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Factor structure of swimmers for evaluating endurance and predicting 5000-m indoor and open water swimming performance

Authors' Contribution:
A Study Design
B Data Collection
C Statistical Analysis
D Data Interpretation
E Manuscript Preparation
F Literature Search
G Funds Collection

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abstract

Background: The purpose of the present study was to describe factor structures to evaluate swimmers' endurance. The second aim was to determine 5000m pool velocity (5000_{Vp}) and 5000m open water swimming velocity (5000_{Vow}).

Material and methods: The study sample comprised 14 swimmers who were candidates for the Turkish Open Water National Team (age: 13.78 ±1.21 years; height: 168.06 ±6.67 m; body mass: 59.06 ±7.99 kg). Anaerobic threshold, critical swimming speed, and 5000m swimming tests were measured in a pool setting, and 5000m open water swimming test was measured in sea conditions.

Results: Results of the factor analysis show that the effect of 4 cardiorespiratory endurance factors, classified as velocity and heart rate (HR), HR and lactate, exercise HR and exercise lactate, were explained at 89.16% in relation to 5000m open water swimming performance, and the first factor had the greatest factor weight and formed 48% of the total variance. Regression coefficients for 5000_{Vp} and 5000_{Vow} were found to be $R^2 = 0.94$ and $R^2 = 0.79$, respectively ($p < 0.05$).

Conclusions: These findings suggest the equations of prediction specified in the present study may provide trainers with more appropriate tools to evaluate performance in juvenile swimmers.

Key words: regression analysis, long distance swimming, anaerobic threshold, critical swimming speed.

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INTRODUCTION

The effectiveness of anthropometric, physiological and sport-specific technical parameters that play a determining role in swimming performance has long been among the frequently studied topics [1, 2]. While these parameters are reviewed in the literature, they are evaluated as dependent or independent variables. When endurance, which is included in the independent variables of physiological parameters affecting swimming performance, is considered as endurance performance in swimming, many independent variables appear to have an effect on this parameter. These include the heart rate, blood lactate levels, swimming speed and the duration of training. Allowing for as much explanation as possible of the correlations between the several variables stated here and simplifying their sizes set the purpose of the factor analysis. In this way, while establishing the structures of the factors through a general factor, it is possible to explain the changes in each variable via special factors [3]. The literature includes numerous studies which explain relationships and changes in swimming performance by using factor analyses. To evaluate the overall pattern of endurance in swimming [4], kinematics in swimming [5], specific motor skills in water polo [6], a statistical method of factor analysis has recently been introduced. However, research to date has not established the actual factor structure of aerobic endurance in swimming.

In addition, in determining swimming performance, which is intensively related to aerobic and anaerobic parameters that are the components of endurance ability [7], data pertaining to these parameters allow for predicting performance at different distances to be a sum and facilitate field practices well. Some researchers claim that the use of maximal oxygen (VO_{2max}) is more effective in determining swimming performance whereas some others believe it is best to use the anaerobic threshold (AnT) level [8, 9]. VO_{2max} values, which yield valuable information in determining endurance fitness levels and cardio respiratory levels, require a highly detailed analysis as they show slight differences during training particularly in athletes with high aerobic capacity [10]. Moreover, since the devices used for these measurements are costly and require a detailed test procedure, they are not considered to be practical. Therefore, as a practical method, AnT values (swimming speed at AnT (AnTv), individual lactate level), which define the highest exercise intensity where sudden blood lactate accumulations are not observed for a long time, are preferred in determining swimming performance. The balance among these mechanisms working in relation with each other in sub-maximal exercise intensity to the maximal one, together with the failure to provide enough oxygen due to the increased exercise load, cause lactic acid production, which restricts the contraction performance of the skeletal muscle [11]. In the practical use of these metabolic responses to exercise in the field of practice, lactate concentrations are used as an important criterion and a prediction method to determine endurance performance [12]. This is due to the fact that when the working rate is expressed in speed or power units, it is stated that the relationship of a working rate at 4mmol of lactate (WRL) with endurance performance is stronger than VO_{2max} [13]. Additionally, studies have shown that WRL, work load, the maximal working level and endurance performance are strongly correlated ($r \geq 0.85$) with each other and that endurance performance can be accurately predicted over WRL using linear regression [14, 15].

However, in addition to the difficulties caused by a water environment in lactate measurement, expensive devices and experts in the field are required for measurements. As a result of these limitations, several tests have been put into use which are both economical and valid. In this respect, Critical Swimming Speed (CSS), which is addressed as one of the anaerobic measurement parameters for swimmers, has frequently been used by researchers [16, 17] and trainers as well. CSS, defined by Wakayoshi et al. as the maintenance of exercise at the highest intensity without exhaustion for a long time [18], corresponds to the maximum lactate steady state swimming speed. CSS is calculated as the slope of the regression line between the swimming velocity at maximal intensity and the corresponding distance [19]. While there are different opinions on the distances to be used in CSS calculations, it is envisaged that it should be determined using distances of 200 m or more at which exhaustion time is at least 2 min or longer [20, 21]. Furthermore, being a criterion related to evaluating aerobic trainings in physiological and technical aspects, calculation of such competition distances as 200–400 m has been reported to be applicable in reflecting the effect of trainings [22]. Costill et al. [23] state that the stroke technique is a significant parameter for energy levels spent during swimming which affects aerobic performance. Therefore, maintenance of technical parameters such as the stroke rate and the stroke length along swimming distances seems to be important for performance. Similarly, Dekerle et al. [22] suggest that stroke values in 30 min test and speed are also closely related with CSS ($r > 0.94$) and that the stroke lengths obtained in CSS speeds could be maintained during this test. With respect to this information, CSS test appears to be a good and practical method for trainers to plan more realistic training sessions during which training intensity and technique are maintained for the improvement of long distances in swimming and to predict the athletes' performance.

The review of the tests carried out on AnT and CSS in swimming shows that these have been associated with distances determined in the pool, but no study has been found on an analysis of these parameters and swimming in an outdoor environment like open water and on the prediction of performance. Hence, the purpose of this study was to describe factor structures of swimmers for evaluating endurance and velocity at 5000 m open water swimming (5000_{Vow}) in youth long distance swimmers.

MATERIAL AND METHODS

PARTICIPANTS

14 candidate athletes for the Open Water National Team consisting of 9 male and 5 female healthy and trained athletes (age: 13.78 ±1.21 years; height: 168.06 ±6.67 cm; body mass: 59.06 ±7.99 kg; BMI: 20.83 ±1.61; swimming experience: 5.21 ±1.15 years) participated in the study. Since no difference in gender was found between male and female athletes in the data to be assessed in factor analysis and regression analysis, [*resting heart rate* (HR_R), $p = 0.060$; AnT_V, $p = 0.589$; *anaerobic threshold heart rate* (AnT_{hr}), $p = 0.988$; *swimming speed at the fourth 400 m of anaerobic threshold test* (400_{VR4}), $p = 0.317$; *heart rate at the fourth 400 m of anaerobic threshold test* (400_{HRR4}), $p = 0.817$; *lactic acid level at the fourth 400 m of anaerobic threshold test* (400_{LAR4}), $p = 0.060$; *CSS*, $p = 0.351$; 5000_{Vp}, $p = 0.352$; *pool 5000 m swimming heart rates (5000HRp)*, $p = 0.322$; *pool 5000 m swimming lactate* (5000_{LAp}), $p = 0.147$; 5000_{Vow}, $p = 0.298$; *open water 5000 m swimming heart beats* (5000_{HRow}), $p = 0.131$; *open water 5000 m swimming lactate* (5000_{LAow}), $p = 0.364$], participants were not divided by gender and they were evaluated as a single group ($n = 14$). An informative meeting on the procedures to be implemented was held with the participating athletes and their families 1 week prior to the tests. The athletes and families read and signed

voluntary consent forms designed for them separately. The present study was confirmed by the Clinical Research Ethics Committee of the Faculty of Medicine (Approval No: 09-9.1/10).

Experimental design

The tests were carried out with the athletes taken into the training camp 20 days after the competition season and, first, the athletes went through physical examination by taking their medical history for health controls. The athletes were made to finish their breakfast 3 hours before the tests and to be ready at the test venues 1 hour before the tests. The AnT test, CSS test, 5000 m pool test (5000_p) and open water 5000 m (5000_{ow}) test were applied as it is shown on the flow chart (Fig. 1) and air, seawater and pool water temperatures were measured as 21°C, 24°C and 27°C at the time of tests, and all tests were carried out in September.

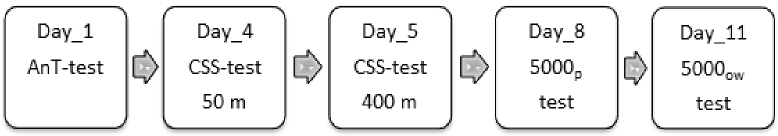

Fig. 1. Study flow chart

Data collection

A face to face interview based on the questionnaire was the data collection method. Interviews took place in the morning in the working hours of the health centers.

Anaerobic threshold test

The threshold swimming test was conducted at 11:00 a.m. in an Olympic swimming pool. Each participant was given the protocol adapted from Wakayoshi et al.'s study (1992), which included 4 × 400m intermittent free swimming with 1 minute passive rests between them and intensities individually increasing up to the maximal ones [24]. Load intensities were determined as the percentages of each athlete's time of individual maximal 400m ($T400_{(max)}$). In accordance with these values, the intensity of the training was increased in each stage as $T400_{(55\%)}$, $T400_{(75\%)}$, $T400_{(90\%)}$, $T400_{(max)}$ of $T400_{max}$ respectively. By playing a signal tone at times corresponding to the 50m pace of each athlete's swimming stage, athletes' pace was aligned. Prior to the tests, standardized 600m warm-up protocol was implemented. The athletes' heart rates were telemetrically measured at each stage with Polar S810i (Polar Electro, OY, Finland). In addition, immediately after each stage, blood was collected from fingertips into 2 heparinized capillary hematocrit tubes and then emptied into special protective tubes (anti glycolytic and coagulant containing) (YSI 2315, YSI Corp. Incorp., Ohio, USA), which were refrigerated (-20°C) until analyses. The values obtained from the measurements were used on the lactate performance curve on the metric graph paper as specified by Coen et al. [25], and individual anaerobic threshold values were determined. Heart rates and swimming speeds fixed at 4 $mmol \cdot l^{-1}$ lactate concentration were calculated using the mathematical interpolation method [26]. In the present study, swimming speed corresponding to 4 $mmol \cdot l^{-1}$ blood LA value was taken as the AnT_V and heart rate as the AnT_{HR}.

Critical swimming speed test

2 days after the anaerobic threshold test, maximal front crawl swimming was performed at 50m on the first day and 400 m on the second one under the same time periods and conditions, and times for 50 m and 400 m were determined. CSS was calculated using the values related to both distances [27].

Determination of the pool and open water swimming performances

5000m swimming tests, one performed in the pool and the other in the open water conditions with two days' interval, were carried out in September at 11.00 o'clock in an Olympic swimming pool and the Aegean Sea (Foça), İzmir/Turkey. During the open water-swimming test, participants were continuously followed and observed by the national team's trainer and doctor. During 5000 m tests, 2-minute breaks were taken at the end of each 1000 m, and the athletes were allowed to intake isotonic liquid (250 ml). Heart rate values and blood lactate measurements were performed by repeating the procedures followed for the anaerobic threshold test.

Statistical analysis

The critical swimming speed, anaerobic threshold speed, 5000 m pool and open water swimming tests measurements were analysed using Statistical Package for the Social Sciences Version 15. Conformity of the data with normal distribution was tested using the Shapiro-Wilk test and the data was also checked with skewness, kurtosis and variation coefficient (CV%) values. Central tendency measurements were expressed as mean and standard deviation. Principal component factor analysis with direct oblimin oblique rotation analysis was done for the factor analysis. For regression analysis, the enter multiple regression model was used to determine 5000 m swimming velocity in pool and open water conditions from seven independent variables. The predictor variables were put in one block; HR_R, AnT_V, AnT_{HR}, CSS, 400_{VR4}, 400_{LAR4} and 400_{HRR4}. Statistical significance was set at $p \leq 0.05$.

Results

In the factor analysis, the 5000 m swimming test, the anaerobic threshold test, the critical swimming speed test and the resting heart rate were evaluated. The principal components analysis was performed on a total of 13 (as an indicator of cardiorespiratory endurance) variables including 5000 m swimming speed, 5000 m heart rate and 5000 m LA level (pool and open water) within 5000 m swimming test parameters, anaerobic threshold speed, anaerobic threshold heart rate frequency, swimming speed at the 400^{th} m of the anaerobic threshold test, heart rate and lactic acid level within anaerobic threshold test parameters, critical swimming speed and the resting heart rate frequency.

To check the sufficiency of the sample, the Kaiser-Mayer-Olkin test (KMO) was conducted, and the measurement level of 0.609 was determined. Bartlett's test for sphericity was found to be statistically significant (Chi-Square 177.633, *p* = .000), and the data were found to be suitable for factorization.

The data were determined to be relevant for factor extraction analysis by performing correlation analysis and checking outlier data. As a result of the Principal Component Analysis (PCA), an r ≥ 0.30 level of correlation was found in more than one pair of the 13 data in the correlation analysis (Table 2). Among the variables, outlier data were found in the AnT_{HR} variable of only 1 subject.

Table 1. Descriptive statistics of the variables

Variable (unit)	Mean	SD	CV%	Min	Max	S-W	Skewness	Kurtosis
HR_R (bpm)	74.28	6.50	8.75	62.00	80.00	0.81	-1.04	-0.32
AnT_V ($m \cdot s^{-1}$)	1.23	0.08	6.50	1.09	1.36	0.95	-0.04	-0.88
AnT_{HR} (bpm)	169.64	6.77	3.99	158.00	181.00	0.94	-0.27	-0.16
400_{VR4} ($m \cdot s^{-1}$)	1.28	0.08	6.25	1.12	1.43	0.96	-0.37	-0.49
400_{HRR4} (bpm)	189.35	8.05	4.25	180.00	203.00	0.90	0.20	-1.40
400_{LAR4} (mM)	8.65	2.17	25.08	5.05	12.36	0.97	0.05	-0.76
CSS ($m \cdot s^{-1}$)	1.33	0.08	6.01	1.19	1.50	0.98	0.01	0.14
5000_{Vp} ($m \cdot s^{-1}$)	1.15	0.09	7.82	1.00	1.34	0.97	0.10	-0.51
5000_{HRp} (bpm)	163.65	7.34	4.48	149.40	172.00	0.90	-0.65	-0.26
5000_{LAp} (mM)	2.53	0.95	37.54	1.34	4.14	0.92	0.39	-0.95
5000_{Vow} ($m \cdot s^{-1}$)	0.99	0.06	6.06	0.84	1.06	0.81	-1.55	2.13
5000_{HRow} (bpm)	166.08	11.55	6.95	150.00	187.00	0.95	0.20	-0.72
5000_{LAow} (mM)	2.95	1.05	35.59	1.56	4.86	0.93	0.26	-1.20

S-W: Shapiro-Wilk test, **HR_R:** resting heart rate, **AnT_V:** anaerobic threshold velocity, **AnT_{HR}:** anaerobic threshold heart rate, **400_{VR4}:** swimming velocity of the fourth 400 m of the anaerobic threshold testing, **400_{HRR4}:** heart rate of 400 m of the fourth anaerobic threshold testing, **400_{LAR4}:** lactic acid level of the fourth 400 m of the anaerobic threshold testing, **CSS:** critical swimming speed, **5000_{Vp}:** 5000m swimming velocity in pool, **5000_{HRp}:** 5000m swimming heart rate in pool, 5000LAp: 5000m swimming lactate in pool, 5000Vow: 5000m swimming velocity in open water, **5000_{HRow}:** 5000m swimming heart rate in open water, **5000_{LAow}:** 5000m swimming lactate in open water

Table 2. Correlation matrix of all variables

	HRR	5000_{HRp}	5000_{Vp}	5000_{LAp}	AnT_V	AnT_{HR}	CSS	400_{HRR4}	400_{VR4}	400_{LAR4}	5000_{HRow}	5000_{Vow}
HR_R												
5000_{HRp}	-.118											
5000_{Vp}	**-.606**	.143										
5000_{LAp}	-.307	**.443**	**.444**									
AnT_V	**-.584**	-.124	**.843**	.057								
AnT_{HR}	-.294	**-.336**	-.150	**-.642**	.183							
CSS	**-.685**	.035	**.971**	**.313**	**.887**	-.030						
400_{HRR4}	-.006	.239	**-.358**	**-.331**	**-.375**	**.387**	**-.306**					
400_{VR4}	**-.683**	-.078	**.885**	.095	**.938**	.128	**.957**	-.239				
400_{LAR4}	-.059	.163	.229	.277	-.014	**-.333**	.247	.211	.194			
5000_{HRow}	**.797**	-.015	**-.705**	-.064	**-.800**	-.223	**-.779**	.170	**-.845**	-.104		
5000_{Vow}	**-.453**	-.074	**.833**	.196	**.866**	-.103	**.884**	**-.334**	**.902**	**.360**	**-.638**	
5000_{LAow}	-.239	.279	**.520**	**.520**	.205	**-.573**	**.529**	-.180	**.400**	**.723**	-.222	**.542**

S-W: Shapiro-Wilk test, **HR_R:** resting heart rate, **AnT_V:** anaerobic threshold velocity, **AnT_{HR}:** anaerobic threshold heart rate, **400_{VR4}:** swimming velocity of the fourth 400 m of the anaerobic threshold testing, **400_{HRR4}:** heart rate of 400 m of the fourth anaerobic threshold testing, **400_{LAR4}:** lactic acid level of the fourth 400 m of the anaerobic threshold testing, **CSS:** critical swimming speed, **5000_{Vp}:** 5000m swimming velocity in pool, **5000_{HRp}:** 5000m swimming heart rate in pool, 5000LAp: 5000m swimming lactate in pool, 5000Vow: 5000m swimming velocity in open water, **5000_{HRow}:** 5000m swimming heart rate in open water, **5000_{LAow}:** 5000m swimming lactate in open water

4 factors were found to have Eigen values over 1 in the PCA. The first factor explains 48% of the total variance, the second factor explains 20.90%, the third one 11.38% and the fourth factor explains 8.86% of it. All four factors together explain 89.16% of the total variance. In addition, 4 factors were analysed for the result of visual observation of the scatter plot graph.

The four-component solution explained 89.16% of the total variance. A direct oblimin oblique rotation was employed to aid interpretability. Under the first factor, variables 400_{VR4} (.963), AnT_V (.940), CSS (.922), 5000_{HRow} (-.922), 5000_{Vp} (.853), HR_R (-.832) and 5000_{Vow} (.787) have the greatest factor weight and these variables could be called the velocity and HR factor. Under the second factor, variables 5000_{HRp} (.871) and 5000_{LAp} (.723) have the greatest factor weight, and they can be called the HR and lactate factor. In the third factor, the variables having the greatest factor weight are 400_{HRR4} (.930) and AnT_{HR} (.628), which can be called the exercise HR factor. Under the fourth factor, on the other hand, 400_{LAR4} (.974) and 5000_{LAow} (.769) are the variables with the greatest factor weight, and they could be called the exercise lactate factor. Component loadings and communalities of the direct oblimin rotation are presented in Table 3.

Table 3. Rotated structure matrix for PCA with the direct oblimin rotation method of four components

	Rotated Component Coefficients				
	C1	C2	C3	C4	Communalities
400_{VR4}	**.963**	-.139	-.153	.128	.818
AnT_V	**.940**	-.176	-.147	-.903	.783
CSS	**.922**	.302	-.114	.164	.922
5000_{HRp}	**-.922**	-.434	-.140	.890	.843
5000_{Vp}	**.853**	.157	-.221	.124	.941
HR_R	**-.832**	-.339	-.270	.181	.894
5000_{Vow}	**.787**	-.212	-.176	.363	.968
5000_{HRow}	-.024	**.871**	.180	.298	.906
5000_{LAow}	.102	**.723**	-.436	.102	.979
400_{HRR4}	-.187	.101	**.930**	.230	.914
AnT_{HR}	.304	-.361	**.628**	-.405	.832
400_{LAR4}	.320	-.234	.252	**.974**	.909
5000_{LAp}	.233	.190	-.152	**.769**	.882

S-W: Shapiro-Wilk test, **HR_R:** resting heart rate, **AnT_V:** anaerobic threshold velocity, **AnT_{HR}:** anaerobic threshold heart rate, **400_{VR4}:** swimming velocity of the fourth 400 m of the anaerobic threshold testing, **400_{HRR4}:** heart rate of 400 m of the fourth anaerobic threshold testing, **400_{LAR4}:** lactic acid level of the fourth 400 m of the anaerobic threshold testing, **CSS:** critical swimming speed, **5000_{Vp}:** 5000m swimming velocity in pool, **5000_{HRp}:** 5000m swimming heart rate in pool, 5000LAp: 5000m swimming lactate in pool, 5000Vow: 5000m swimming velocity in open water, **5000_{HRow}:** 5000m swimming heart rate in open water, **5000_{LAow}:** 5000m swimming lactate in open water. **Note:** major loadings for each item are bolded.

Table 4. Summary of multiple regression analysis for variables predicting velocity of 5000 m swimming in pool and open water conditions

Dependent variable	Independent variable	*B*	*SE_B*	*B*
5000_{Vp}	Constant	-0.188	0.405	
	HR_R	0.00069	0.002	0.047
	AnT_V	0.01905	0.199	0.017
	AnT_{HR}	-0.00154	0.001	-0.110
	CSS	1.148	0.239	0.986*
5000_{Vow}	Constant	0.0046	0.485	
	HR_R	0.00187	0.002	0.198
	AnT_V	0.349	0.238	0.472
	AnT_{HR}	-0.00103	0.001	-0.114
	CSS	0.448	0.286	0.598

*p < .05, B: unstandardized regression coefficient, SE_B: standard error of the coefficient,
β: standardized coefficient. **5000_{Vp}:** 5000m swimming velocity in pool, **5000_{Vow}:** 5000m swimming velocity in open water, HRR: resting heart rate, **AnT_V:** anaerobic threshold velocity, **AnT_{HR}:** anaerobic threshold heart rate, **CSS:** critical swimming speed, these models correct predicting rate 95.9% on pool and 79.6% on open water conditions.

The enter multiple regressions was run to predict 5000_{Vp} and 5000_{Vow} from 7 independent factor variables [predictors (one block): HR_R, AnT_V, AnT_{HR}, CSS, 400_{VR4}, 400_{LAR4} and 400_{HRR4})]. In order to check the linearity between the dependent and independent (predictors) variables, the partial regression plots was examined; the partial regression plots show linearity in HR_R, AnT_V, AnT_{HR}, CSS and 400_{VR4} variables with 5000_{Vp}, but non-linearity was found with the 400_{LAR4} and 400_{HRR4}, and these two predictor variables were excluded from the analysis. Then variable 400_{VR4} was excluded from the analysis due to the multicollinearity problem. The test for independence of observations was statistically computed with the Durbin-Watson test. The Durbin-Watson statistics for these analyses was 1.693 for 5000_{Vp} and 1.136 for 5000_{Vow}, while it can be accepted that there was independence of errors (residuals). The homoscedasticity assumption was tested and the residuals equally spread over the predicted values of the dependent variables (5000_{Vp} and 5000_{Vow}). Also, there were no outliers, high leverage points (means 0.285) and there were not any high influential (Cook's distance) points (<1) in the 14 cases, and the distribution was approximately normal (5000_{Vp} and 5000_{Vow}) in the P-P and Q-Q Plots.

The results of the enter multiple regression analyses (regression coefficients and standard errors) for 5000_{Vp} and 5000Vow are presented in Table 4 with four predictor variables (HR_R, AnT_V, AnT_{HR}, CSS). These variables statistically significantly predicted 5000_{Vp}; $F(4, 9) = 52.901$, $p < .0005$, adj.$R^2 = 0.94$, and 5000_{Vow}; $F(4, 9) = 13.707$, $p < .001$, adj.$R^2 = 0.79$.

Table 4. Summary of multiple regression analysis for variables predicting velocity of 5000 m swimming in pool and open water conditions

Dependent variable	Independent variable	*B*	SE_B	*B*
	Constant	-0.188	0.405	
	HR_R	0.00069	0.002	0.047
5000_{Vp}	AnT_V	0.01905	0.199	0.017
	AnT_{HR}	-0.00154	0.001	-0.110
	CSS	1.148	0.239	0.986*
	Constant	0.0046	0.485	
	HR_R	0.00187	0.002	0.198
5000_{Vow}	AnT_V	0.349	0.238	0.472
	AnT_{HR}	-0.00103	0.001	-0.114
	CSS	0.448	0.286	0.598

*p < .05, B: unstandardized regression coefficient, SE_B: standard error of the coefficient, **β:** standardized coefficient. **5000_{Vp}:** 5000m swimming velocity in pool, **5000_{Vow}:** 5000m swimming velocity in open water, HRR: resting heart rate, **AnT_V:** anaerobic threshold velocity, **AnT_{HR}:** anaerobic threshold heart rate, **CSS:** critical swimming speed, these models correct predicting rate 95.9% on pool and 79.6% on open water conditions.

The general form of the equations to predict 5000_{Vp} and 5000_{Vow} from HR_R, AnT_V, AnT_{HR} and CSS were as follows (from the coefficients, Table 4); linear regression line and confidence and prediction intervals were shown in scatter plot graph (Fig. 2).

The results of the linear regression analyses (regression coefficients and standard errors) for 5000_{Vp} and 5000_{Vow} are provided in Table 5 with the CSS predictor variable. This variable statistically significantly predicted 5000_{Vp}; $F(1, 12) = 199.706$, $p < .0005$, adj.$R^2 = 0.94$, and 5000_{Vow}; $F(1, 12) = 42.885$, $p < .0005$, adj.$R^2 = 0.76$.

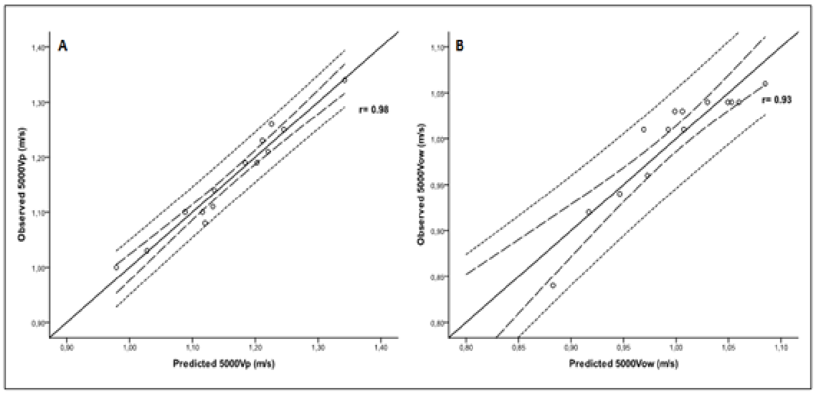

Fig. 2. Scatter plot of the observed and predicted 5000_{Vp} (A) and 5000_{Vow} (B)

Predicted 5000_{Vp} = -0.188 + (0.00069 x HR_R) + (0.01905 x AnT_V) - (0.00154 x AnT_{HR}) + (1.148 x CSS)
Predicted 5000_{Vow} = 0.0046 + (0.00187 x HR_R) + (0.349 x AnT_V) - (0.00103 x AnT_{HR}) + (0.448 x CSS)

Table 5. Summary of linear regression analysis for variable predicting velocity of 5000m swimming in pool and open water conditions

Dependent variable	Independent variable	*B*	SE_B	*B*
5000_{Vp}	Constant	-0.353	0.107	
	CSS	1.131	0.080	0.971*
5000_{Vow}	Constant	0.111	0.136	
	CSS	0.663	0.101	0.884*

*p < .05, B: unstandardized regression coefficient, SE_B: standard error of the coefficient, **β:** standardized coefficient. **5000_{Vp}:** 5000m swimming velocity in pool, **5000_{Vow}:** 5000m swimming velocity in open water, HRR: resting heart rate, **AnT_V:** anaerobic threshold velocity, **AnT_{HR}:** anaerobic threshold heart rate, **CSS:** critical swimming speed, these models correct predicting rate 95.9% on pool and 79.6% on open water conditions.

The general form of the equations to predict 5000_{Vp} and 5000_{Vow} from CSS was as follows (from the coefficients, Table 5):

$$\text{Predicted } 5000_{Vp} = -0.353 + (1.131 \text{ x CSS})$$
$$\text{Predicted } 5000_{Vow} = 0.111 + (0.663 \text{ x CSS})$$

DISCUSSION

To our knowledge, the prediction of long distance swimming performance (i.e. 5000m swimming) using physiological variables and CSS in swimmers aged 12–15, has never been performed yet. Moreover, no study can be found in the literature examining and determining the factors that affect long-distance swimming in juvenile swimmers.

The main findings of the present study show that the resting heart rate, the anaerobic threshold velocity, the anaerobic threshold heart rate and the critical swimming speed parameters can be used to predict performances in 5000_{Vp} and 5000_{Vow}. In addition, they reveal that 5000_{Vp} and 5000_{Vow} performances can be predicted at better levels by using only CSS values as a more practical method to predict results.

The current findings demonstrate a medium to strong correlation between HR_R, AnT_V, AnT_{HR}, CSS and 5000-m open water and indoor swimming performances in swimmers aged 12–15, which is in agreement with previous researchers who found a strong relationship between swimming velocity at the anaerobic threshold, the anaerobic heart rate and endurance performance, which are important for the assessment of swimming performance [28, 29] and are better predictors of performance in long distance events than VO_{2max} [28, 30]. However, depending on the competition tactics, tempo increases in the last parts or other periods of the competition cause lactate levels to rise, and the data obtained from these show that the athletes complete the competition at close to the anaerobic threshold levels [31]. Studies show that the lactate threshold variables and swimming speeds that correspond to 4 $mmol \cdot L^{-1}$ lactate concentration are closely related in explaining the aerobic endurance development in swimming and determining the athletes' future performances [32]. Relationships between speeds corresponding to the lactate threshold and performance can also be found in the studies carried out by Olbrecht et al. [14] with 30-minute swimming performances of swimmers as well as those by Barlow et al. [33] carried out with cyclists and by Tanaka et al. [34] with runners. In this respect, the anaerobic threshold parameters we assessed were similarly found to have medium and strong correlations with 5000m performances (r-values ranging from 0.453 to 0.884). Moreover, the factor analysis carried out to determine the parameters affecting endurance performance in open water swimming supports these studies. At the end of the factor analyses, the effect of 4 cardiorespiratory endurance factors classified as velocity and HR, HR and lactate, exercise HR and exercise lactate was explained at 89.16% in relation with 5000m open water swimming performance. 400_{VR4} (.963), AnTV (.940), CSS (.922), 5000_{HRow} (-.922), 5000_{Vp} (.853), HR_R (-.832), 5000_{Vow} (.787) variables under the first factor had the greatest factor weight and formed 48% of the total variance. Quantitative data indicated that endurance performance was more sensitive to changes in speed variables in swimming. In accordance with the findings obtained from the present study and other studies, variables of speed corresponding to the anaerobic threshold level and the heart rate are the most appropriate and valid parameters to predict endurance performance. Supporting this finding, Faude et al. [10] state in their review that the concept of lactate threshold can be used as the gold standard of predicting endurance performances in future competitions.

Rocker et al. [35] suggest that longer distances in competitions tend be more predictive than variables describing performance in comparison with shorter distances, and fewer parameters are needed in determining the predictive model. In this respect, the use of CSS in performance predictions of different activities [36, 37] and, like in this study, in determining the swimmers' cardiorespiratory fitness levels in an approximately 73-minute swim in 5000m open water will yield valid results. Moreover, the strong correlation of CSS with 5000_{Vp} and 5000_{Vow} obtained in this study and the fact that it is found in the first factor, which affects 5000m endurance performance the most, show that critical velocity can be used as a valid variable in predicting 5000m endurance performance in open water swimmers aged 12–15.

CONCLUSIONS

According to the findings of this study, equations from HR_R, AnT_V, AnT_{HR}, CSS (R^2 = 0.94 for 5000_{Vp}, R^2 = 0.79 for 5000_{Vow}) and equations from CSS (R^2 = 0.94 for 5000_{Vp}, R^2 = 0.76 for 5000_{Vow}) can be applied for the prediction of 5000_{Vp} and 5000Vow swimming performance in juvenile open water swimmers. Performance differences of 0.4% and 0.8% in Olympic swimmers [38] and less than 1.4% in elite senior swimmers [39] observed between the competitions in which they participate show that swimmers need changes of as little as 0.5% for a chance of a medal and, therefore, all benefits which could be created in performance must be calculated in their finest detail. For this reason, the hypothesis that a combination of variables from different physiological categories would predict better performance variables from the same category was not supported.

PRACTICAL APPLICATIONS

Methods of prediction specified in the current study may be further strengthened with measurement of technical skill parameters, whilst additional physical and physiological variables may provide a holistically comprehensive approach when identifying juvenile swimmers who possess the potential for success in open water swimming. In addition, the present study may provide trainers with important information about the swimmers' training development and performance with very simple, cheap and practical methods.

REFERENCES

[1] Tsekouras YE, Kavouras SA, Campagna A, et al. The anthropometrical and physiological characteristics of elite water polo players. Eur J Appl Physiol 2005;95(1):35-41. https://doi.org/10.1007/s00421-005-1388-2

[2] Hellard P, Dekerle J, Avalos M, Caudal N, Knopp M, Hausswirth C. Kinematic measures and stroke rate variability in elite female 200-m swimmers in the four swimming techniques: Athens 2004 Olympic semi-finalists and French National 2004 Championship semi-finalists. J Sport Sci 2008;26(1):35-46. https://doi.org/10.1080/02640410701332515

[3] Wei M, Jin K. Swimmer selection optimization strategy research based on SPSS factor analysis. J Chem Pharmac Res. 2014;6(3):1059-1068.

[4] Dopsaj M, Arlov D, Blagojević M. Factorial structure of the 'Endurance indicator model' (EIM) in swimming with first-year Police academy students. Nauka, bezbednost, policija. 1997; 2(1):110-123.

[5] Blanksby B, Skender S, Elliott B, McElroy K, Landers G. An analysis of the rollover backstroke turn by age-group swimmers. Sports biomechanics / International Society of Biomechanics in Sports 2004;3(1):1-14. https://doi.org/10.1080/14763140408522826

[6] Aleksandrovic M, Radovanovic D, Okicic T, Madic D, Georgiev G. Functional abilities as a predictor of specific motor skills of young water polo players. J Hum Kinet. 2011;29:123-132. https://doi.org/10.2478/v10078-011-0046-5

[7] Laffite LP, Vilas-Boas JP, Demarle A, Silva J, Fernandes R, Billat VL. Changes in physiological and stroke parameters during a maximal 400-m free swimming test in elite swimmers. Can J Appl Physiol. 2004;29:S17-S31. https://doi.org/10.1139/h2004-055

[8] Rodriguez F, Mader A. Energy metabolism during 400 and 100-m crawl swimming: Computer simulation based on free swimming measurement. In: Biomechanics and Medicine in Swimming IX. 2003, 373-378.

[9] Fernandes RJ, Keskinen KL, Colaco P, et al. Time limit at VO2max velocity in elite crawl swimmers. Int J Sport Med. 2008;29(2):145-150. https://doi.org/10.1055/s-2007-965113

[10] Faude O, Kindermann W, Meyer T. Lactate threshold concepts how valid are they? Sport Med. 2009;39(6):469-490. https://doi.org/10.2165/00007256-200939060-00003

[11] Gibson AS, Noakes TD: Evidence for complex system integration and dynamic neural regulation of skeletal muscle recruitment during exercise in humans. Brit J Sport Med. 2004;38(6):797-806. https://doi.org/10.1136/bjsm.2003.009852

[12] Weltman A. The blood lactate response to exercise, vol. 4. Champaign Ill.: Human Kinetics;1995.

[13] Morgan D, Baldini FD, Martin PE, Kohrt WM. Ten kilometer performance and predicted velocity at VO2max among well-trained male runners. Med Sci Sport Exer. 1989;21(1):78-83. https://doi.org/10.1249/00005768-198902000-00014

[14] Olbrecht J, Madsen O, Mader A, Liesen H, Hollmann W. Relationship between swimming velocity and lactic concentration during continuous and intermittent training exercises. Int J Sports Med. 1985;6(2):74-77. https://doi.org/10.1055/s-2008-1025816

[15] Weltman A, Snead D, Seip R, et al. Prediction of lactate threshold and fixed blood lactate concentrations from 3200-m running performance in male runners. Int J Sport Med. 1987;8(6):401-406. https://doi.org/10.1055/s-2008-1025694

[16] Costa AM, Silva AJ, Louro H, et al. Can the curriculum be used to estimate critical velocity in young competitive swimmers? J Sport Sci Med. 2009;8(1):17-23.

[17] Neiva HP, Fernandes RJ, Vilas-Boas JP. Anaerobic Critical Velocity in Four Swimming Techniques. Int J Sports Med. 2011;32(3):195-198. https://doi.org/10.1055/s-0030-1268474

[18] Wakayoshi K, Yoshida T, Udo M, et al. A Simple Method for Determining Critical Speed as Swimming Fatigue Threshold in Competitive Swimming. Int J Sports Med. 1992;13(5):367-371. https://doi.org/10.1055/s-2007-1021282

[19] Wakayoshi K, Yoshida T, Udo M, et al. Does critical swimming velocity represent exercise intensity at maximal lactate steady-state. Eur J Appl Physiol O. 1993;66(1):90-95. https://doi.org/10.1007/BF00863406

[20] Bishop D, Jenkins DG, Howard A. The critical power function is dependent on the duration of the predictive exercise tests chosen. Int J Sport Med. 1998;19(2):125-129. https://doi.org/10.1055/s-2007-971894

[21] Hughson RL, Orok CJ, Staudt LE. A High-velocity treadmill running test to assess endurance running potential. Int J Sport Med. 1984;5(1):23-25. https://doi.org/10.1055/s-2008-1025875

[22] Dekerle J, Sidney M, Hespel JM, Pelayo P. Validity and reliability of critical speed, critical stroke rate, and anaerobic capacity in relation to front crawl swimming performances. Int J Sports Med 2002;23(2):93-98. https://doi.org/10.1055/s-2002-20125

[23] Costill DL, Kovaleski J, Porter D, Kirwan J, Fielding R, King D. Energy-expenditure during front crawl swimming - predicting success in middle-distance events. Int J Sport Med. 1985;6(5):266-270. https://doi.org/10.1055/s-2008-1025849

[24] Wakayoshi K, Ikuta K, Yoshida T, Udo M, Moritani T, Mutoh Y, Miyashita M. Determination and validity of critical velocity as an index of swimming performance in the competitive swimmer. Eur J Appl Physiol. 1992;64(2):153-157. https://doi.org/10.1007/BF00717953

[25] Coen B, Urhausen A, Kindermann W. Individual anaerobic threshold: Methodological aspects of its assessment in running. Int J Sport Med. 2001;22(1):8-16. https://doi.org/10.1055/s-2001-11332

[26] Mader A, Liesen H, Heck H, et al. Zur beurteilung der sportartspezifischen Ausdauerleistungsfähigkeit im Labor. Sportarzt Aportmed. 1976;27(80):199.

[27] Ginn E, Commission AS. Critical speed and training intensities for swimming. National Sports Research Centre; 1993.

[28] Yoshida T, Chida M, Ichioka M, Suda Y. Blood lactate parameters related to aerobic capacity and endurance performance. Eur J Appl Physiol. 1987;56(1):7-11. https://doi.org/10.1007/BF00696368

[29] Bosquet L, Leger L, Legros P. Methods to determine aerobic endurance. Sports Med. 2002;32(11):675-700. https://doi.org/10.2165/00007256-200232110-00002

[30] Hagberg JM, Coyle EF. Physiological determinants of endurance performance as studied in competitive racewalkers. Med Sci Sport Exer. 1983;15(4):287-289. https://doi.org/10.1249/00005768-198315040-00006

[31] VanHeest JL, Mahoney CE, Herr L. Characteristics of elite open-water swimmers. J Strength Cond Res. 2004;18(2):302-305. https://doi.org/10.1519/00124278-200405000-00018

[32] Pyne DB, Lee H, Swanwick KM. Monitoring the lactate threshold in world-ranked swimmers. Med Sci Sport Exer. 2001;33(2):291-297. https://doi.org/10.1097/00005768-200102000-00019

[33] Barlow K, Weltman A, Schurrer R, Henritze J. Prediction of maximal effort bicycle ergometer endurance performance. Int J Sports Med. 1985;6(4):190-196. https://doi.org/10.1055/s-2008-1025838

[34] Tanaka K, Matsuura Y, Matsuzaka A, et al. A longitudinal assessment of anaerobic threshold and distance-running performance. Med Sci Sport Exer. 1984;16(3):278-282. https://doi.org/10.1249/00005768-198406000-00014

[35] Roecker K, Schotte O, Niess AM, Horstmann T, Dickhut HH. Predicting competition performance in long-distance running by means of a treadmill test (vol 30, pg 1552, 1998). Med Sci Sport Exer. 1998;30(12):1750-1750. https://doi.org/10.1097/00005768-199810000-00014

[36] Pepper ML, Housh TJ, Johnson GO. The Accuracy of the critical velocity test for predicting time to exhaustion during treadmill running. Int J Sports Med. 1992;13(2):121-124. https://doi.org/10.1055/s-2007-1021242

[37] Kendall KL, Smith AE, Fukuda DH, Dwyer TR, Stout JR. Critical velocity: A predictor of 2000-m rowing ergometer performance in NCAA D1 female collegiate rowers. J Sport Sci. 2011;29(9):945-950. https://doi.org/10.1080/02640414.2011.571274

[38] Pyne DB, Trewin CB, Hopkins WG. Progression and variability of competitive performance of Olympic swimmers. J Sport Sci. 2004;22(7):613-620. https://doi.org/10.1080/02640410310001655822

[39] Stewart AM, Hopkins WG. Consistency of swimming performance within and between competitions. Med Sci Sport Exer. 2000;32(5):997-1001. https://doi.org/10.1097/00005768-200005000-00018

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