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THE MATH MODELING OF THE STAGES OF RESULT DEVELOPMENT IN HIGH PROFILE ELITE SWIMMERS FOR THE 50m, 100m, 200m, 400m AND 1500m FREESTYLE

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Abstract. *The modern theoretical concept of sport training concentrated on achieving top sport results is based on a principle of perennial directional training that includes sports, preparation and competition. The given perennial process is based upon functional entireties of educational-directional training of the same sort, i.e. based on specific entireties divided into preparation periods. Every mentioned part, despite being functionally connected to the other parts, consists of differently designed training purposes called stages. The purpose of this research is to determine the models based upon which we could evaluate the stages of result development for the men's 50, 100, 200, 400 and 1500m freestyle.*
This research has been carried out using data from secondary sources and it belongs to the category of chronobiological research. The sample consisted of 41 top male swimmers who won medals, that is, entered the finals at World and European Championships or at the Olympics during the last decade (Olympic size pool). This way, the research sample was categorized as consisting of swimmers with elite competition achievements. The modeling was performed using a mathematical method applying fitting of the polynomial degree function of the basic form n degree $y = a_0 + a_1x + a_2x^2 + ... a_nx^n$. *Two patterns have been calculated: 1) the given patterns in the change of the results at competitions in relation to the swimmers' age 2) the pattern in the trend of change of the results at competitions in relation to the swimmers' age within the tested discipline. The results showed that a reliable model, through which the given patterns are described, could be defined for every freestyle discipline. This enabled, in the first place, the measuring of the observed phenomenon and its description using the universal language of mathematics, and secondly, it opened the possibility of control and correction of applied training procedures that all trainers use when they want to compare the obtained model with the one they are applying.*

Key words: *sport training technology, training stage models, math modeling, swimmers, free style*

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1. INTRODUCTION

The modern theoretical concept of sport training concentrated on achieving top sport results is based upon the principle of perennial directional training that includes sports, preparation and competition. The given perennial process is based upon functional entireties of educational-directional training of the same sort, i.e. based on specific entireties divided into preparation periods. Every mentioned part, despite being functionally connected to the other parts, has a uniquely designed training purpose. These periods are theoretically defined as preparation stages and they represent so-called different structural entireties in relation to the fitness levels of an athlete or a team for competition (Zhelyazkov & Dasheva, 2001).

As the process of perennial directional training that includes sports, preparation and competition and applied training takes too long (up to one or even several decades) and consists of several phases, it is very difficult to design the training itself, not to mention the applied training quality control mechanisms used for the correction and evaluation of its efficiency. The only scientifically founded procedure by which we could reliably control the applied training effects and sports achievements in relation to chronological age is the comparison of an athlete's actual state with the existing model characteristics if the given model is predefined (Zaciorski, 1982).

In sport science, models represent an important cognitive base and medium primarily because they successfully erase the ever-present subjectivism as the basic flaw of human thinking (Ristanović, 1989). Models also define the control criterion needed for the efficient improvement of every system (and therefore the training system as well) at its initial level (Dopsaj & al., 1996; Olbrecht, 2000; Dopsaj & al., 2003; Edelmann-Nusser & al., 2002).

Since the given method can be applied in general as well, that is, in relation to perennial training, competition and sport preparations, it can also be applied in regards to any stage of that training. This problem opened the scientific debate about how much swimmers should train in order to achieve their full physical potential. Some authors believe that swimmers can achieve their full potential only if they swim over 10 000 m per day (3-4 hours a day). The others claim that they can do it by swimming only 4000-6000 m per day (1.5-2hrs a day). This discussion about how much physical training is needed for optimal performance is based on the assertion that any improvements to a swimmer's shape depend on how much a swimmer can do during training (such as the number of meters swam daily, frequency of training, optimum number of competitions, etc.) (Costil & al., 1992; Voroncov, 1996; Olbrecht, 2000).

The described problem is acknowledged as being very important for sport theory and practice, so as far as swimming is concerned, there is much published research that is directly related to defining the model structure or certain laws regarding the effect of the applied training in regards to given stage of a swimmer's development.

The problem of the further improvement to the swimming world record has been studied by means of a historiography method (Volkov & Popov, 1997), as has been the model for changes in results in relation to freestyle swimming events of swimmers who have different competition efficacy (Dopsaj & al., 1996), the definition of whether the ability to swim depends on any capacity related to gender and age (Tanaka & Seals, 1997), changes in the results of medal winners in certain disciplines from applying math modeling via polynomial functions (Thanopoulos & Matković, 2000), the modeling and prediction of swimmers' shape and competition results in one micro cycle by applying the method of neuron nets (Edelmann-Nusser & al., 2002), modeling changes in swimmers' abilities in relation to age as part of specific swimming techniques applied in water polo (Dopsaj & al., 2003), the modeling, in relation to prediction, the results that need to be achieved in order to win a medal at the upcoming Olympics (Heazelwood, 2006). However, up until now, no attempt has been made to define the model of the stages of the result development of swimmers by applying mathematical method as the most reliable metrological procedure (Ristanović, 1989; Popović, 2003). Instead, this kind of attempt has been performed only on the level of empiric-descriptive analysis (Voroncov, 1996). Those very laws defined in a scientifically acceptable and reliable way could provide coaches with new knowledge and help create plans and programs for achieving top swimming results and enable the means to control designed plans and programs.

The purpose of this research is to determine the models based upon which we could evaluate the stages of result development in male top free style swimmers for the 50, 100, 200, 400 and 1500m freestyle events.

In addition, this research should represent the basis for future research that would examine the same space but on a population of female swimmers, as well as on the population of male swimmers that use other swimming techniques.

2. Subjects and Methods

2.1. Methods

The research has been carried out using data from secondary sources (Ban, 1999) and it belongs to the category of chronobiological research (Hair & al., 1998; Fajgelj, 2003). As unprocessed data, we used the results from databases of national swimming federations as well as those released by FINA (Fédération Internationale de Natation) and LEN - Ligue Européenne de Natation, available on World Wide Web at: (http://www.fina.org/; http://www.lenweb.org/).

2.2. Research and variable sample

The sample of processed results consisted of 41 top male swimmers who had won medals, that is, entered the finals at World and European Championships or at the Olympics during the last decade (Olympic size pool – Popov, Shoeman, Hoogeband, Draganja, Nystrand, Brambila, Thorp, Hacket, etc.). This way, the research sample was categorized as consisting of swimmers with elite competition achievements, (Dopsaj & al., 1996), which was the first criterion of sample selection. The sample structure and competition sections were the following: 50m freestyle – 9 swimmers; 100m freestyle – 8 swimmers; 200m freestyle – 9 swimmers; 400m freestyle – 9 swimmers; 1500m freestyle – 6 swimmers. The next selection criterion was that the swimmers had top results in at least 5 swimming seasons i.e. different competition years. In this way, the basic methodological condition of modeling is being fulfilled – certain phenomenon can be reliably mathematically modeled via an appropriate method considering that the given phenomenon is characterized by at least 5 points inside the defined space (Ristanović, 1989; Milovanović, 1991; Popović, 2003). In other words, the basic sample of variables consisted of the best annual results from at least 5 different years in which the selected swimmers performed, up to the 2006 season.

The age of twelve is taken as the initial year from which on the projected model results were shown. This is the chronological age from which the first level of sport selection and talent record keeping starts in current scientific, methodological and training procedures (Zaciorski, 1982; Dopsaj & al., 2003; Hohmann & Seidel, 2003; Tomkinson & al., 2003)

2.3. Method of statistical data processing

Rough data was processed in the following way: first, for every swimmer from the sample the best result for the given year was analyzed in relation to the chronological age of the year in which the result was achieved (5 years minimum). In this way, the obtained results based upon which, from the phenomenological aspect of the given bio system "swimmer-competition result-chronological age", it was possible to define the law that shows the change in result achievement in relation to age. This was calculated for every tested event. In this way, the given bio system is mathematically described and the given law of change in competition results in relation to the swimmers' age as part of the studied event was expressed through a method of fitting by a polynomial degree function of the n degree (Ristanović, 1989):. $y = a_0 + a_1x + a_2x^2 + ... a_nx^n$, where y is the result in the given discipline in relation to age; $a_0, a_1, a_2, ..., a_n$ – the polynomial coefficients; x - age. The choice of function degree was based upon two criteria: the degree of a phenomenon's explanation, expressed via the determination coefficient (R^2), and the empirical principle (Ristanovic, 1989).

Second, the increment was also defined, that is, changes in the results are shown in percents in relation to chronological age. In order to define the data, a phenomenological approach was applied (Fajgelj, 2003). As part of this approach, it was hypothetically assumed that every individual swimmer appeared in the sum of possible high results at a certain moment in chronological age. The given age moment was probably the consequence of the influence of a multidimensional factor: adequate organic-biological maturity, swimming talent, psychological and personality structure with a predisposition to achieve top results and the cumulative influence of the applied training technique. In other words, at that age the individual is being recognized as having the potential to achieve top competition results or as a first-class swimming talent. The given chronological moment can be hypothetically treated as the null age, and the results achieved in this period would represent null results in addition to being the results based on which a swimmer of that age can be treated as an individual with predispositions for achieving top results. A further process implied calculating the difference in the achieved results for every following year expressed in percents. In this way, the given bio system segment "change in a swimmer's results in relation to competition age" is mathematically described and the given pattern in the trend of change in the competition results in relation to a swimmer's age as part of the studied event is also expressed by fitting the polynomial degree function of the basic form of the n degree (Ristanović, 1989): $y = a_0 + a_1x + a_2x^2 + ... a_nx^n$, where y is result of the change in relation to a swimmer's age, expressed in percents; $a_0, a_1, a_2, ..., a_n$ the polynomial coefficients, x - age. Since in this case the defined function was a parabola, applying the given model enabled the calculation of two hypothetical points:

- The line of deflection of the parabola's anterior part of the x axis, i.e. the coordinate system abscissa, that can be hypothetically defined as chronological age (in relation to the tested sample of swimmers) in which the swimmers enter the category promising to be top competitors,

- The line of deflection of the parabola's posterior part of the *x* axis, i.e. the coordinate system abscissa, that can be hypothetically defined as chronological age (in relation to the tested sample of swimmers) that represents the bio-chronological limit after which the swimmer no longer possesses the organic basis needed for achieving top swimming results.

All of the results, for every studied event (the 50m, 100m, 200m, 400m and 1500m freestyle) are shown as defined polynomial functions that represent a calculated modeled pattern: 1) the stages of result development in relation to age; 2) the dependence of progress on the null results in relation to a swimmer's age in a 50 m swimming pool (Hair & al., 1998).

The results were processed applying the following statistical software packages: Microsoft® Office Excel 2003 (Copyright © 1985 – 2003 Microsoft Corporation), and STATGRAPHICS Plus 5.1 (Copyright © 1994 – 2001 Statistical Graphics Corp.).

3. RESULTS AND DISCUSSION

3.1. Model of top class swimmer's stages of result development for the 50 m freestyle

Figure 1 shows the obtained model of the 4th degree, the top class swimmers' stages of result development for the 50m freestyle. The model has the form: $y = 0.000052x^4 - 0.006327x^3 + 0.286845x^2 - 5.697548x + 64.2585$. The determining coefficient i.e. percent of explained variance is 98.3161% (R^2=0.983161) and the prediction error is very low, only 1.6839%.

Figure 2 shows the obtained model of the 4th degree, the dependence of progress, i.e. changes in results for the 50m freestyle on the null results in relation to a swimmer's age. The model has the form: $y = -0.00026x^4 + 0.0281x^3 - 1.12654x^2 + 19.8887x - 125.42432$. The determining coefficient i.e. percent of explained variance is 61.049% (R^2=0.61049), and the prediction error is 38.951%.

Table 1 shows the projected results obtained by applying a defined prediction model of the stages of result development for the 50m freestyle (crawl) as well as the projected changes in results in relation to the null year results (null result), expressed in percents.

The first model is defined very successfully because it has a high prediction level, 98.3161% and a very low prediction error of only 1.6839%. As for the second model, we could say its definition is satisfactory since its prediction level is at 61.049%, and its prediction error at the level of 38.951% (slightly more than 1/3 of the result). The given prediction error of the second model can even be considered logical because the sample consists of high profile sprinter swimmers and their racing time is the shortest. That means that every error, regardless of whether it is tactical or technical, every error in the plan and program that causes a lower level of preparation can lead to a greater variation in the results achieved at a competition. Of course, greater result variation can be the cause of relevant deviation in the prediction of the model of progress and the change in competition results of the current season in regards to the null result.

Based on results seen in Table 1., it can be concluded that based on used methodology of data processing and in relation to the critical age of the sample of swimmers, their predisposition for achieving top results for the 50m freestyle is greatest at the age of 14.4, where the result level must be 25.04s. Top swimming results for the given event can be maintained (maintenance and exploitation phase of result achievements, Zhelyazkov & Dasheva, 2001) up to the age of 37 (37.3 years) providing that the swimmer took part in a regular and adequate training process until the given period. Furthermore, the results of the analysis indicate that the highest increment in competition results takes place at the age of 21, and the result peak is between the ages of 23 and 25, with results from 22.53s to 22.55s, and very high (almost maximum) results can be achieved up until the ages of 30 or 32, with results of about 22.80s.

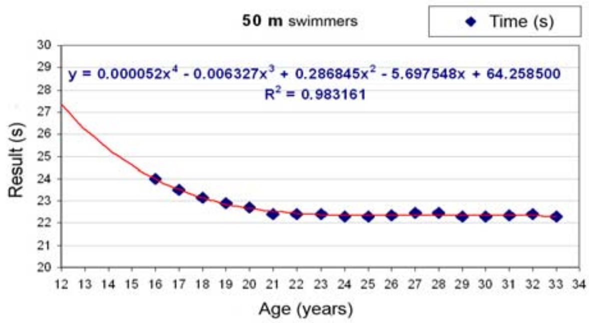

Fig. 1. Model of top class swimmers' stages of results development for the 50m freestyle

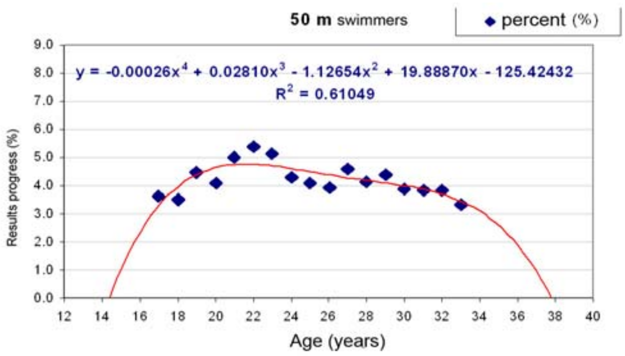

Fig. 2. Dependence of progress on the null result in relation to a swimmer's age for the 50m freestyle

Table 1. Projected results in relation to age for the 50 m freestyle

Age (year)	12	14.4	16	18	20	22	24	26	28	30	32	34	36	37.3
Projected result (s)	27.34	25.04	24.02	23.20	22.75	22.56	22.53	22.59	22.69	22.78	22.87	22.95	23.05	23.14
Progress starting at null yr (%)		0.00	2.31	3.93	4.58	4.67	4.49	4.23	3.98	3.72	3.36	2.68	1.36	0.00

3.2. Model of top class swimmers' stages of result development for the 100m freestyle

Figure 3 shows the obtained model of the 4th degree, the top class swimmers' stages of result development for the 100m freestyle. The model has the form: $y = 0.00038x^4 – 0.03773x^3 + 1.40723x^2 – 23.46764x + 196.83657$. The determining coefficient i.e. percent of explained variance is 97.603% (R^2=0.97603), and the prediction error is very low, only 2.297%.

Figure 4 shows the obtained model of the 4th degree, the dependence of progress, i.e. changes in results for the 100m freestyle on the null results in relation to a swimmer's age. The model has the form: $y = –0.00101x^4 + 0.10041x^3 – 3.75089x^2 + 61.96711x – 375.95162$. The determining coefficient i.e. percent of explained variance is 87.074% (R^2=0.87074), and the prediction error is 12.926%.

Table 2 shows the result predictions obtained by applying the defined equation of the stages of result development model for the100m freestyle (crawl), as well as the prediction of change in results in relation to the null result, expressed in percents.

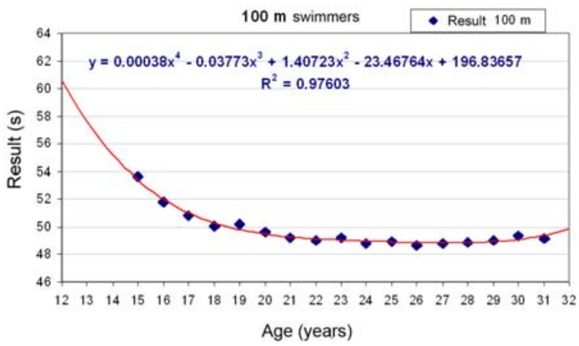

Fig. 3. Model of top class swimmers' stage of result development for the 100m freestyle

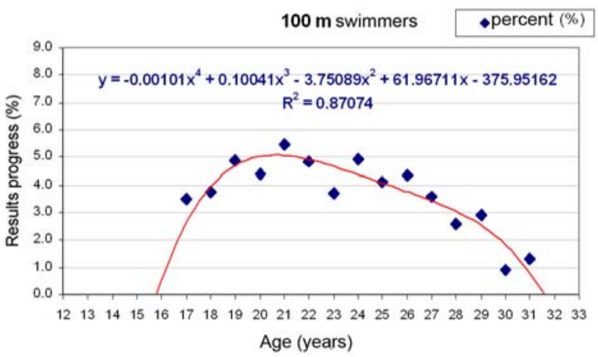

Fig. 4. Dependence of progress on null result in relation to a swimmer's age for the 100m freestyle

Table 2. Projected results in relation to age for the 100m freestyle

Age (year)	12	14	15.8	18	20	22	24	26	28	30	30.2
Projected result (s)	60.55	55.17	52.21	50.21	49.34	48.92	48.67	48.47	48.33	48.40	48.43
Progress starting at null yr (%)			0.00	3.73	4.71	4.46	3.72	2.85	1.83	0.23	0.00

Both models are defined very successfully because they have a high prediction level 97.603% and 87.074%, and very low prediction errors of only 2.297% and 12.926%. Obviously, since the distance was twice as long (100m instead of 50m), the swimmers managed to minimize potential technical or tactical errors made during the race, so since the interval was longer, the swimmers were able to, from a relative aspect, minimize potential variation of competition result.

Based on results seen in Table 2., it can be concluded that based on the used methodology of data processing and in relation to the critical age of the sample of swimmers, their predisposition for achieving top results for the 100m freestyle is greatest at the age of 15.8, where the result level must be 52.21s.

In the case of the 50m freestyle, the modeled results show that the critical age of for achieving top results for the 100m freestyle is moved up by 1.4 years, meaning that the swimmers should be older.

It is a well known fact that in contrast to the 50m freestyle event that takes energy supplies from the creatine-phosphate energy source (the CP system) and which implies training domination in order to develop maximum swimming speed, the 100m freestyle event training implies the use of specific training exercises in order to develop so-called speed endurance. This training demands additional training loads that predominantly burden the glycolic energy mechanism, with a maximum work intensity pattern. This is very stressful and hard training and it demands prior adequate preparation of general endurance as well as adequate bio-maturity of the organism. It is only after this introductory preparation period that it is possible to gradually increase the number of times the load is used during training, based on the glycolysis development type, i.e. speed or specific endurance development (Voroncov, 1996; Olbrecht, 2000; Zhelyazkov & Dasheva, 2001). The given conditions most probably cause the calculated results, which means that predisposition for achieving top results at the 100 m freestyle event can reliably be defined not earlier than at the age of 15.8, i.e. 1.4 years later than in the case of the 50 m section.

Based on these results, it can be concluded that the highest results for the given event can be maintained up until the age of 30 (30.2). Further analyses show that the highest increment in competition results takes place at the age of 20, with results of 49.36s, and very high (almost maximum) results can be achieved up until the ages of 28 or 29, with results of about 48.33s (Table 2.).

3.3. Model of top class swimmers' stages of result development for the 200m freestyle

Figure 5 shows the obtained model of the 4th degree, the top swimmers' stages of result development for the 200m freestyle. The model has the form: $y = 0.00023x^4 - 0.02262x^3 +$

$0.90933x^2 - 17.11656x + 231.88701$. The determining coefficient i.e. percent of explained variance is 96.429% (R^2=0.96429), and the prediction error is very low, only 3.571%.

Figure 6 shows the obtained model of the 4th degree, the dependence of progress, i.e. changes in results for the 200 m freestyle on the null result in relation to a swimmer's age. The model has the form: $y = -0.00090x^4 + 0.07356x^3 - 2.25602x^2 + 31.32894x - 162.95159$. The determining coefficient i.e. percent of explained variance is 85.841% (R^2=0.85841), and the prediction error is 14.159%.

Table 3 shows the predictions of the results obtained by applying the defined equation of the stages of result development model for the 200m freestyle (crawl) as well as the prediction of change in results in regards to the null result, expressed in percents.

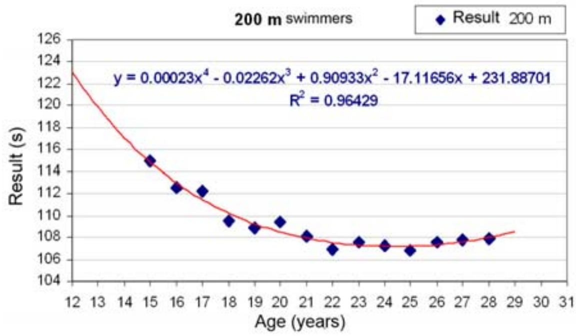

Fig. 5. Model of top class swimmers' stage of result development for the 200m freestyle

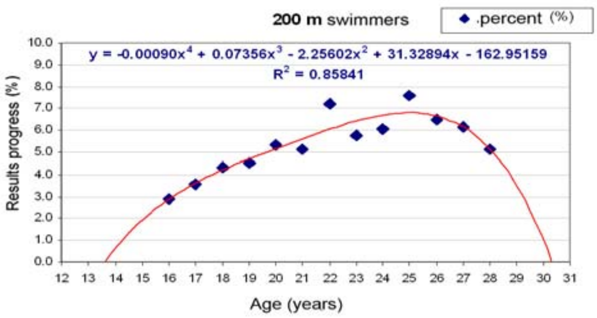

Fig. 6. Dependence of progress on the null result in relation to a swimmer's age for the 200m freestyle

Table 3. Projected results in relation to age for the 200m freestyle

Age (year)	12	13.6	16	18	20	22	24	26	28	30	31.1
Projected result (s)	2:03.11	1:58.26	1:53.23	1:50.64	1:49.13	1:47.46	1:48.47	1:49.10	1:50.35	1:52.35	1:53.82
Progress starting at null yr (%)		0.00	3.09	4.54	5.70	6.81	7.77	8.14	7.14	3.62	0.00

Both models are defined very successfully because they have a high prediction level of 96.429% and 85.841%, and very low prediction errors of only 3.571% and 14.159%. The predictive value of the result for the 200m freestyle model is very similar to the defined 100m model which indicates that swimming at both distances uses energy from the same energy source (Heck & al., 2003). However, although swimming exhausts energy from the same glycolic system, in order to have a good performance for the 200m freestyle, it is necessary to have a well developed capacity of the aforementioned system, while the 100m freestyle event demands dominant power and intensity development of the given energy system (Olbrecht, 2000; Heck et al., 2003). Also, most swimmers from the sample that took part in the 100m freestyle event also participated in the 200m one. In this way, the source of data variability had the same origin, which might be the cause of a similar model structure.

Based on results seen in Table 3., it can be concluded that the critical age for achieving top results for the 200m freestyle event is 13.6 years, where the result level must be 1:58.26. During the 200m freestyle event, the dominant energy source is glycolysis, but, a well developed oxidative i.e. aerobe mechanism is also of great importance. It is well known that the bio-organic sensitive phase for maximal development of aerobic ability in men begins during the first phase of puberty i.e. between the ages of 13 and 14. This period is known for abrupt increment in the dimensionality of the longitudinal skeleton and, therefore, the consequent rapid development of all internal organs, especially the pulmonary and cardio-vascular systems (Voroncov, 1996; Tomkinson et al., 2003). This gives a functional-physiological basis that enables talented swimmers to make greater progress in achieving results for the 200m freestyle event in comparison to those less talented simmers in the same event, so they stand out as more talented at an earlier age phase in comparison to more talented swimmers for the 50m and 100 m freestyle events.

On the other hand, the highest results for the given event can be maintained up until the age of 31 (31.1) provided that the swimmer took part in a regular and adequate training process. A further analysis shows that the highest increment in competition results happens a lot later than in the case of the 50m and 100m freestyle events, as late as at the age of 26 with a result of 1:49.64 and very high (almost maximum) results can be achieved in a longer time span, from the age of 21 (1:47.70) up until the age of 27 with results of 1:49.64.

Top swimmers in these events achieve their maximum results (competition peak) at a significantly later age - 26, which is most probably caused by a multidimensional mechanism that has several characteristic parameters such as: competitive experience, achieved technical level and technical swimming skills in surmounting the given discipline, a fully mature swimmer's personality, both psychologically and motivationally , and being very well trained from the aspect of speed or specific endurance development. In order to posses this kind of specific adaptation it is necessary to take part in perennial good quality training that causes the development of organic systems necessary for the achievement of top results. Those are: a high level of anaerobe capacity, a high level of lactate tolerance, the ability to make and tolerate great oxygen debt, an organism's ability to tolerate a high degree of acidosis, local muscle endurance in regards to strength or speed strength, the ability to control an efficient swimming technique in a state of decompensation due to fatigue, etc. (Troup, 1990; Voroncov, 1996; Dopsaj et al., 1996; Lindle et al., 2000; Olbrecht, 2000; Edelmann-Nusser et al., 2002; Heck et al., 2003).

3.4. Model of top class swimmers' stage of result development for the 400m freestyle

Figure 7 shows the obtained model of the 3rd degree, the top swimmers' stage of result development for the 400m freestyle. The model has the form: $y = -0.01765x^3 + 1.40853x^2 - 36.45159x + 534.61336$. The determining coefficient i.e. percent of explained variance is 91.803% (R^2=0.91803), and the prediction error is very low, only 8.197%.

Figure 8 shows the obtained model of the 4th degree, the dependence of progress, i.e. changes in the results for the 400m freestyle event on the null results in relation to a swimmer's age. The model has the form: $y = -0.00108x^4 + 0.10585x^3 - 3.87858x^2 + 62.43705x - 366.0605$. The determining coefficient i.e. percent of explained variance is 73.520% (R^2=0.73520), and the prediction error is 26.480%.

Table 4 shows the prediction of results obtained by applying the defined equation of the stage of result development model for the 400m freestyle (crawl) as well as the prediction of change in results in regards to the null result, expressed in percents.

The first model has been defined very successfully because it has a high prediction level (91.803%) and a very low prediction error of only (8.197%). As for the second model, we could say its definition is satisfactory since its prediction level is at 73.520%, and prediction error at the level of 26.480% (slightly over 1/4 of the result).

The results for the 400m freestyle model are very similar to the ones for the 50m freestyle model where the result model defines their high prediction level while the progress model defines a considerably lower prediction level. The determined state indicates the fact that any continuity in the progress of swimmers swimming the 400m freestyle, i.e. taking part in one of the so-called middle distances, has a much higher variability than for the 100m and 200m events, and is similar to the determined continuity for the 50m event. The preparation method for the two events (the 50m and 400m freestyle) is completely different, because according to the strain criterion, they belong to different energy sources (Troup, 1990). The 50m freestyle event is chronologically the shortest, so technical and tactical mistakes can be a dominant source of result variability, while the time span for a 400m freestyle event is about 4 minutes. This leads to the conclusion that technical errors during swimming have the smallest influence on to the projected result variability. However, tactical errors and errors in projecting the training process can be the cause of modeled relevant variability of the prediction of any progress in achieving results in relation to age.

How successful the swimmer is going to be swimming the 400m freestyle event, besides adequate technical swimming characteristics, depends first of all on precise fitness in regards to adequate intensity zones, and that is primarily related to the anaerobic zone i.e. lactate limit (Wakayoshi et al., 1992; Bonifazi et al., 1993; Olbrecht, 2000). Therefore, every wrong dosage of training intensity would consequently produce inadequate competitor fitness (preparation level) which would increase the variability in achieving results.

Based on the results seen in Table 4., it can be concluded that based on the used methodology of data processing and in relation to the sample of swimmers, the critical age for achieving top results for the 400m freestyle event is the age of 14.9, where the result level must be 4:05.81 seconds.

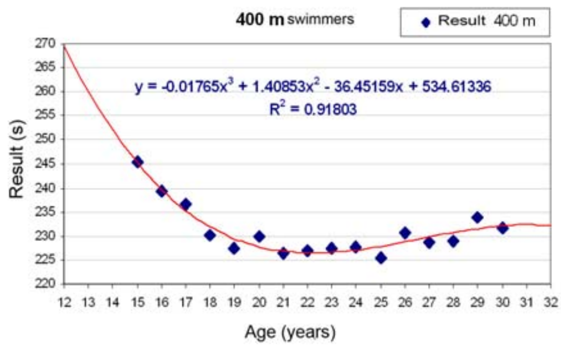

Fig. 7. Model of top class swimmers' stage of result development for the 400m freestyle

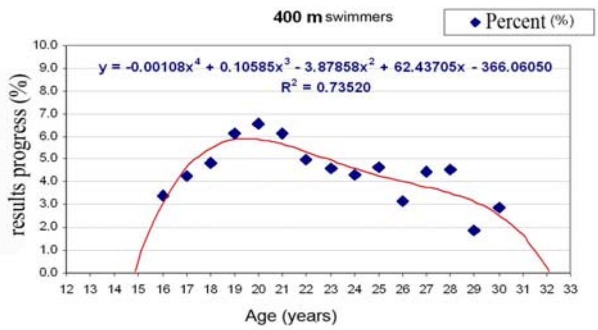

Fig. 8. Dependence of progress on the null result in relation to a swimmer's age for the 400m freestyle

Table 4. Projected results in relation to age for the 400m freestyle

Age (year)	12	14.9	16	18	20	22	24	26	28	29.5
Projected result (s)	4:29.52	4:05.81	3:59.29	3:51.91	3:47.79	3:46.47	3:47.09	3:47.82	3:50.80	3:51.95
Progress starting at null yr (%)		0.00	2.80	5.09	5.25	4.42	3.32	2.27	1.16	0.00

In the case of the events we have analyzed so far (the 50, 100 and 200m freestyle), the modeled results showed that the critical age for achieving top results in these events is the highest. Although an oxidative energy source dominates during the 400m freestyle event, it is also very important to have a well-developed glycolic energy mechanism. Practically, the given combination is responsible, and in order to achieve best results for the given section, the ability to race in mixed aerobe-anaerobic swimming intensity zones is of greatest importance. However, in addition to this, it is necessary that the swimmer adapts during training from the aspect of energetic and technical swimming efficiency. The mentioned adaptation processes demand longer periods of time and adequate competitive experience of the swimmer (Troup, 1990; Voroncov, 1996; Olbrecht, 2000). It is possible that the set of described factors caused the talent for achieving top results in the 400m freestyle event not to show until the age of 15 (14.9).

The obtained results showed that the highest annual increment of the mentioned results can be expected at the age of 19, at a level of 5.35% in regards to the null age and the result peak between the ages of 21 and 23 (result span from 3:46.47 to 3:46.84) and very high (almost maximum) results can be achieved up until the ages of 26 or 27 (results under 3:50.00).

3.5. Model of top class swimmers' stage of result development for the 1500m freestyle

Figure 9 shows the obtained model of the 4th degree, top swimmers' stage of result development for the 1500m freestyle event. The model has the form: $y = 0.0180x^4 – 1.6049x^3 + 54.0682x^2 – 817.4680x + 5574.0093$. The determining coefficient i.e. percent of explained variance is 95.83% (R^2=0.9583), and the prediction error is only 4.17%.

Figure 10 shows the obtained model of the 3rd degree, the dependence of progress, i.e. changes in the results for the 1500m freestyle on the null result in relation to a swimmer's age. The model has the form: $y = 0.0061x^3 – 0.4656x^2 + 11.295x – 84.554$. The determining coefficient i.e. percent of explained variance is 81.59% (R^2=0.8152), and the prediction error is 18.48%.

Table 5 shows the result predictions obtained by applying the defined equation of the stage of result development for the 1500m freestyle (crawl) model as well as the prediction of changes in results in regards to the null result, expressed in percents.

The first model is defined very successfully because it has a high prediction level (95.83%) and a very low prediction error of only 4.17%. As for the second model, we could say that its definition is satisfactory since its prediction level is at 81.59%, and the prediction error at level of 18.48% (slightly over 1/5 of the result).

The determined state indicates the fact that the continuity of progress among swimmers swimming the 1500m freestyle, i.e. taking part in the so-called large track event, has a much lower variability than its counterpart shortest distance i.e. the 400m and 50m freestyle events, while its variability is approximately similar to the 100m and 200m events. The 1500m section belongs to the category of dominantly aerobic energy strain where a highly developed aerobic mechanism (aerobic power) and having adequate swimming capacity at high aerobic intensity are the most important kinds of fitness from the aspect of competition result success (Troup, 1990; Wakayoshi & al., 1992; Bonifazi & al., 1993; Olbrecht, 2000). Since professional swimmers complete the aforementioned events in less than 15 minutes, a part of the variability of success belongs to the aspect of tactics and a swimmer's ability to swim the whole section with a precisely dosed tempo that is at optimum intensity, and which provides the best possible result. This precise type of fitness is highly correlated to precisely dosed training intensity, i.e. the so-called sub-limit intensity, or swimming intensity at the level of a maximum lactate steady state (Olbrecht, 2000). An indirect effect of the training is building the swimmer's sense for so-called "precise tempo swimming" which is in fact a developed ability to do the swimming at tactically planned intensity (Tanaka & Seals, 1997). Consequently, professional swimmers have developed this sense best, since they are the best and most experienced competitors. This is most likely the reason why both models are defined the way they are, even though it is related to the longest Olympic section with a relevantly low prediction error.

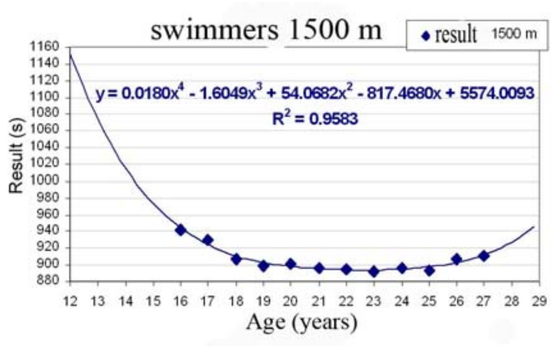

Fig. 9. Model of top class swimmers' stage of result development for the 1500m freestyle

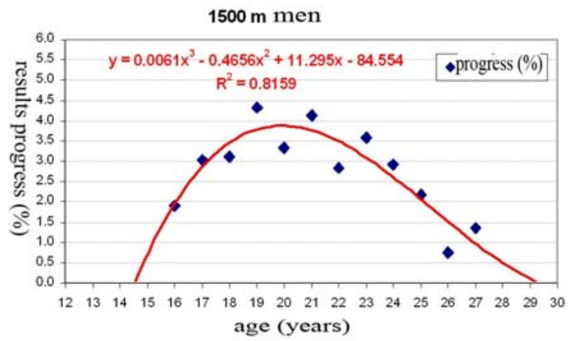

Fig. 10. Dependence of progress on the null result in relation to swimmers age for the 1500m freestyle

Table 5. Projected results in relation to age for the 1500m freestyle

Age (year)	12	14.5	16	18	20	22	24	26	28	29.9
Projected result (s)	19:10.88	16:32.96	15:44.08	15:10.85	14:57.84	14:53.79	14:54.38	15:02.18	15:26.71	16:20.40
Progress starting at null yr (%)		0.00	1.96	3.48	3.91	3.55	2.68	1.59	0.60	0.00

Based on results seen in Table 5 it can be concluded that the critical age for achieving top results for the 1500m freestyle event is the age of 14.5, where the result level must be about 16:32.96.

In to the case of the sections we have analyzed so far (the 50, 100, 200 and 400m freestyle), the modeled results showed that the critical age for achieving top results in this event is in accordance with the others. However, the event length and a swimmer's adaptation to the swimming technique demand a lot of time and training-competition experience in terms of adequately needed adaptation of not the only swimmer's body, but of his adequate personality traits as well (innovation and desiderative characteristics) (Troup, 1990; Petković, 1996; Voroncov, 1996; Olbrecht, 2000; Čoh & al., 2004). This might explain the fact that the talent for achieving top results for the 1500m event is not that obvious until the age of 14.5. The obtained results showed that the highest annual increment of the mentioned results can be expected at the age of 20 at the level of 3.91% in regards to null age, and the result peak between the ages of 22 and 24 (result span from 14:53.79 to 14:54.38 and very high (almost maximum) results can be achieved up until the age of 26, providing that the swimmer took part in a regular and adequate training process (results under 15:00.00).

4. Conclusion

Based on the applied work method, the chosen sample and applied mathematical and statistical procedures, it was possible to calculate the models which define top class swimmers' stages of development for the 50, 100, 200, 400 and 1500m freestyle events. Two patterns have been calculated: 1) the given patterns in the changes in competition results in relation of a swimmer's age 2) the pattern in the trend of change in competition results in relation to a swimmer's age within the studied event.

Based upon the results obtained by this research it can be concluded that:

- The critical age (null age) for achieving top results for 50m freestyle is the age of 14.4, where the result level must be 25.04 s. Top swimming results for the given event are possible to maintain (maintenance and exploitation phase of result achievements- Zhelyazkov & Dasheva, 2001) up to the age of 37 (37.3 years), providing that the swimmer took part in a regular and adequate training process until the given period of time. The highest increment in competition results happens at the age of 21, and the result peak between the ages of 23 and 25, with results from 22.53s to 22.55s, and very high (almost maximum) results can be achieved up until the ages of 27 or 28, with a result span from 22.64s to 22.69s.
- The critical age (null age) for achieving top results for the 100m (the null result) freestyle is the age of 15.8, where the result level must be 52.21 s. The highest results for the given distance can be maintained up until the age of 30 (30.2). A further analysis shows that the highest increment in competition results takes place at the age of 20, with result of 49.34s, and very high (almost maximum) results can be achieved up until the ages of 28 or 29, with results of about 48.33s.
- The critical age (null age) for achieving top result for the 200m (the null result) freestyle is the age of 13.6, where the result level must be about 1:58.26. The highest results for the given distance can be maintained up until the age of 31. The highest increment in competition results does not take place until the age of 26, with results of 1:49.64, very high (almost maximum) results can be achieved over a longer time span, from the age of 21 (1:47.70) up until the age of 27 with results of 1:49.64.
- The critical age (null age) for achieving top results for the 400 m (the null result) freestyle is the age of 14.9, where the result level must be about 4:05.19. The obtained results showed that the highest increment of the mentioned results can be expected at the age of 19 at a level of 5.35% compared to null age, and the result peak between the ages of 21 and 23 (with a result span from 3:46.47 to 3:46.84) and very high (almost maximum) results can be achieved up until the ages of 26 or 27 (results under 3:50.00).

- The critical age (null age) for achieving top results for the 1500 m (the null result) freestyle is the age of 14.5, where the result level must be about 16:32.96. The obtained results showed that the highest increment of the mentioned results can be expected at the age of 20, at the level of 3.91% in regards to null age and the result peak between the ages of 22 and 24 (with a result span from 14:53.79 to 14:54.38) very high (almost maximum) results can be achieved up until the age of 26 (results under 15:00.00).

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MATEMATIČKO MODELOVANJE ETAPNIH NIVOA RAZVOJA REZULTATA VRHUNSKIH PLIVAČA NA 50, 100, 200, 400 I 1500 METARA SLOBODNIM STILOM

Tomislav Okičić, Dejan Madić, Milivoj Dopsaj, Miodrag Đorđević

Moderni teorijski koncept sportskog treninga, orijentisanog na postizanje vrhunskih sportskih rezultata, zasniva se na principu višegodišnje trenažno-takmičarsko-sportske usmerenosti primenjenog trenažnog rada. Dati višegodišnji proces organizaciono je zasnovan na funkcionalnim celinama istorodnog edukativno-trenažnog usmerenja, odnosno na posebnim celinama podeljenim na periode pripreme, od kojih svaki za sebe, iako povezan funkcionalno, ima projektovan različiti trenažni cilj nazvanim – etape. Cilj ovog istraživanja je utvrđivanje modela na osnovu kojih bi se mogla vršiti procena etapnog razvoja rezultata u plivanju na deonicama od 50, 100, 200, 400 i 1500m slobodnim stilom kod muškaraca koji predstavljaju populaciju najboljih vrhunskih plivača. Istraživanje je izvršeno pomoću podataka iz sekundarnih informacionih izvora i pripada kategoriji hronobioloških istraživanja. Sirovi uzorak obrađenih rezultata sastojao se od 41 vrhunskog plivača muškaraca koji su bili osvajači medalja, odnosno finalisti na Svetskim i Evropskim prvenstvima, ili Olimpijskim igrama u poslednjoj deceniji (bazen olimpijskih dimenzija). Na taj način uzorak ispitanika bio je kategorisan kao - sportisti plivači sa elitnim takmičarskim dostignućem. Modelovanje je izvršeno pomoću matematičke metode primenom metode fitovanja polinomijalnom stepenom funkcijom n-*tog stepena opšteg oblika:* $y = a_0 + a_1x + a_2x^2 + ... a_nx^n$. *Izračunate su dve zakonitosti i to: 1) data zakonitost promene takmičarskog razultata u funkciji uzrasta plivača, i 2) zakonitost promene trenda takmičarskog razultata u funkciji uzrasta plivača na ispitivanoj disciplini. Rezultati su pokazali da je za svaku distancu bilo moguće definisati pouzdan model kojim su opisane date zakonitosti, što je omogućilo kao prvo, merenje posmatranog fenomena i njegovo opisivanje univerzalnim jezikom matematike, a kao drugo, obezbedilo je mogućnost kontrole i potrebne korekcije primenjivanih trenažnih postupaka svih trenera koji, dobijeni model žele uporediti sa sopstveno primenjivanim.*

Ključne reči: *tehnologija sportskog treninga, etapni modeli, matematičko modelovanje, plivači, slobodni stil.*