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Correlations between peripubertal male swimmers' results of short-distance swimming tests and land-based sprint and endurance tests

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Abstract

Study aim: Children are "non-metabolic specialists", and the hierarchy of energy sources engaged in their exercise is poorly understood. This study compared the results of dry-land endurance and speed tests between peripubertal swimmers (aged 12–13 years) and their untrained peers, and examined their correlations with the swimmers' performance in sprint swimming tests.
Material and Methods: Twenty peripubertal male swimmers and 25 same-age untrained boys (controls) performed dry-land speed (50 m sprint) and endurance (20 m shuttle run test – 20mSRT) tests. The swimmers were also subjected to 25, 50, 75, and 100 m swimming tests involving three different strokes. In the statistical analysis, Pearson's correlation coefficients and stepwise multiple regression analysis with backward elimination were used.
Results: The swimmers' speed and endurance proved to be significantly greater compared to controls ($p<0.001$ and $p<0.001$, respectively). Significant correlations were found between the results of the 50 m sprint test and the 20mSRT for the whole group ($r = -0.838$; $p < 0.001$) and the swimmers ($r = -0.720$; $p < 0.001$). In the swimmers, the results of both dry-land tests were significantly correlated with the results of the swimming tests. The best predictors of their performance on the 50 m sprint run test and the 20mSRT were the 25 m front crawl velocity ($p < 0.001$) and the 75 m backstroke velocity ($p < 0.001$), respectively.
Conclusions: Despite the swimming training emphasising aerobic capacity, the swimmers' speed and endurance proved greater than in the controls. The swimming velocity predicts the results of the 50 m sprint run test for all strokes.

Keywords: Sprint swimming performance – Land-based motor abilities – Endurance – Speed – Peripubertal boys

Introduction

According to some authors (Gerver & de Bruin, 2003), puberty is "a sensitive period" or "a window of opportunity", because the accelerated development of many physiological systems that takes place then creates optimal biological conditions for enhancing children's endurance and speed. Other authors, however, dispute the presence of sensitive periods in human motor development (Van Hooren & De Ste Croix, 2020).

Swimming is the sport with the largest number of events during the Olympic Games due to a wide variety of swimming distances (from 50 to 10,000 m) and strokes (freestyle, breaststroke, butterfly stroke, and backstroke). This multitude of events requires competitive swimmers to have extraordinary versatility and appropriate somatic, physiological, and psychological characteristics to be successful (Geladas et al., 2005; Jürimäe et al., 2007; Rejman et al., 2018). Thus, world swimming federations recommend recruiting prospective competitive swimmers at a relatively young age (around 10 years), because the ability to swim does not develop naturally in humans with age, unlike walking and running (Sousa et al., 2012).

In recent years, a number of studies on swimming training have been published, which point to the benefits of dry-land exercises for swimmers' performance (Amaro et al., 2017; Potdevin et al., 2011; Weston et al., 2015) and technique, including stroke length and stroke rate (Barbosa et al., 2010). According to their authors, swimmers' performance on motor skills tests are also meaningful predictors of their ability to win swimming events.

While physical training for pre- and peripubertal children primarily consists of endurance exercises selected

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according to the Long-Term Athlete Development (LTAD) model (Lang & Light, 2010), researchers tend to concentrate on the impact of dry-land training on young swimmers' muscular strength and power. Because the literature suggests that strength and power training benefit swimmers older than 13 years of age (Seffrin et al., 2022), it is unsurprising that swimmers recruited to study the effects of dry-land training are aged between 14 and 21 years.

Given that pre- and peripuberty is the time of natural development of physical capacity, the purpose of additional physical activities undertaken by children should be to improve their fitness (Armstrong, 2013). A sport that meets the criterion in the case of 12–13-year-olds is swimming, but no studies comparing aerobic capacity and running speed between swimmers under 13 years of age and their untrained peers and examining correlations between these motor abilities and swimmers' performance in competitions have yet been published.

Researchers generally agree that the ability to exercise for an extended period and aerobic capacity are related to each other. A three-year study of prepubertal male swimmers (aged 10–12 years) by Kuberski et al. (2022) found that their 400 m and 50 m swimming times were best correlated with maximum oxygen uptake (VO_2max) and the standing long jump length, respectively. Geladas et al. (2005) established a statistically significant correlation between 100-metre front crawl swimming times and the standing long jump length in the studied boys and girls aged 12–14 years. These results indicate that the muscle power of the lower limbs (Dobbs et al., 2015) significantly determines young swimmers' performance in front crawl swimming, at least over distances of 50 and 100 m. However, because pre- and peripubertal children are "non-metabolic specialists" (Bar-Or, 1983), whether the same association is also valid for intermediate distances (e.g., 25 m or 75 m) and strokes other than front crawl has not yet been confirmed.

Based on the existing evidence of a close relationship between the sprint time of maximal speed phase and the length of the standing long jump (Lin et al., 2023), this study set out to compare the endurance and speed of swimmers aged 12–13 years and their untrained peers, and to examine correlations between swimmers' endurance and speed and their ability to swim front crawl, breaststroke, and backstroke sprints. The butterfly stroke was left out of the study because 12 to 13-year-old boys performing the butterfly make the largest number of technical errors as their fatigue increases, which may have negative consequences for their swimming velocity.

Material and methods

Subjects

Forty-five boys aged 12–13 years volunteered to participate in the study (Table 1). The experimental group (SWIM) was formed of 20 boys who, in addition to having regular physical education (PE) classes at school, had participated in swimming training at Świętokrzyskie Voivodeship sports clubs for at least 3 years prior to the study, which recruited them without screening. The control group (CON) consisted of 25 boys who attended elementary school no. 27 in Kielce and did not participate in any regular physical activity other than PE classes. The biological age of the participants was determined using the so-called maturity offset (MO) method, which estimates the number of years from age at peak height velocity (APHV). Participants' MO was estimated based on their age and body height as per the formula proposed by Moore et al. (2015). As required by the Declaration of Helsinki, the boys and their parents were familiarised with the purpose and protocol of the study and consented in writing to take part in it. The study protocol was examined and approved by the Bioethics Commission at Jan Kochanowski University in Kielce (decision no. 10/2022).

Study protocol

All anthropometric measurements and tests were performed between 8.00 a.m. and 12.00 p.m. in participants' schools and/or swimming clubs' facilities. Their heart rate (HR_{rest}) was measured in a seated position by palpation, after 15 minutes of rest. Arterial blood pressure was determined using a manual sphygmomanometer (AG1-20, Microlife, Switzerland). Body mass and height measurements were taken with accuracy of up to 0.1 kg and 0.5 cm, respectively, with an MS 6110 scale provided with an HM-202P stadiometer (Charder, Taiwan). To calculate participants' body mass index (BMI) values, their body mass was divided by the square of their height (expressed in metres). After anthropometric measurements, participants performed a 15-minute full-body warm up (a 3-minute trot, joint flexibility exercises, body weight exercises, and stretching exercises) preparing them for an endurance test (the maximal multistage 20-m shuttle run test – 20mSRT) (Leger et al., 1988) and a speed test (a 50-m sprint), both of which began with a standing start. Only one, randomly chosen test was performed on a given day. At least one day of rest was allowed between the tests.

In addition to the dry-land tests that all participants performed, the swimmers were also subjected to tests in an indoor 25 m swimming pool (25, 50, 75, and 100 m front crawl, breaststroke, and backstroke performed with maximal effort). Prior to the tests, they did the same warm-up that preceded dry-land tests and an individual 20-minute warm-up routine in the water, similar to the one they performed before a race (200 m front crawl, 200 m backstroke, 4*x*50 m in the stroke to be tested with emphasis on swimming technique, 4x25 m in the stroke to be tested, with velocity increasing from 70% to 90% of maximum velocity, 100 m in any stroke, 3–4 starts specific to a given stroke). Trials began with a jump off the block and were performed by one boy at a time to ensure accuracy of measurements. Swimming tests for each stroke (25, 50, 75 and 100 m) were performed every other day. Between the tests, participants were allowed rest periods of at least 12 minutes, until they fully recovered. The dry-land tests and the swimming tests were separated by a one-day interval. Altogether, all dry-land and swimming tests were completed by a swimmer within an average period of 9 days.

Participants' performance during the dry-land tests and the swimming tests was measured using a TYR Z-200 stopwatch (USA) by the same person to minimise the risk of measurement errors.

Swimming training characteristics

The swimmers' training programme was designed in line with the British Swimming Federation guidelines for children and youth (Lang & Light, 2010) and provided for 5-8 weekly sessions of 90 minutes each. The ratio between endurance and speed exercises was approximately 3 to 1, and the average distance participants swam during a session was about 3000–4000 m.

Statistical methods

The normality of distribution of the data was tested by the Shapiro-Wilk test. When distributions were not normal, data were transformed into log values before analysis. The statistical significance of the differences between swimmers' and controls' variables was assessed with the Student t-test for independent samples. Mean swimming velocities recorded for individual distances were analysed using a one-factor (distance) repeated measures ANOVA. As the post-hoc test, the Newman-Keuls test was applied. Additionally, the effect size (eta squared – η^2), i.e. the quotient of the sum of squares of an effect size for a given variable to the total sum of squares in the ANOVA model, was calculated. Using swimming velocities recorded for each swimmer and swimming style (front crawl, breaststroke, and backstroke), the slope of the regression line was presented as a swimming distance vs. velocity. Correlations between variables were established by calculating Pearson's correlation coefficients (r). Because multiple comparisons are known to be vulnerable to type-1 error, the Benjamini-Hochberg method with a false discovery rate of 0.1 proposed by McDonald (2014) was applied as a precaution. The Benjamini-Hochberg method is used to estimate the false discovery rate, i.e., the proportion of statistically significant false-positive results, by comparing the value of p obtained for a correlation with the critical value calculated from $(i/m) \cdot Q$, where i = rank of p-value; m = total number of tests; Q = chosen false discovery rate. Each p-value calculated for a given correlation is statistically significant when lower than the critical value (McDonald, 2014). The contributions from particular variables to the results of the swimming tests were assessed by performing a stepwise multiple regression analysis with backward elimination on variables with statistically significant correlations with the dependent variable. The results of the calculations are presented as arithmetic means and standard deviations (±SD), or as medians (M) and interquartile ranges (IQR) for data whose distributions were not normal. Excluding multiple comparisons (the Benjamini-Hochberg method), the level of significance was always set at p<0.05. All calculations were performed using Statistica 12.0 software by StatSoft (Poland).

Results

The SWIM and CON groups were not statistically significantly different regarding boys' calendar age, maturity offset, body mass, body height, resting heart rate, and systolic and diastolic blood pressure; however, the controls had higher BMI values ($p < 0.05$) (Table 1).

The swimmers performed statistically significantly better than the controls on the 50 m sprint run test ($p < 0.001$) and the 20mSRT ($p < 0.001$) (Table 2), but in both groups, the results of the tests were significantly and negatively correlated with each other. Pearson's r values were −0.815 ($p < 0.001$) for the controls and −0.720 ($p < 0.001$) for the swimmers. A similar correlation, −0.838 ($p < 0.001$), was obtained for the entire group ($n = 45$).

Table 1. Characteristics of the controls (CON n=25) and the swimmers (SWIM n=20)

Variable	CON	SWIM	p
age [years]	13.00 ± 1.00	12.96 ± 0.96	ns
MO [years]	−0.51 ± 0.55	−0.50 ± 0.81	ns
body mass [kg]	52.21 ± 9.21	47.66 ± 12.66	ns
body height [m]	1.62 ± 0.07	1.61 ± 0.12	ns
BMI [kg · m^{-2}]	19.79 ± 2.05	17.99 ± 2.51	< 0.05
HR_{rest} [beats · min^{-1}]	90.80 ± 8.55	88.40 ± 10.74	ns
BP_{syst} [mm Hg]	125.0 ± 10.0	122.1 ± 6.9	ns
BP_{diast} [mm Hg]	73.60 ± 7.52	75.00 ± 11.25	ns

Abbreviations: BMI – body mass index; BP_{diast} – diastolic blood pressure; BP_{syst} – systolic blood pressure; HR_{rest} – resting heart rate; MO – maturity offset.

Table 2. Results of dry-land exercise tests for controls (CON $n = 25$) and swimmers (SWIM $n = 20$)

Variable	CON	SWIM	p
50m sprint [s]	9.65 ± 0.82	8.82 ± 1.17	< 0.001
20mSRT – covered distance [m]	1060 ± 100	1320 ± 163	< 0.001

Abbreviations: 20mSRT – 20-metre shuttle run test.

A one-factor ANOVA of mean 25, 50, 75, and 100 m swimming velocities showed statistically significant differences within the given stroke ($p < 0.001$ in all cases) (Table 3). A post-hoc analysis also found statistically significant differences between mean swimming velocities over successive distances within the same stroke (i.e., 25 m and 50 m; 50 m and 75 m; and 75 m, and 100 m) (Table 3). The differences were reflected in the regression slope, showing the greatest decline in swimming velocity with increasing distance for the front crawl, and the smallest for the backstroke (Table 3). Particular strokes had statistically significantly different slope values ($p < 0.05$), with post-hoc analysis showing that only the slope values for the front crawl and backstroke were significantly different ($p < 0.05$). Interestingly, the breaststroke slope values were the only ones to be statistically significantly correlated with the results of the 50 m sprint test ($r = 0.454$; $p < 0.05$).

Table 3. Velocities achieved by the swimmers ($n = 20$) during front crawl (FC), breast stroke (BRS), and backstroke (BS) swimming tests and the linear regression slope values

Stroke	Swimming velocity [$m \cdot s^{-1}$]				F for swimming velocities	Slope	F for slope
	25 m	50 m	75 m	100 m			
FC	1.62 ± 0.15	1.53±0.15***	1.46±0.15***	1.42 ± 0.15**	65.18 $p < 0.001$ $\eta^2 = 0.774$	−0.07±0.03^a	3.51 $p < 0.05$ $\eta^2 = 0.156$
BRS	1.25 ± 0.18	1.14±0.14***	1.10 ± 0.15*	1.06 ± 0.11*	43.36 $p < 0.001$ $\eta^2 = 0.695$	−0.06 ± 0.03	
BS	1.36 ± 0.16	1.30±0.15***	1.26 ± 0.15*	1.23 ± 0.13*	28.30 $p < 0.001$ $\eta^2 = 0.598$	−0.04±0.03^a	

* – compared with the previous velocity (* – $p < 0.05$; ** – $p < 0.01$; *** – $p < 0.001$); a – comparison between front crawl and backstroke slope values (a – $p < 0.05$); η^2 – effect size.

Statistically significant correlations were established between mean swimming velocities obtained for all swimming distances, both within and between particular strokes (Table 4). Apart from 50 m breaststroke and 50 m backstroke, and 50 m breaststroke and 75 m backstroke, Pearson's r values ($p > 0.05$) proved to be statistically significant for all other combinations of strokes and distances.

The Benjamini-Hochberg procedure found statistically significant correlations between swimmers' speed and endurance measured on dry land and the results of the swimming tests (Table 5).

According to the multiple regression analysis of mean swimming velocities, the best predictors of almost all of them were the results of the 50 m sprint test. An exception was the mean 75 m backstroke velocity, which correlated the most strongly with the results of the 20mSRT (data not shown). The results of the 50 m sprint run were most reliably predicted by the 25 m front crawl velocity, which explained 66.8% of their variability (Table 6). Assuming that other variables are constant, a 0.1 m/s increase in the 25 m front crawl velocity would reduce the 50 m sprint time by 0.434 s. Using this simplification, a swimmer's performance on the 50 m sprint test can be calculated as:

$$\log_{10} 50\text{m sprint} = -0.175 \cdot 25\text{mFC} + 1.216 \pm 0.019$$

or, when a swimming velocity needs to be predicted, as:

$$25\text{mFC} = (1.216 - \log_{10} 50\text{m sprint})/0.175$$

Table 4. Pearson's correlation coefficient values between front crawl (FC), breaststroke (BRS), and backstroke swimming velocities (BS) for 25, 50, 75 and 100 m (n = 20)

Variable	25 m FC	50 m FC	75 m FC	100 m FC	25 m BRS	50 m BRS	75 m BRS	100 m BRS	25 m BS	50 m BS	75 m BS	100 m BS
25 m FC	**X**											
5 0m FC	0.945 $p<0.001$	**X**										
75 m FC	0.869 $p<0.001$	0.881 $p<0.001$	**X**									
100 m FC	0.891 $p<0.001$	0.882 $p<0.001$	0.938 $p<0.001$	**X**								
25 m BRS	0.754 $p<0.001$	0.748 $p<0.001$	0.703 $p<0.001$	0.726 $p<0.001$	**X**							
50 m BRS	0.605 $p<0.01$	0.555 $p<0.05$	0.554 $p<0.05$	0.554 $p<0.05$	0.890 $p<0.001$	**X**						
75 m BRS	0.724 $p<0.001$	0.738 $p<0.001$	0.709 $p<0.001$	0.716 $p<0.001$	0.888 $p<0.001$	0.856 $p<0.001$	**X**					
100 m BRS	0.681 $p<0.01$	0.677 $p<0.01$	0.693 $p<0.001$	0.673 $p<0.01$	0.871 $p<0.001$	0.893 $p<0.001$	0.978 $p<0.001$	**X**				
25 m BS	0.776 $p<0.001$	0.778 $p<0.001$	0.735 $p<0.001$	0.802 $p<0.001$	0.509 $p<0.05$	0.462 $p<0.05$	0.543 $p<0.05$	0.529 $p<0.05$	**X**			
50 m BS	0.800 $p<0.001$	0.846 $p<0.001$	0.759 $p<0.001$	0.850 $p<0.001$	0.580 $p<0.01$	0.434 ns	0.558 $p<0.05$	0.520 $p<0.05$	0.940 $p<0.001$	**X**		
75 m BS	0.809 $p<0.001$	0.881 $p<0.001$	0.809 $p<0.001$	0.859 $p<0.001$	0.604 $p<0.01$	0.433 ns	0.635 $p<0.01$	0.582 $p<0.01$	0.868 $p<0.001$	0.878 $p<0.001$	**X**	
100 m BS	0.874 $p<0.001$	0.932 $p<0.001$	0.864 $p<0.001$	0.920 $p<0.001$	0.689 $p<0.001$	0.494 $p<0.05$	0.660 $p<0.01$	0.605 $p<0.01$	0.872 $p<0.001$	0.913 $p<0.001$	0.937 $p<0.001$	**X**

The results of the 20mSRT best correlated with the 75 m backstroke velocity, which explained 48.3% of their variability (Table 6). In this case, a 0.1 m/s increase in the 75 m breaststroke velocity would increase the distance run in the 20mSRT by 76.850 m. Based on this simplification, the distance a swimmer would achieve in the 20mSRT can be calculated as:

$$\text{20mSRT-distance} = 768.5 \cdot \text{75mBS} + 352.0 \pm 120.4$$

or, when a swimming velocity needs to be predicted, as:

$$\text{75mBS} = (\text{20mSRT-distance} - 352.0)/768.5.$$

Discussion

By highlighting the scarcity of studies investigating relationships between exercise, sports, and the physical fitness of children and youth, the WHO's report of 2020 (World Health Organization, 2020) prompted the authors to examine and compare speed and endurance of 12–13-year-old male swimmers and their untrained peers (controls). Both of these abilities were found to be better developed in the swimmers and to be significantly correlated with the swimmers' performance in swimming tests. A multiple regression analysis pointed to the 25 m front crawl velocity and the 75 m backstroke velocity as the best predictors of the results of the 50 m sprint run test and the 20mSRT, respectively.

Table 5. Pearson's correlation coefficient values between the results of the speed and endurance tests and the results of the 25, 50, 75 and 100 m swimming tests (FC, BRS and BS) (n = 20), adjusted for a false discovery rate of 0.1

Variable	50 m sprint		Variable	20mSRT distance		Benjamini-Hochberg-critical value
	r	p		r	p	
25 m FC	–0.818	< 0.001	75 m BS	0.695	< 0.001	0.008
50 m FC	–0.778	< 0.001	25 m FC	0.689	< 0.001	0.017
25 m BRS	–0.705	< 0.001	50 m FC	0.684	< 0.001	0.025
75 m BRS	–0.659	0.002	25 m BRS	0.619	0.004	0.033
100 m BS	–0.651	0.002	75 m BRS	0.594	0.006	0.042
100 m FC	–0.642	0.002	100 m FC	0.590	0.006	0.050
100 m BRS	–0.626	0.003	75 m FC	0.589	0.006	0.058
75 m FC	–0.613	0.004	100 m BS	0.584	0.007	0.067
50 m BS	–0.596	0.006	50 m BS	0.549	0.012	0.075
75 m BS	–0.588	0.006	100 m BRS	0.539	0.014	0.083
50 m BRS	–0.574	0.008	25 m BS	0.493	0.027	0.092
25 m BS	–0.519	0.019	50 m BRS	0.457	0.043	0.100

Abbreviations: 20mSRT – 20-metre shuttle run test; FC – front crawl; BRS – breaststroke; BS – backstroke

Table 6. Results of stepwise multiple regression analysis with backward elimination between dependent variables (speed and endurance measurements) and independent variables (swimming test velocities)

Dependent variable	r^2	SEE	Independent variable	β ±SE of β	B ±SE of B	p
50 m sprint [s]	0.668 p < 0.001	±0.019	intercept	–	1.216 ± 0.047	< 0.001
			25 m FC	−0.818 ± 0.136	−0.175 ± 0.029	< 0.001
20mSRT – covered distance [m]	0.483 p < 0.001	±120.423	intercept	–	352.034 ± 237.621	ns
			75 m BS	0.695 ± 0.169	768.498 ± 187.439	< 0.001

Abbreviations: 20mSRT – 20-metre shuttle run test; BS – backstroke; FC – front crawl;

Anthropometric measurements did not find the swimmers to be statistically significantly different from the controls in body mass and body height. Although considerably lower than in the controls, their BMI values were in the wide normal range for boys in this age group (de Onis et al., 2007), which was in agreement with other authors' reports (Bielec et al., 2021; Machado et al., 2022). Because BMI is widely used as an approximation of the amount of fat tissue (Freedman & Sherry, 2009), lower BMI values in the swimmers than in the controls may have been related to their lower fat mass associated with greater energy expenditure during a week (180 min of exercise at school (4 PE classes of 45 min each) plus 450 min of swimming training (at least 5 sessions of 90 min) amount to 630 min of physical activity per week; the controls only exercised for 180 minutes during PE classes (see the Methods section)). The aerobic profile of swimming training may have also contributed to young athletes having lower BMI. According to research, regular aerobic exercise helps reducing adiposity and limiting weight gain (Laframboise & Degraauw, 2011).

The ability of physical training to influence children's aerobic capacity remains a controversial matter (Baquet et al., 2003; Baxter-Jones & Maffulli, 2003). In contrast with most cross-sectional studies and investigations into the short-term effect of physical activity on children's aerobic capacity that show, like this study, that it can improve it (see Armstrong & Welsman, 2020), longitudinal studies rarely support this conclusion (Kuberski et al., 2022; Silva et al., 2022; Zarzeczny et al., 2022).

The effect of physical training on children's anaerobic capacity is also arguable. According to some authors mentioned in the Introduction, anaerobic capacity starts developing at a faster pace around the age of 13 years (see Bar-Or & Rowland, 2004), which they attribute to a slightly delayed formation of some physiological characteristics of the skeletal muscles, such as muscle pennation angle, type II muscle fibre activation, muscle phosphocreatine stores, muscle glycogen stores, and intra-muscular anaerobic enzyme activity (Armstrong, 2019; Armstrong et al., 2015; Armstrong et al., 2017). The finding in this study that anaerobic capacity starts to develop in boys as they reach 12 years of age is inconsistent with the results presented by Bar-Or and Rowland but accords with those reported by Armstrong and Welsman (2020), who pointed to the age of 11 as the onset of faster development of anaerobic capacity in children.

The correlations between the results of the 50 m sprint run test and the 20mSRT were similar between swimmers and controls. Because the results of the tests are widely used as indicators of anaerobic capacity (Kalamen, 1968) and aerobic (cardiorespiratory) capacity (Leger et al., 1988), respectively, it may be that the metabolic profiles of swimmers and controls were not yet sufficiently developed to specifically indicate to which sport, endurance or speed-based, they were predisposed. While supporting Bar-Or's hypothesis (Bar-Or, 1983) that children are "non-metabolic specialists", the similarity of correlations between the results of the 50 m sprint test and the 20mSRT between the groups is intriguing, given the emphasis that swimming training places on developing aerobic capacity.

The strong correlation between the results of both these tests in the groups of swimmers and controls is a notable finding, but explaining it convincingly is difficult, because of an insufficient number of variables. However, given that the swimmers had considerably lower BMI values and that their body mass was not statistically significant different from that of controls, the most likely explanation refers to the amount of fat-free mass (FFM). According to research evidence, increases in FFM encompass the effects of maturation on anaerobic and aerobic fitness, as they are strongly related to the timing and tempo of maturation (Armstrong & Welsman, 2020). Because endurance and speed were measured in the study using running-based tests and the ability to run is negatively related to fat mass (Welsman & Armstrong, 2019), it is likely that the swimmers performed better than the controls on both tests because they had less fat mass in relation to fat-free body mass.

The significance of the correlations between swimming velocities recorded for different distances within a stroke and between strokes suggests that the quality of participants' swimming technique was similar between the strokes. This might imply that swimming velocity is unrelated to the stroke, but in fact it is not so. The analysis of strokes pointing to a decline in swimming velocity with increasing distance (slope differences) and additional calculations using two-way ANOVA with repeated measures (differences in swimming velocity vs stroke; data not shown) revealed statistically significant differences in swimming velocity between the strokes ($F = 3.51$; $p < 0.05$ and $F = 3.76$; $p < 0.05$, respectively). These results are similar to the findings reported by other authors (Barbosa et al., 2006; Barbosa et al., 2011; Rogowska et al., 2023).

A positive correlation between the slope of the linear regression calculated with breaststroke swimming velocities and the 50 m sprint times seems to indicate an association between the rate of decline in breaststroke velocity and the rate of muscle ATP production during a 50 m sprint run. The correlation was only observed for the breaststroke, probably because this stroke is the most demanding energetically among all strokes we examined (Barbosa et al. 2006).

In the swimmers, high correlations between aerobic and anaerobic capacity measured on dry-land co-occurred with significant correlations between the results of endurance and speed tests and swimming velocities recorded for all distances and strokes. Because the swimming test distances used in the study are commonly regarded as short distances during which anaerobic metabolism is an important source of energy for the working muscles, it can be concluded that the swimmers were "non-metabolic specialists" also during in-water exercise, despite the swimming training's strong emphasis on athletes' aerobic capacity.

That the strongest correlations were found between the results of the 50 m sprint run test and the 25 m front crawl test is not surprising, because the fastest swimming velocities are recorded for the 25 m front crawl. According to research, anaerobic processes are the main source of energy enabling muscle contractions during both these tests (Capelli et al., 1998; Kalamen, 1968; Zamparo et al., 2000).

An interesting finding was that the swimmers' endurance was best correlated with the results of 75 m backstroke swimming. Although the 75 m backstroke is also counted among the so-called short distances where anaerobic processes contribute a major portion of energy to the working muscles, the significance of this correlation seems to be associated with backstroke swimmers' almost unlimited access to oxygen. There are two facts that seem to explain it: 1) the average time recorded for 75 m backstroke was 60.3 s (from 47.67 to 72.96 s); and 2) the importance of aerobic energy for the working muscles increases with extending duration of swimming effort (Capelli et al., 1998; Zamparo et al., 2000). Given that Zamparo et al. (2000) observed that in swimmers aged 12–17 years, 48.6% of the energy expended during front crawl performed with maximal effort for 70.7 s came from aerobic processes, the proportion of aerobic processes in our swimmers may have been comparable or even greater, because backstroke is more energy intensive than front crawl (Barbosa et al., 2006).

However, why the results of the 20mSRT were the most strongly correlated with swimming velocity recorded for the 75 m backstroke and not the 100 m backstroke is not so clear. The energy used for muscle contractions during backstroke swimming certainly came from both aerobic and anaerobic sources, because: 1) a decline in backstroke velocity was not statistically significantly related to the results of the 50 m sprint test or the 20mSRT; and 2) all swimming tests took place in a 25 m pool where the swimmers had to make turns which consumed additional (mainly anaerobic) energy. Therefore, the results of the 75 m backstroke test can be assumed to best reflect the percentage of aerobic energy utilised during the 20mSRT.

The correlations between the results of dry-land and in-water tests detected in the study can be very useful for coaches, providing an insight into swimmers' physiological capacities, enabling the evaluation of training outcomes, and prompting adjustments to training plans. However, the study also has some limitations and weaknesses that affect its findings: 1) as only 3 swimming strokes (front crawl, breaststroke, and backstroke) and relatively short swimming distances (up to 100 m) were analysed, it is not possible to infer about the butterfly stroke or the effects of longer swimming distances (200 or 400 m); 2) all participants were boys aged 12–13 years, so the results of the study are limited to this specific group and should not be generalised to the overall population of boys and girls of different ages; 3) the relatively small sample size necessitates caution in interpreting the results.

The limitations and weaknesses of this study indicate that future research should also include the butterfly stroke and look more closely at energy sources in children swimming distances up to 100 m, and the correlations between their swimming performance on longer distances and the results of dry-land tests.

Conclusions

The results of the dry-land tests showed that the 12–13-year-old swimmers could run longer and faster than their untrained peers. The study also confirmed that boys in this age range were "non-metabolic specialists", and this characteristic was not changed by the aerobic focus of swimmers' training. The best correlations were found in the study between the results of the 50 m sprint run and the 25 m front crawl and between the 20mSRT and the 75 m backstroke; this indicates that aerobic processes may play a significant role as a source of energy for muscle contractions in boy swimmers aged 12–13 years performing 75–100 m swims with maximal effort.

Practical implications

The results of the study can be a basis for coaches training male swimmers aged between 12 and 13 years to evaluate the effectiveness of in-water training and dry-land exercises if used. Lower BMI values and greater endurance and speed of the young swimmers can also be a convincing argument for parents who are hesitant about whether swimming is an appropriate sport for their children.

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