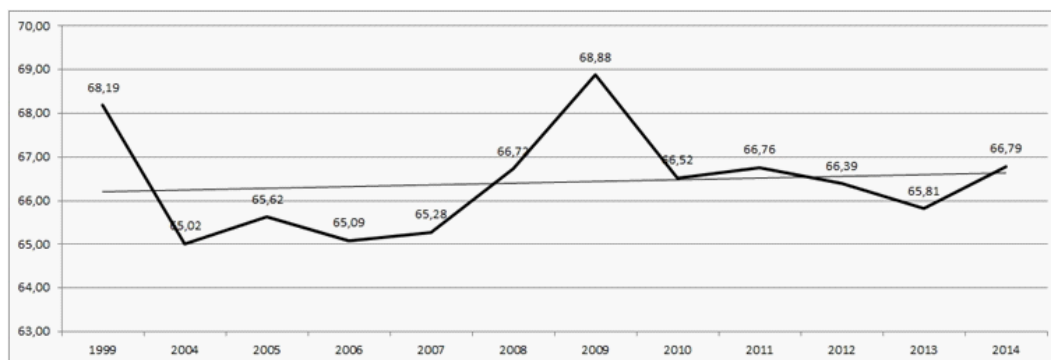


FIG. 3. Female javelin throwers' results variability (empirical data) and linear trend determined for the years 1999 through 2014.

cant. Training methodology changed as a result of alterations in javelin construction and so did the assumptions regarding throwing trajectory, javelin flight, angle of release, initial velocity and air resistance [3, 4, 5, 18, 19, 20, 21].

The throwers' adaptation period to new javelin parameters lasted between 5 to 7 years. However, significant results improvement took longer, i.e., between 8 to 10 years. The trend increase was only noted in the years 2006-2008. In general, until 1998 the mean result improved by 54.6% (100% - results of 1946) whereas from 1999 through 2011 the result only increased by 1.3%. Thus, until the centre of gravity change, the dynamics of female throwers' results variability was much more noticeable (Figs. 2 and 3). What, then, were the factors which had affected javelin throw results and the dynamics of results variability?

During the World Congress on Sport Sciences held in Finland in 1999, linear regression models were presented showing analyses of the relationship between javelin throw distance (JTD) and the following parameters: release speed, angle of release and uncorrected angle of attack. Regression analysis revealed that the three parameters accounted for 54% of the variance in the official result of elite male and female javelin throwers, and that the best parameter to predict the throw distance was the release speed [22]. The authors of previously performed biomechanical investigations of the javelin throw (using mathematical modelling) analysed javelin release parameters including release speed, angle of release, angle of the elbow, attack angle and release height [23, 24]. The authors concluded that the most important factor to determine javelin throw distance was the release speed resulting from body mass correlated with run-up speed and

TABLE 2. Women's javelin throw results for the years 2015-2018 as predicted from nonlinear regression models (NR) and time-series models (TS). Following javelin centre of gravity translocation.

Event	Place	Year	NR [m]	R ²	TS [m]	j ²
Javelin throw	1÷10	2015	66.18 ± 3.21	0.76	66.15 ± 3.24	0.31
		2016	66.26 ± 3.18		66.20 ± 3.23	
		2017	66.32 ± 3.24		66.25 ± 3.26	
		2018	66.37 ± 3.25		66.30 ± 3.27	

TABLE 3. Women's javelin throw results predicted by different models and the best result achieved during the London 2012 Summer Olympics.

Event	Gender	Place	Year	NR	TS	RBF	London 2012
						1-5-1	
Javelin throw	♀	1÷10	2012	66.17	66.18	66.69	66.54

Note: NR-nonlinear regression model, TS-time-series model, RBF-radial basis functions model.

TABLE 4. Women's javelin throw results predicted for the years 2015-2018 as predicted from time-series models using radial basis functions model (RBF).

Event	Predictions for places	Year	Network structure	Quality	Quality	Quality (V)	Error	Error	Error
			RBF	(T)	(T)		(T)	(T)	(V)
			1-5-1	0.94	0.96	0.97	0.126	0.129	0.011
Javelin throw	1+10	2015				66.55 ± 0.30 m			
		2016				66.60 ± 0.32 m			
		2017				66.61 ± 0.42 m			
		2018				66.62 ± 0.44 m			

appropriate angle of release. Mero [25] and other researchers investigated the contributions of particular body segments to javelin throwing during the last thrust phases. A 3-D analysis was performed on male and female javelin throwers during the finals of the 1992 Olympic Games in Barcelona. However, neither the correlations between the movement of body segments engaged in the javelin throw and throw distance itself nor predictive issues were fully elucidated. Similar investigations were undertaken by Murakami [26]. The purpose of their study was to clarify the relationships between the distance thrown and kinematic parameters of the throwing movement. The best throws of eight male finalists at the 2005 IAAF World Championships in Athletics and forty-nine Japanese male throwers were analysed using regression models. Maier [27] developed a neural network model to predict javelin flights, with a mean difference between the model and real throws of 2.5%. The model was used to generate maps of distances reached for different combinations of release parameters. It was found that the most important parameter was the release velocity and that a moderate side angle of attack should be used to attain the longest throws. For release velocities up to 27–28 m s⁻¹ javelins should have an angle of attack about 1–3° larger than the angle of release. For higher velocities a reverse relationship was observed. The authors believe that the model can be used as a coaching aid to optimise athletes' throws during training and competition. The results confirmed the advantage of neural networks over regression models for javelin throw prediction. Hatton [4] used regression models for optimizing the javelin throw in the presence of prevailing winds. Based on the physics and dynamics of the javelin flight, he developed a regression model which allowed him to devise a Windows program for predicting javelin flight distance within about 1%. A lot of researchers believe in the use of result prediction models, and especially artificial neural networks, for optimization of training and selection processes.

The functions of time-series trends and verification of empirical data fit

It was found that the empirical data were very well fitted to linear function of the trend since only 31% of result change were not accounted for by the trend function.

The verified time-series models for the year 2012 were as follows:
 Women - $f_{1-10K}(t_{\text{javelinN}}) = 65.4 + 0.05 \cdot 14 = 66.1 \text{ m} \pm 6.32 \text{ m}$ (4)

Predictive models and predicting event results

Since trend functions were correctly defined, sport results predictions were prepared for successive years using time-series, regression and RBF neural network models. The verification process of predictive models constructed for 5-year periods demonstrated high-degree fitting of empirical data to preliminary models ($F=10.90$). Thus, the correctness of the models was confirmed. Compared to mathematical models, neural networks showed higher degree fitting of input data (quality) and low error values in all groups-training, testing and validation (Table 2 and Table 4).

Comparisons of a/ inter-model predictivity and b/ model predictions with the results of athletic events during the London 2012 Summer Olympics helped determine the accuracy of result forecasting (Table 3). The neural model (RBF-1-5-1; $R^2=0.97$) yielded the most accurate predictions for London 2012; the predicted value was by 0.15 m higher than the actual result (most correlated than NR or TS). The value from the time-series model was by 0.36 m worse than the result achieved; the prediction from the regression model was comparable.

The results of predictive modelling for the years 2015 through 2018 (Table 4) also turned out interesting. The predictions of regressive, time-series and neural models showed weak convergence to Mleczko's [28] predictive analyses of 2015 results. Mleczko [28] predicted a throw distance of 76.84 m. The closest result of 66.62 m was obtained from our RBF model (the difference compared to Mleczko's [28] model amounted to 10.22 m). The doubts can only be solved in 2015. The 2015 prediction of Mleczko [28] is by 4.34 m higher compared to the ultimate result (endpoint) estimated by Einmahl and Magnus [10]. Analysis of trends and results variability since 1999 suggests that Mleczko's [28] predictions are overoptimistic. Einmahl and Magnus [10] estimated the ultimate result (endpoint) in women's javelin throw at 72.50 m.

CONCLUSIONS

Based on the above mentioned data and results variability analysis it might be presumed that, in the nearest future, results variability will increase by approximately 9.7%. Percent improvement of javelin throw distance calculated on the basis of the 1999 raw input data is 1.4% (end of 2014). The difference in javelin throw distance

ce between 1999 and the recently estimated ultimate results amounts to 11% (raw data). An analysis of predictive models variables and the dynamics of results variability during the last 15 years indicates that neural models yield most accurate forecasts of mean results of ten top female throwers during the upcoming 4 years. Thus, it might be presumed that women's world record will be improved around 2018 or a little later.

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