



Mathematical modeling analysis of the performance evolution along the career-span of female swimmers

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ABSTRACT

Children and youth sports performance should always consider the growth and maturation processes⁽¹⁾, and their influence in the growth rate of results along the sports career. In this extent, the purpose of this work was to study, on one hand, the growth rate of results in all swimming events of female Olympic calendar from the initial sports education till the stage of high level performance and, on the other hand, try to establish a relationship with the growth, maturation and training process of female swimmers. For this purpose a sample constituted by female swimmers in Portuguese swimming Rankings over the last four years (1998 to 2002) in an approximately amount of 6,000 data was used. The growth rate of results (GRR) was calculated based in the following algorithm: (initial time-final time)/initial time. The results pointed out, let us conclude that: (i) a general tendency of GRR. Increasing was verified from 11 to 12 years and from 14 to 16 years in 25 m swimming pool; (ii) a similar tendency was verified in 50 m swimming pool, but with superior GRR tendencies. Those results can be explained, more than by the training process, by the growth, development and maturation process.

INTRODUCTION

Correct orientation on the training process in its different stages, the loads dimension, the set of the training means and methods and respective contents, should be programmed considering the processes and growth age of several organs and systems of young female athletes who have differentiated rhythms, namely those which are main support to swimming demands as a modality. According to Hahn⁽²⁾, at 10/11 years of age children present a very significant evolution in their motor learning skills, differentiation/control and balance, as well as velocity, acquisition and stabilization of motor tasks mainly based on action reaction⁽³⁻⁵⁾, associated with the development of the central nervous system and maturation of several physiological links of the conditional system⁽⁶⁻⁹⁾, being it a privileged stage for the technical training, and appropriate stimulation tends to produce better results⁽¹⁰⁾. Muscular development follows a similar pattern to bone development. The muscle fibers increase in size but not in number, throughout childhood and adolescence⁽¹¹⁻¹⁴⁾. Annual improvement in strength and power with peaks which are reached when they are around 16 is observed⁽¹⁵⁾. Up to 12 years of age the aerobic metabolism is more developed than the other ones⁽¹⁶⁻¹⁷⁾.

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Concerning motor learning, the movements tend to be performed through tasks selection⁽⁸⁾. It would be defined as the planning for action and be represented through the movement⁽⁹⁾. Another important point to be highlighted is that the presentation of a model, especially if the presentation is controlled by the learner him/herself, enables superior learning than that controlled by the technician⁽¹⁸⁻¹⁹⁾.

Finally, one can highlight another factor which has received attention from researchers in the motor learning field: the establishment of goals⁽²⁰⁾.

Within this context, we tried in this study, based on the analysis of the growth rate of the sports results in Portuguese female swimmers, from the initial sports education until the stage of high level performance, to reflect on the influence that the growth and maturation processes have in the female swimmers results, with the purpose to better structure, organize and control the training process for female swimmers.

METHODOLOGY

Sample characterization

The sample consisted of the ten best times from all events from the Olympic calendar, in 25 and 50 meter-swimming pools, from the national rankings from 1997/1998 until 2000/2001, reached by all swimmers of all formation and training groupings in the female gender. The adopted procedures are according to the Helsinki Declaration, 1975, and were approved by the scientific committee of the UTAD (Universidade de Trás-os-Montes e Alto Douro) for its performance (resolution 1273/03).

TABLE 1
Age groupings used in the study's sample

	Year 1	Year 2	Year 3	Year 4
Grouping 3	G6-G5 1988-1987	G6-G5 1989-1988	G6-G5 1990-1989	G6-G5 1991-1990
Grouping 2	G4-G3 1986-1985	G4-G3 1987-1986	G4-G3 1988-1987	G4-G3 1989-1988
Grouping 1	G2-G1 1984	G2-G1 1985	G2-G1 1986	G2-G1 1987
Jun./Sen	1983 and older	1984 and older	1985 and older	1986 and older

Procedure

After data collection and corresponding exploring analysis, data were organized in two determinant models: i) formulation of the model for age and collection of best times (100/200 m; 400 m; 800 m); ii) formulation of the model for calculation of the growth rate(%) of the sports results and its modeling.

Mathematical modeling for optimum age for best results

The mathematical model proposed by Van Tilborgh *et al.*⁽²¹⁻²²⁾ was applied with six defined stages for the calculation of the evolution rate of the sports results by techniques and distance grouping:

Stage 1: Calculation of a constant (C_{event}) specific for each event for later calculation, considering each individual time of a punctuation. The punctuation system is based on a function which respects a mathematical modeling, in which the Absolute National Record (ANR) for each event, gender and swimming pool receives 1000 points;

Stage 2: Relativization of the event punctuation according to the chosen age group, so that punctuation corresponds to a given time in an age group, either by a side coherent with the embarrassment which is provided by the absolute national record in the mentioned event, and or coherent with the age in which this time is obtained. Therefore, the use of the mean of the 10 best female swimmers picked from the updated rankings charts of the Portuguese Swimming Federation (FPN) is crucial. Having this value, the punctuation formula was applied and an absolute punctuation was obtained;

Stage 3: Ending of the upper part of the curve, above 18 years of age, once, especially in men, the generalization of the absolute national records is obtained above this age. The age which will have the 1000 points (maximal corresponding to the absolute national record obtained) is calculated through a linear regression model, in the 5 known data pairs (age and punctuation);

Stage 4: Use of the mean of the 10 best swimmers of the absolute ranking for the event considered, and later conversion for the same punctuation, indexing this value to the pairs of values of the age groups;

Stage 5: Based on the previous considerations, a new regression line (second polynomial degree) is calculated, being this line considered as the 100%;

Stage 6: Finally, the model calculates the individual performance (punctuation) based on the respective age groups. Individual time is converted for a punctuation. The exact punctuation corresponding to age is then calculated in percentage using the age in the regression equation.

Modeling for the calculation of the growth rate (%) of the sports results and their modeling

After the outliers derived from the exploratory analysis have been expurgated the following algorithm: (Initial time-Final time)/Initial time*100 was applied for the calculation of the evolution rate per individual event.

The curve modeling considering the application of several polynomial units was performed in order to estimate the growth rate behavior of the sports results concerning the different age segments. An embarrassment to the modeling was introduced, corresponding to value in abscise of the optimum age of the sports result obtained, based on the mathematical algorithm application presented in the previous stage.

The adjustment quality evaluation was performed through two criteria: i) the value of the determination coefficient (R^2), being the highest value chosen and considered as one of the indicators of the sample's quality; ii) the estimate error, which measures the dispersion of the adjustment performed.

When the mathematical modeling of the growth curves of the sports results is applied, and the embarrassment which has been calculated in the previous point is included, we can obtain different types of adjustment according to the degree of the polynomial unit chosen.

Thus, the choice of the most suitable polynomial unit lied on the one which in the different segments of the curve presented lower residue value, allowing hence being more certain in the prediction of results.

RESULTS

Optimum age for sports results

Table 2 shows the results of the analysis of the rankings for female swimmers, with calculation of the respective age for the best times per event.

TABLE 2
Results of the analysis of the rankings and application of the mathematical model for the female swimmers

Event	Linear adjustment equation (age/points)	Best time predictable age	Equation of the relationship % between age and performance
100 L	$Y = 69.93 * \text{age} - 334.47$	19.45	$y = -6.135 * (\text{age})^2 + 228.92 * (\text{age}) - 1343.7$
200 L	$Y = 72.425 * \text{age} - 333.66$	18.42	$y = -6.372 * (\text{age})^2 + 239.95 * \text{age} - 1407.2$
400 L	$Y = 75.19 * \text{age} - 348.15$	17.93	$y = -8.0713 * (\text{age})^2 + 287.73 * \text{age} - 1712$
100 m Br	$Y = 69.93 * \text{age} - 334.47$	19.09	$y = -6.1135 * (\text{age})^2 + 228.92 * \text{age} - 1343.7$
200 m Br	$Y = 90.75 * \text{age} - 613.18$	17.78	$y = -10.785 * (\text{age})^2 + 373.33 * \text{age} - 2418.5$
100 m C	$Y = 65.888 * \text{age} - 281.46$	19.45	$y = -5.56438 * (\text{age})^2 + 212.4 * \text{age} - 1221.9$
200 m C	$Y = 84.03 * \text{age} - 550.09$	18.45	$y = -9.6151 * (\text{age})^2 + 338.4 * \text{age} - 2189.1$
100 m Mar.	$Y = 83.467 * \text{age} - 502.55$	18.00	$y = -9.2171 * (\text{age})^2 + 325.95 * \text{age} - 2057.3$
200 m Mar.	$Y = 104.17 * \text{age} - 865.09$	17.9	$Y = -9.7817 * (\text{age})^2 + 362.48 * \text{age} - 2526.7$
200 m Est.	$Y = 77.7 * \text{age} - 396.58$	17.98	$y = -7.0165 * (\text{age})^2 + 261.58 * \text{age} - 1571.7$
400m Est.	$Y = 102.19 * \text{age} - 733.15$	16.96	$y = -13.763 * (\text{age})^2 + 464.99 * \text{age} - 3062.4$

Table 3 analyses events groupings by distance criterion, with calculation of the respective age, mean of the best times per event.

TABLE 3
Mean results of the analysis of the rankings and application of the mathematical model by style and distance

	Butterfly	Backstroke	Breaststroke	Crawl	Styles	Mean	± SD
100 m	18	19.45	19.09	19.45		18.99	± 0.68
200 m	17.9	18.45	17.78	18.42	17.98	18.10	± 0.30
400 m				17.93	16.96	17.44	± 0.68

Based on the analysis of the obtained results, we are able to verify that in Portugal, and whenever female swimmers are considered, they tend to obtain their best times earlier the longer the distance of the event.

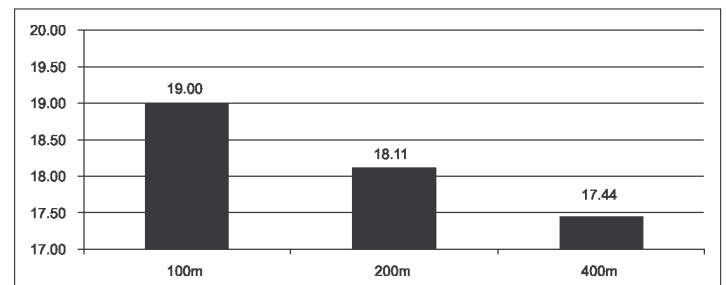


Figure 1 – Chart of the mean values of the ages in years for best times, by distance (meters)

Growth curves by distance and curve modeling with embarrassment obtained in model 1

In the following figure we can observe the results which derived from the analysis of the rankings for the female swimmers,

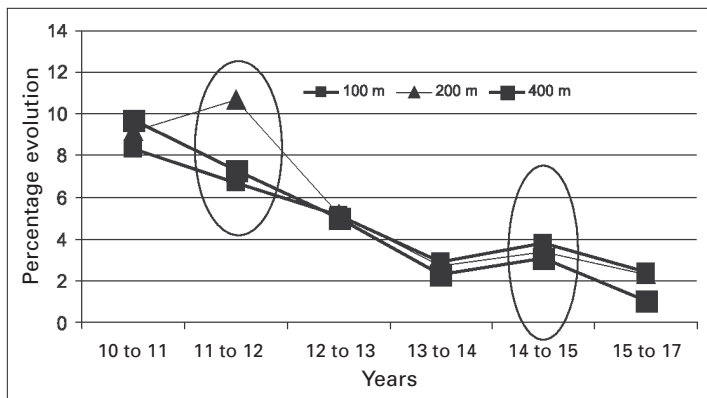


Figure 2 – Chart of the mean values of growth rate (years) of the sportive outcomes throughout the ages and by grouping of swimming distances, for the female sex

with the calculation of the growth rate of the sports results marks per event.

After the analysis of this figure concerning the growth rate of the sports results by grouping of swimming distances, a curve with two growth peaks was verified: i) one between 11-12 years of age; ii) from this age on a decrease of the values of the growth rate is verified with a new growth peak at 14-15 years of age.

When the evolution of the sports results in the different techniques in 25 m and 50 m swimming pools is analyzed (figures 3 and 4), a similar trend is observed both in short (25 m) and long swimming pools (50 m). However, a trend of higher growth is verified in a 50 m swimming pool, both at 11-12 years and at 14-15 years.

When the mathematical model of the growth curves of the sports results was applied, and the embarrassment which was calculated in the previous point is included, we can obtain different types of adjustment according to the degree of the chosen polynomial unit.

Thus, the choice of the most suitable polynomial unit laid on the one in which the different segments of the curve presented lower residue value, allowing us to be more certain in the prediction of results. The total chart of the modeling equations obtained for the different groupings of distance and one explanatory example of the chart obtained by the mathematical modeling were presented.

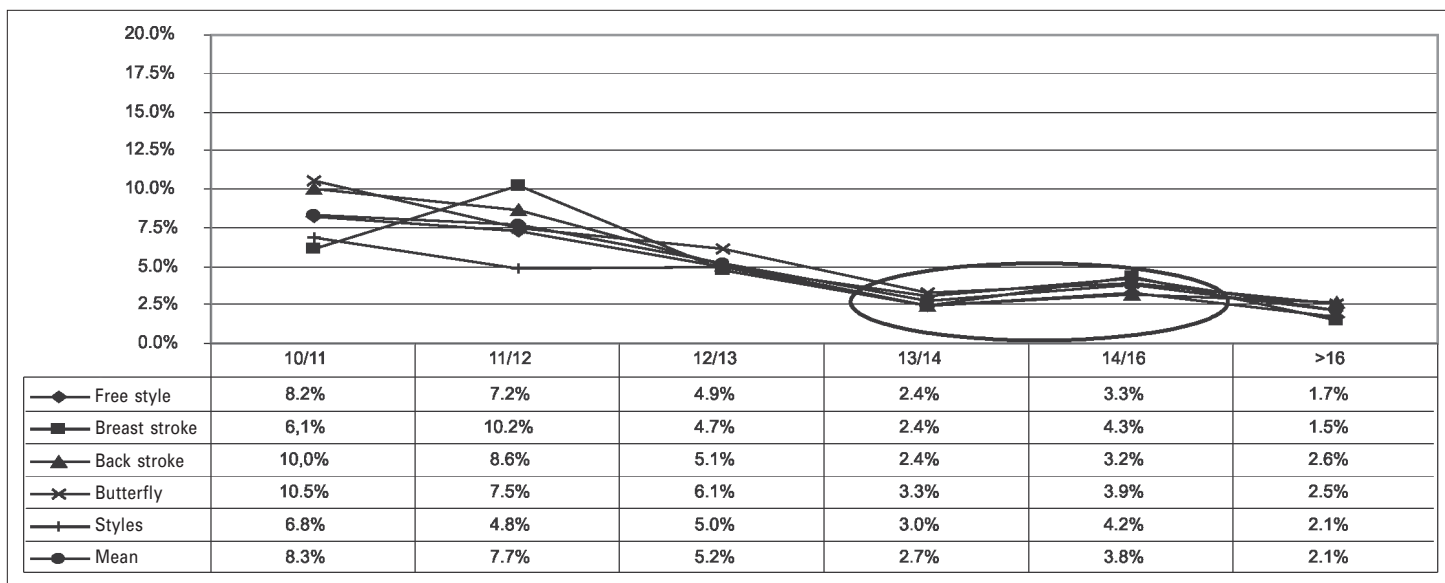


Figure 3 – Representative chart of the increment rate of the outcomes in the different techniques in short swimming pool (25 meters)

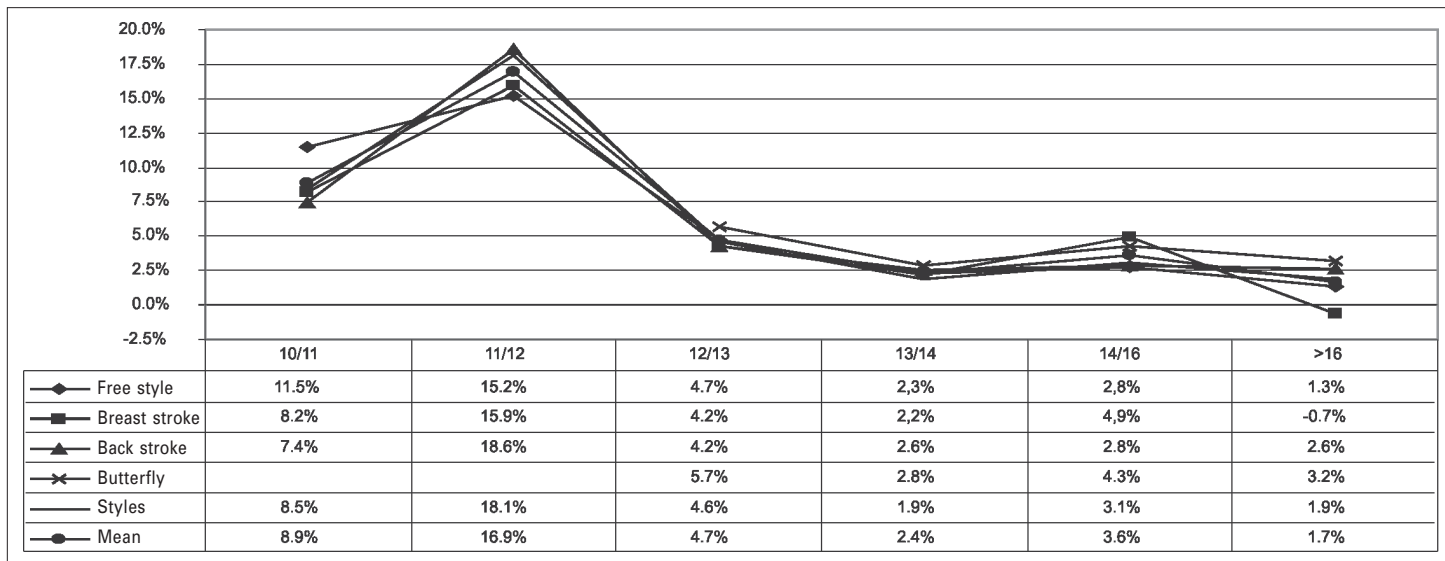


Figure 4 – Representative chart of the increment rate of the outcomes in the different techniques in 50-meter swimming pool

TABLE 4
Results of the mathematical modeling by event distance and age segment, for the female gender

Event	Age segment	Polynomial unit	Residue
100 m	10-12	$y = -0.061837 * \text{age}^4 + 3.5172 * \text{age}^3 - 73.518 * \text{age}^2 + 667.8 * \text{age} - 2214$	7.53
	12-18	$y = -0.0070607 * \text{age}^3 + 0.48646 * \text{age}^2 - 10.879 * \text{age} - 79772$	9.016
200 m	10-12	$y = -0.084444 * \text{age}^4 + 4.7446 * \text{age}^3 - 98.377 * \text{age}^2 + 890.21 * \text{age} - 2955$	8.24
	12-14	$y = 0.13897 * \text{age}^2 - 5.3613 * \text{age} + 51.552$	9.95
	14-18	$y = 0.03039 * \text{age}^3 - 1.1447 * \text{age}^2 + 12.326 * \text{age} - 27.863$	9.89
400 m	10-11	$y = -0.018904 * \text{age}^4 + 0.95902 * \text{age}^3 - 17.749 * \text{age}^2 + 140.31 * \text{age} - 388.41$	1.37
	11-12	$y = 0.115213 * \text{age}^2 - 5.3204 * \text{age} + 47.318$	2.39
	12-14	$y = -0.018904 * \text{age}^4 + 0.95902 * \text{age}^3 - 17.749 * \text{age}^2 + 140.31 * \text{age} - 388.41$	1.37
	14-15	$y = -0.067298 * \text{age}^3 + 2.8938 * \text{age}^2 - 41.903 * \text{age} + 207.04$	1.62
	15-16	$y = -0.018904 * \text{age}^4 + 0.95902 * \text{age}^3 - 17.749 * \text{age}^2 + 140.31 * \text{age} - 388.41$	1.37
	16-17	$y = -0.067298 * \text{age}^3 + 2.8938 * \text{age}^2 - 41.903 * \text{age} + 207.04$	1.62
	17-18		

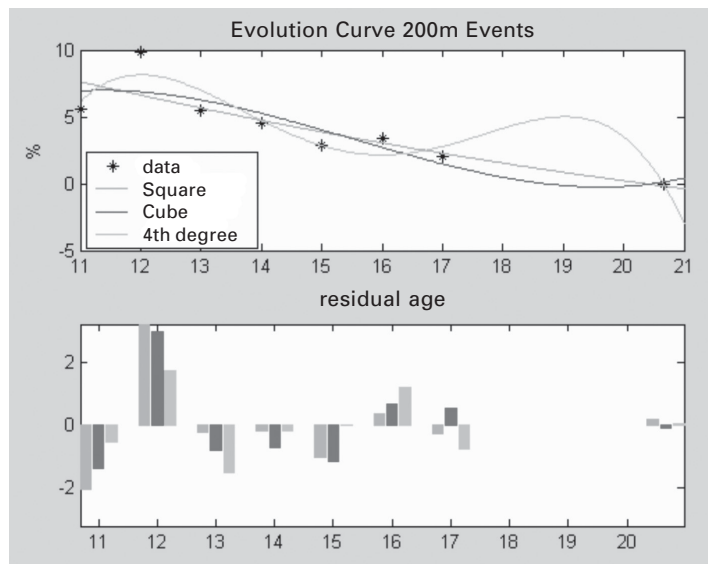


Figure 5 – Mathematical modulations and respective residues of the mean values of the growth rates of sportive results throughout the ages and by grouping of the swimming distances (an example for the 200 m events)

DISCUSSION

In females, the age in which the best scores were obtained is earlier than the one verified for males; such fact has also been described in the literature^(23,26). It is also more probable in females the occurrence of motor talents, with extreme skill at the main functional systems associated with particularities of the biological development which enable the reaching of high sports practices 1 to 3 years earlier than the optimum ages established. Such fact may not only be observed in long distance modalities (400 and 800 m) but also in the velocity ones (100 and 200 m).

Therefore, as well as it can be observed by the analysis of figure 2, there are two well-defined periods of remarkable increase of the growth rate in the sports results by event distance, fact also described in the literature^(23,26).

The first stage, which occurs between 11 and 12 years of age, can be explained as a phase in which both training and motor apti-

tude are very significant in the motor learning capacities, differentiation/control, balance⁽²⁾ as well as velocity, acquisition and stabilization of motor tasks⁽³⁾, associated with the development of the central nervous system and the maturation of several physiological links of the conditional system⁽⁶⁾.

The second stage, which occurs between 14 and 15 years of age, can be explained by clear manifestation in this age of the beginning of the maximal exponent of muscular development⁽¹¹⁻¹²⁾, promoting a strength and power improvement peak⁽¹⁵⁾, as well as the end of ossification⁽²⁷⁻²⁸⁾.

Motor control acquisition would be characterized as the result of the dynamic interaction of several subsystems in a particular context⁽¹³⁾. Such viewpoint proposes a non-linear rhythm of development, with differences between individuals⁽¹⁴⁾.

This justification of the different stages of formation and differentiation of the body's systems may partly justify the mean values of the growth rates (years) of the sports results along the ages and by swimming distances grouping, for females, as presented in figure 2.

Concerning the differences found in the evolution of the sports results between long and short swimming pools, the most remarkable growth rate increase of the sports results between 11 and 12 years of age, in 50 m pool, may derive from the laps. It is known that the determinant factor of laps' success, besides the issues associated with technique accuracy, has to do with power during the contact phase. The smaller the number of laps in an event in these ages in which the muscle-skeletal system in structural and functional terms is still developing, the higher the probability for the event time to be determined by the free style, a fact which is verified in a 50 m pool. However, there are not relevant data in the reference and consulted literature which allows us compare our evolution results with other obtained in other studies.

When the optimum ages of the sports results for the female swimmers are verified, they tend to obtain their best times earlier the longer the distance of the event, which is according to the most of the biography of world level swimmers who obtained the best results (times) at early ages^(23,32).

Higher growth rates of the results in longer events are seen in earlier ages (between 11 and 12 years), while in shorter events the results increase closer to 14-16 years of age^(23,32).

On the other hand, the relationship between the kids' anthropometrical characteristics and motor development shows that child's weight and height changes are associated with changes in the properties of the musculo-skeletal system, including tonus and strength^(12,17).

During the maturation process the individual experiments body manifestations such as increase of stiffness which is influenced by alterations in muscular co-contraction⁽²⁹⁾.

According to Maglisho⁽³⁰⁾, the longer the events, the lower the contribution of the lactic and anaerobic energy sources, and consequently the higher the aerobic contribution. The reason for fatigue in short events is the inability to keep velocity high due to muscular phosphate creatine reserves depletion as well as the inability to make the anaerobic metabolism operational fast enough. Fatigue in middle and long distance events is caused by the acidosis caused by the lactate accumulation. Thus, higher increase in longer events in these ages may be due to aerobic metabolism be more developed than the others^(27-28,31), which will increase during childhood and adolescence through the increase of the amount of glycogen stored in the muscles and lower concentration of phosphocreatine⁽¹⁶⁾. Lower increase in shorter events is due to the low capacity of performing anaerobic work before puberty, as well as the too low lactate tolerance level^(30,32).

Higher rates of increase from the 14 to 16 years in shorter events may be explained since these events require greater energy mobilization through the anaerobic way than longer events. Anaerobic capacity is more developed in this age group^(27,33) because in this

period the beginning of the maximal exponent of muscular development is verified in girls⁽¹¹⁻¹²⁾, which promotes the strength and power improvement peak around 16 years⁽¹⁵⁾. This fact also justifies the increase of the maximal blood lactate level up to 14/15 years⁽³⁰⁾.

CONCLUSIONS

The conclusions concerning the proposed aims are respectively: (i) the results demonstrated the need to reside the training process in specific capacities of each maturational phase referred in the bibliographical review, once improvement of the sports results in each event have been confirmed in their specific requirements; (ii) the literature review joined with the results indicators of the training process for different scales (increasing rates), show us that the results are closely connected with the growth, maturation and development processes and their maximal development periods; (iii) the results show the need to limit the training process to the optimum periods of the development of the several conditional and coordinative capacities, so that a whole limited to the individual according to her personal characteristics evidenced during growth can be built.

Concerning optimum ages for sports results, we concluded that a rational structure of the sports career is needed, with the purpose to reach better sports results, to mediate between 8-10 years, justifying hence, the structure change of the sports program in the long and medium run, so that: i) the training process structure closely corresponds to individual particularities of the swimmers (long distance, middle distance and sprint); ii) a redirecting of the training contents and its magnitude in the existing conditioning is verified; iii) measures for special promotion and institutional placement become available in the specificities of the sports preparation.

Concerning the growth rate of the sports results and its modeling, we may conclude that there are factors associated with the growth, development and maturation processes beyond the natural changes which derive from the training process, which help to explain the results changes. Moreover, we observed that the sports training process tends to start at ages even earlier in swimming, and the child's maturation occurs earlier due to the training process. Besides that, life quality has improved, eating habits and health public services are better.

More emphatic conclusions on the predominance of each of these components (training and biological factors) should consider other variables, such as the training time, the beginning of the training process and the structuring of the training process, among others.

As far as we are concerned, this study is one the first in this field, thus, it presents some limitations. One of the most important is the concurrent non-validation of the results which derive from the mathematical modeling with real growth curves in the training process during more than one sports stage. Nevertheless, some suggestions are crucial for future investigations: i) correction of the curve values in the swimmers' maturation levels evaluated (early, normal and late), inferring corrections in the growth curve of the sports results; ii) comparison of the values obtained for event and stage of sports outlining with real values which derive from the follow-up of one or more training stages.

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REFERENCES

1. Malina R. Biological maturity status of young athletes. Young athletes. Biological, psychological and educational perspectives. Champaign, Illinois: Human Kinetics Books, 1988.
2. Hahn E. Teoría del entrenamiento. Posibilidades y riesgos del entrenamiento con niños, cap. 2. Entrenamiento con niños. Teoría, práctica, problemas específicos. Barcelona: Deportes Técnicos, Ediciones Martinez Roca, 1988;62-95.

3. Hommel B, Musseler J, Aschersleben G, Prinz W. The theory of event coding (TEC): a framework for perception and action planning. *Behav Brain Sci.* 2001; 24(5):849-78.
4. Knoblich G, Flach R. Predicting the effects of actions: interactions of perception and action. *Psychol Sci.* 2001;12(6):467-72.
5. Mechsner F, Kerzel D, Knoblich G, Prinz W. Perceptual basis of bimanual coordination. *Nature.* 2001;414(6859):69-73.
6. Shephard R. Physical activity and growth. Chicago/London: Year Book Medical Publishers, Inc., 1982.
7. Deshpande N, Patla AE. Dynamic visual-vestibular integration during goal directed human locomotion. *Exp Brain Res.* 2005;166(2):237-47.
8. Kunde W. Response-effect compatibility in manual choice reaction tasks. *J Exp Psychol Hum Percept Perform.* 2001;27(2):387-94.
9. Johnson SH. Thinking ahead: the case for motor imagery in prospective judgments of prehension. *Cognition.* 2000;10;74(1):33-70.
10. Fogassi L, Ferrari PF, Gesierich B, Rozzi S, Chersi F, Rizzolatti G. Parietal lobe: from action organization to intention understanding. *Science.* 2005;308(5722): 662-7.
11. Saltin B, Gollnick P. Skeletal muscle adaptability: significance for metabolism and performance. *Handbook of Physiology.* Baltimore: Waverly Press, 1983;555-632.
12. Adolph KE, Avolio AM. Walking infants adapt locomotion to changing body dimensions. *J Exp Psychol.* 2000;26(3):1148-66.
13. Clark JE, Phillips SJ. A longitudinal study of intralimb coordination in the first year of independent walking: a dynamic systems analysis. *Child Dev.* 1993;64(4): 1143-57.
14. Smith LB, Thelen E. Development as a dynamic system. *Trends Cogn Sci.* 2003; 7(8):343-8.
15. Beunen G, Malina M. Growth and physical performance relative to the timing of the adolescent sport. In: Pandolf KB, editor. *Exerc Sport Sci Rev.* 1988;16:503-40. New York: Mcmillan.
16. Bar-Or O. Some notes on physiological and medical considerations of exercise and training of children. In: Binkhorst RA, Kemper HCG, Saris WHM, editors. *International series on sports sciences: Vol. 15. Children and Exercise XI* (pp. 356-353). Champaign, IL: Human Kinetics; 1985.
17. Bartlett DJ. Relationship between selected anthropometric characteristics and gross motor development among infants developing typically. *Pediatr Phys Ther.* 1998;10:114-9.
18. Wrisberg CA, Pein RL. Note on learners' control of the frequency of model presentation during skill acquisition. *Percept Mot Skills.* 2002;94(3 Pt 1):792-4.
19. Wulf G, Gartner M, McConnell N, Schwartz A. Enhancing the learning of sport skills through external focus feedback. *J Mot Behav.* 2002;34(2):171-82.
20. Ugrinowitsch H, Dantas LEPBT. Efeito do estabelecimento de metas na aprendizagem do arremesso do basquetebol. *Revista Portuguesa de Ciências do Desporto.* 2002;2:58-63.
21. Van Tilborgh L. Stuw- en remkrachten bij schoolslagzwemmers: berekening uit filmanalyse (Propulsion and drag forces in breaststroke swimmers: calculation from film analysis). (Doctoral Thesis Physical Education and Appendices). Leuven: K.U.Leuven; 1987.
22. Van Tilborgh L, Willems EJW, Persyn U. Estimation of breaststroke propulsion and resistance resultant impulses from film analysis. In: Ungerechts B, Wilke K, Reischle K, editors. *Swimming science V* (International series on sport sciences 18), Champaign (Illinois): Human Kinetics, 1988;67-72.
23. Platonov VN, Fessenko SL. Los sistemas de entrenamiento de los mejores nadadores del mundo. Ilyll. Barcelona: Paidotribo, 1994.
24. Sambanis M, Kofotolis N, Kalogeropoulou E, Nourios G, Sambanis P, Kalogeropoulos J. A study of the effects on the ovarian cycle of athletic training in different sports. *J Sports Med Phys Fitness.* 2003;43(3):398-403.
25. Stafford DE. Altered hypothalamic-pituitary-ovarian axis function in young female athletes: implications and recommendations for management. *Treat Endocrinol.* 2005;4(3):147-54.
26. Ivkovic A, Bojanic I, Ivkovic M. The female athlete triad. *Lijec Vjesn.* 2001;123 (7-8):200-6.
27. Wilmore J, Costill D. Part G, Special populations in sport exercise. Growth, development and the young athlete, cap. 17. *Physiology of sport and exercise.* Champaign, Illinois: Human Kinetics Books, 1994;402-20.
28. Karahan M, Erol B. Muscle and tendon injuries in children and adolescents. *Acta Orthop Traumatol Turc.* 2004;38(Suppl 1):37-46.
29. Stricker PR. Sports training issues for the pediatric athlete. *Pediatr Clin North Am.* 2002;49(4):793-802.
30. Holt KG, Butcher R, Fonseca ST. Limb stiffness in active leg swinging of children with spastic hemiplegic cerebral palsy. *Pediatr Phys Ther.* 2000;12:50-61.
31. Maglischo E. *Swimming even faster.* Mountain View California: Mayfield Publishing Co., 1982.
32. Farrow D, Young W, Bruce L. The development of a test of reactive agility for netball: a new methodology. *J Sci Med Sport.* 2005;8(1):52-60.
33. Heinonen OJ, Kujala UM. Problems of a young, growing athlete. *Duodecim.* 2001; 117(6):647-52.