Original paper

An assessment of selected motor skills in young female swimmers and their associations with swimming test results – a pilot study

Ocena poziomu wybranych zdolności motorycznych i ich współzależności z wynikami testów pływackich u młodych pływaczek – badanie pilotażowe

Paulina Rogowska, Piotr Bujak, Ryszard Jarosław Zarzeczny

Institute of Health Sciences, Jan Kochanowski University, Kielce, Poland

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Key words: motor skills, swimming, dryland testing, peripubertal girls.

Słowa kluczowe: zdolności motoryczne, pływanie, testy zdolności motorycznej wykonywane na lądzie, dziewczęta w wieku okołopokwitaniowym.

Abstract

Introduction: The most recent WHO report (2020) highlighted the scarcity of information regarding how different physical activities and sports influence the development of motor skills in young people.
Aim of the research: This study set out to determine if dryland speed, endurance, strength, and flexibility would differentiate peripubertal female swimmers from their untrained peers, and how the swimmers' performance on dryland motor skills tests would correlate with the results of standard 25-, 50-, 75-, and 100-m swimming tests involving front crawl, breaststroke, and backstroke.
Material and methods: Twenty-eight peripubertal female swimmers and 22 same-age girls in the control group performed the following tests of motor skill: the 50-m sprint run test (speed), the 20-m shuttle run test (cardiorespiratory fitness), the 30-s sit-up test (abdominal muscle endurance), the backward overhead medicine ball throw test (back muscle strength), and the sit and reach test (flexibility).
Results: The swimmers performed significantly better than the control group on tests assessing speed ($p < 0.01$), abdominal muscle endurance ($p < 0.001$), back muscle strength ($p < 0.001$), and flexibility ($p < 0.01$) but did not differ from the control group in the level of cardiorespiratory fitness. Speed, cardiorespiratory fitness, and abdominal muscle endurance were best predicted by 25-m backstroke velocity ($p < 0.001$ in all cases), back muscle strength by 25-m front crawl velocity ($p < 0.05$), and flexibility by 25-m breaststroke velocity ($p < 0.01$).
Conclusions: Although swimming training for peripubertal children emphasizes cardiorespiratory fitness, it only significantly improved the studied swimmers speed, strength, abdominal muscle endurance, and flexibility.

Streszczenie

Wprowadzenie: Według ostatniego raportu WHO (2020) brakuje badań u młodzieży dotyczących wpływu aktywności fizycznej w różnych dyscyplinach sportu na rozwój zdolności motorycznych.
Cel pracy: Porównanie poziomu wytrzymałości, szybkości, siły i gibkości dziewcząt w wieku okołopokwitaniowym uprawiających pływanie z nietrenującymi rówieśnicami, a także zbadanie u pływaczek współzależności wyników tych zdolności motorycznych uzyskanych na lądzie z wynikami standardowych testów pływackich wykonywanych na dystansie 25, 50, 75 i 100 m stylem dowolnym, klasycznym i grzbietowym.
Materiał i metody: Badania przeprowadzono w grupie 28 pływaczek i 22 dziewcząt z grupy kontrolnej, które poddane były standardowym testom sprawności motorycznej: szybkości – sprint biegowy na 50 m; wydolności tlenowej – 20 m wahadłowy test biegowy; wytrzymałości mięśni brzucha – test 30 s skłonów tułowia z pozycji leżącej; siły mięśni grzbietu – test rzutu piłki lekarskiej w tył ponad głową i gibkości – test dosiężny z pozycji siedzącej.
Wyniki: Pływaczki cechowały się wyższymi wartościami szybkości ($p < 0,01$), wytrzymałości mięśni brzucha ($p < 0,001$), siły mięśni grzbietu ($p < 0,001$) oraz gibkości ($p < 0,01$), jednak wyniki wydolności tlenowej nie były istotne statystycznie względem kontroli. Najlepszym predyktorem dla szybkości, wydolności tlenowej i wytrzymałości mięśni brzucha była prędkość pływania na dystansie 25 m stylem grzbietowym ($p < 0,001$); dla siły mięśni grzbietu – 25 m stylem dowolnym ($p < 0,05$), natomiast dla gibkości – 25 m stylem klasycznym ($p < 0,01$).
Wnioski: Chociaż trening pływacki stosowany w wieku okołopokwitaniowym charakteryzuje się typowo aerobowym profilem, to jednak w istotny sposób kształtuje on jedynie szybkość, siłę, wytrzymałość mięśni brzucha i gibkość trenujących dziewcząt.

Introduction

The stages of human biological development differ regarding the pace of morphological and functional changes. The greatest dynamics of growth and changes occurs in the first 3 post-natal years and in adolescence [1]. During these 2 ontogenetic stages, many systems of the human body start functioning at a qualitatively new level; at the same time, the human body becomes particularly sensitive to external stimulants (e.g. physical activity) [2].

According to Cameron and Schell [1], girls usually go through adolescence between the ages of 8 to 19 years and boys between the ages of 10 and 22 years, with the development of their motor skills occurring between the ages 11–15 and 12–16, respectively. Because the development of individuals' motor skills is naturally programmed in their genotype, researchers seek to determine which external factors can influence the process, and how.

The need to study how additional physical activity influences the biological development of adolescent boys and girls was highlighted in the WHO report of 2020 [3]. A 2016 survey [3] revealed that the physical activity of 73.7% of boys and 84.2% of girls aged 11–17 years in Poland was below the level recommended by the WHO in 2010. The global percentage of insufficiently physically active youths in that age group was estimated to stand at as much as 81%. The 2020 WHO guidelines [4] recommend that children and adolescents aged 5–17 years engage daily in 60 min of moderate-to-vigorous-intensity aerobic exercise.

Most studies investigating the effect of additional physical activity on children's biological development have found it beneficial [1, 5, 6]. It needs to be noted, however, that researchers studying how physical activity influences children tend to equate additional physical activity with participation in any sport, disregarding the fact that different sports contribute differently to the development of even the same motor skill.

Swimming is a very popular form of additional physical activity offered to pupils by many schools. Its attractiveness is probably associated with measurable physiological gains (greater cardiorespiratory fitness and muscular strength), psychological gains (increased self-confidence and ability to concentrate, reduced anxiety), and social gains (better relations with peers) observed in children who regularly attend swimming sessions. Engaging large muscle groups and minimizing strain on the joints and spine, swimming is also recommended for health maintenance and rehabilitation. Lastly, swimmers are at a lower risk of injury compared with other athletes [7].

Of all Olympic disciplines, swimming has the largest number of competitive events, which are divided into 4 different swimming styles (front crawl, backstroke, butterfly, and breaststroke) and racing distances (from 50 m to 1500 m). Therefore, to be successful, swimmers must undergo comprehensive physiological conditioning (enhancing their aerobic and anaerobic capacity) and motor conditioning (improving endurance, strength, and power) and have appropriate body build [8, 9]. Unsurprisingly, sports clubs recruit for competitive swimming in children as young as 9–10 years [10], making sure that they meet strict criteria regarding the anthropometric (low body mass and high body height) and physiological parameters (high aerobic and anaerobic capacity) [8, 9]. However, the results of swimming tests have shown that although the parameters are good predictors of adult swimmers' performance, they do not always work well in the case of adolescent and younger swimmers [11], probably because of natural differences in the biological development of children and different swimming and motor skills of children recruited by sports clubs.

One of the main physiological principles guiding the preparation of athletic training programs is the principle of specificity, according to which training programs should include exercises addressing the specific demands of the athletes' sport and the nature of its environment, as well as stimulating the development of an energy system(s) important for successful competition. This means that muscle work in the water is the most beneficial for swimmers; recent research has shown, however, that making dryland exercises part of swimming training is also important [12] because they can improve the performance of competitive swimmers [13, 14] and swimming technique, including stroke length and stroke rate [15].

Although the studies reported that an athlete's dryland motor competence and competitive swimming performance could be related to each other, the importance of this finding is significantly limited by the fact that most of them involved male swimmers aged 14–21 years who performed dryland power and strength training the effect of which on swimming performance (the time of completing a test) was assessed for one swimming style only (front crawl).

Aim of the research

This study set out to compare endurance, speed, strength, and flexibility between girls aged 12–13 years participating in swimming training and their non-training peers and to determine correlations between the swimmers' performance on dryland motor skills tests and standard swimming tests involving front crawl, breaststroke, and backstroke.

Material and methods

Subjects

The study participants comprised 50 girls aged 12–13 years recruited on a voluntary basis. The experimental group consisted of 28 girls living in the Świętokrzyskie voivodeship, who had regular physical education (PE) classes at their schools and had been participating in swimming training at sports clubs for at least 3 years. They were recruited by the clubs without having to meet any specific entry criteria. The inclusion criteria for the study required participants to be girls aged 12–13 years with at least 3 years of swimming experience and to have consent from their parents or guardians to participate in the study. The exclusion criteria included an illness, an injury, or a lack of consent.

The control group comprised 22 untrained girls attending elementary school no. 27 in Kielce, who did not engage in physical activity other than during the PE classes. Their eligibility for the study was determined using the same inclusion and exclusion criteria as those applied to the experimental group participants, excluding the swimming training criterion.

The maturity offset (MO) of the participants was determined based on their age and body height using the formula of Moore *et al.* [16]. All girls and their parents were familiarized with the purpose and methods of the study and gave their written informed consent to participate as required by the Declaration of Helsinki. The study protocol was approved by the Biomedical Committee at the Jan Kochanowski University in Kielce (decision No. 10/2022).

Study protocol

The motor skill and swimming tests were conducted in participants' schools and sports clubs between 8.00 a.m. and 12.00 p.m. Heart rate measurements (HR_{rest}) were taken in a sitting position after 15 min of rest, and then arterial blood pressure was measured with a manual sphygmomanometer (Microlife, AG1-20, Switzerland). Participants' body mass and body height were determined with an accuracy of 0.1 kg and 0.5 cm, respectively (using the MS6110 Stand-on Floor Scale provided with an HM-202P stadiometer; Charder, Taiwan), which were then used to calculate each participant's body mass index (BMI) by dividing their body mass in kilograms by the square of their height expressed in metres.

Anthropometric measurements were followed by a 15-minute warm-up consisting of a 3-minute trot, joint mobility exercises, simple support exercises, and stretching exercises. Then, the participants performed motor skills tests to determine their cardiorespiratory fitness, speed, abdominal muscle endurance, back muscle strength, and flexibility. Each participant performed only one randomly selected test per day and then was allowed at least 1 day of rest.

In addition to the physical fitness tests that all participants performed, the swimmers were also administered 25-, 50-, 75-, and 100-m front crawl, breaststroke, and backstroke tests. Although competitive swimming events involve distances of 50 and 100 m as a standard, we introduced intermediate distances of 25 and 75 m because many coaches, particularly those who train child and youth swimmers, use the results of a combination of shorter tests to predict swimmers' performance over longer distances. For instance, the results of the 2 × 25-m and 4 × 25-m swimming tests are used to anticipate the swimming results over distances of 50 and 100 m, respectively [17]. All swimming tests were conducted in a 25-metre-long indoor pool. Before the tests, the swimmers did a general warm-up followed by a standard pre-race warm-up lasting 20 min. All tests began with a dive start and were performed by only one swimmer at a time to ensure accuracy of measurements. The different tests were conducted on different days so that the participants were rested and performed at their best.

Motor skills tests

Speed was measured in seconds with a 50-m sprint test with a standing start, which was performed by the participants in pairs to increase their motivation to compete [18].

Participants' cardiorespiratory fitness was assessed using a 20-m shuttle run test (20-mSRT) [19]. It required them to run between 2 lines spaced 20 m apart at a speed dictated by pre-recorded loud beeps, whose accuracy was checked beforehand. The initial speed of 8.5 km/h was increased by 0.5 km/h after each one-minute stage. One stage consisted of multiple "shuttles", whose number increased with speed. The test was performed individually in the presence of other participants to encourage competition until a participant failed to complete 2 consecutive shuttles in time or until exhaustion. The level of cardiorespiratory fitness was assessed based on the number of shuttles completed during the 20-mSRT, maximum 20-mSRT speed (recorded for the last completed stage), and maximum oxygen uptake (VO_2max) calculated with the following formula [19]:
$VO_2max = 31.025 + 3.238 \times X - 3.248 \times A + 0.1536 \times X \times A$,
where X – maximum 20-mSRT speed; A – participant's calendar age.

Abdominal muscle endurance and trunk strength were derived from the results of a 30-s sit-up test [20]. In the test, participants lying in a supine position with legs bent at 90°, feet placed 30 cm apart, the head resting on the hands with interlocked fingers, and elbows pointed forward were required to sit up and touch their knees with the elbows, instantly return to the starting position, and sit up again. The test outcome was the number of sit-ups completed in 30 s.

The explosive strength of back muscles was determined using the backward overhead medicine ball throw test (BOMBT) involving a 3 kg ball. Holding the ball with both hands in front of them while standing with their feet slightly apart, the participants were to throw it backward overhead as far as they could. One or two preparatory swings were allowed. The test-retest reliability of the BOMBT is 0.996 at $p < 0.01$ [21]. The test outcome was the distance (in metres) from the throwing line to where the ball first touched the ground.

Flexibility was assessed with the sit and reach flexibility test [20] measuring trunk and hamstring flexibility. The test outcome was the distance (in centimetres) from the tips of the middle fingers to the line joining the heel extremities.

Swimming training program

The training program the swimmers were undergoing was designed in line with the British Swimming Federation's guidelines for children and adolescents [22] and provided for 5–8 weekly sessions of 90 min. The ratio of aerobic exercises to anaerobic exercises during a session was approximately 80% to 20%, and the average distance swam by participants was approx. 3000 to 4000 m.

Independent and depended variables

The first stage of the statistical analysis involved a comparison between the swimmers and the control group. The set of dependent variables consisted of body mass, body height, BMI, maturity offset, resting heart rate, resting arterial diastolic and systolic blood pressure, and the results of the 20-m shuttle run test, the 50-m sprint test, the 30-s sit-up test, the backward overhead medicine ball throw test, and the sit-and-reach test. The independent variable was participation in swimming training. The second stage of analysis focused on the swimmers and the correlations between their swimming performances and the results of the motor skills tests. This analysis had 2 components. First, the results of the motor skills test were used as independent variables and swimming velocities over distances of 25, 50, 75, and 100 m related to particular styles served as dependent variables. Then, swimming velocities were used as independent variables, and the results of the motor tests represented dependent variables.

Statistical analysis

All variables were tested for normal distribution by using the Shapiro-Wilk test. Those that did not have normal distributions were converted into logarithms so that the parametric tests could be applied. Their mean values are shown in the tables as medians and their dispersion around the medians as interquartile ranges (IQR). The statistical significance of differences in the investigated variables between the swimmers (SWIM) and the control group (CON) was established using Student's *t*-test for independent samples. The results of the swimming tests (participants' mean velocities for each swim distance) were examined using repeated-measures ANOVA with one factor (distance). Regression slopes were calculated for each swimmer and swimming style (backstroke, breaststroke, and front crawl) based on swimming distance versus mean swimming velocity. Correlations between the selected groups of variables were evaluated by calculating Pearson's linear correlation coefficients (*r*). As a precaution against type-I error associated with multiple comparisons, the Benjamini-Hochberg procedure and a false discovery rate of 0.1 proposed by McDonald [23] were applied. The contribution of each variable to the results of the swimming tests was determined by means of a stepwise multiple regression analysis with backward elimination, omitting variables other than those statistically significantly correlated with the dependent variable.

Computations were performed in Statistica 12.0 software by StatSoft (Poland). The results are shown as arithmetic means with standard deviations (± SD) or medians (M) and interquartile ranges (IQR) in the case of data that did not have normal distributions. The level of significance was set at $p < 0.05$, excluding multiple comparisons (the Benjamini-Hochberg procedure).

Results

All participants were past the age of peak height velocity (PHV). The SWIM and CON groups were not significantly different in terms of the maturity offset (MO), calendar age, body mass, body height, BMI, resting heart rate, and resting diastolic and systolic blood pressure ($p > 0.05$) (Table 1).

The results of the motor skills tests revealed that the swimmers outperformed the control group girls in speed ($p < 0.01$), abdominal muscle endurance ($p < 0.001$), strength of back muscles ($p < 0.001$), and flexibility ($p < 0.01$). However, the groups did not differ in either the results of the 20-mSRT results or VO_2max values derived from them ($p > 0.05$) (Table 1).

Pearson's *r* values showing correlations between the results of the motor tests for the whole sample ($n = 50$) indicated that they were statistically significant in almost all cases (Table 2). Only the participants' VO_2max derived from the 20-mSRT was not statistically significantly correlated with the result of the BOMBT measuring the explosive strength of back muscles ($r = 0.257$; $p > 0.05$). Given that VO_2max values were derived from the results of the 20-mSRT and that they did not correlate with the BOMBT results, the total distance covered during the 20-mSRT was used in further analysis to assess participants' cardiorespiratory fitness.

Mean swimming velocities were calculated for all distances and strokes based on swimming times. In this case, Pearson's *r* showed that the outcomes of particular tests were statistically significant correlated to each other (data not shown).

Table 1. The characteristics of the control group (CON; *n* = 22) and the group of swimmers (SWIM; *n* = 28)

Variable	CON	SWIM	*P*-value
Age [years]	12.875 (0.854)	12.777 ±0.595	ns
MO [years]	0.962 ±0.457	1.085 ±0.602	ns
Body mass [kg]	47.614 ±5.929	49.936 ±7.649	ns
Body height [m]	1.609 ±0.042	1.629 ±0.066	ns
BMI [kg/m^2]	18.350 ±1.772	18.722 ±1.956	ns
HR_{rest} [beats/min]	87.636 ±7.829	88.679 ±9.798	ns
BP_{syst} [mm Hg]	123.864 ±6.923	122.536 ±9.555	ns
BP_{diast} [mm Hg]	74.545 ±8.672	73.679 ±8.633	ns
50 m sprint [s]	9.851 ±0.713	9.169 ±0.812	< 0.01
20-mSRT – covered distance [m]	1061.818 ±111.083	1085.714 ±134.534	ns
VO_2max [ml/min/kg]	46.402 ±2.140	46.636 ±2.343	ns
30-s sit-ups [no. of repetitions]	18.000 (3.750)	23.357 ±3.466	< 0.001
BOMBT [m]	3.755 ±0.643	4.900 (0.550)	< 0.001
Sit and reach [cm]	20.659 ±5.752	27.089 ±7.259	< 0.01

MO – maturity offset, BMI – body mass index, HR_{rest} – resting heart rate, BP_{syst} – systolic blood pressure, BP_{diast} – diastolic blood pressure, 20-mSRT – 20-metre shuttle run test, VO_2max – maximum oxygen uptake, BOMBT – backward overhead medicine ball throw test

Table 2. Pearson's correlation coefficients between the results of the motor skills tests (*n* = 50)

Variable	50-m sprint	20-mSRT – cov.distance	VO_2max	30-s sit-ups	BOMBT	Sit and reach
50-m sprint	X	–0.753 $p < 0.001$	–0.615 $p < 0.001$	–0.472 $p < 0.001$	–0.409 $p < 0.01$	–0.402 $p < 0.01$
20-mSRT – cov. distance	–0.753 $p < 0.001$	X	0.843 $p < 0.001$	0.378 $p < 0.01$	0.364 $p < 0.01$	0.294 $p < 0.05$
VO_2max	–0.615 $p < 0.001$	0.843 $p < 0.001$	X	0.334 $p < 0.05$	0.257 ns	0.288 $p < 0.05$
30-s sit-ups	–0.472 $p < 0.001$	0.378 $p < 0.01$	0.334 $p < 0.05$	X	0.681 $p < 0.001$	0.509 $p < 0.001$
BOMBT	–0.409 $p < 0.01$	0.364 $p < 0.01$	0.257 ns	0.681 $p < 0.001$	X	0.352 $p < 0.05$
Sit and reach	–0.402 $p < 0.01$	0.294 $p < 0.05$	0.288 $p < 0.05$	0.509 $p < 0.001$	0.352 $p < 0.05$	X

20-mSRT – 20-metre shuttle run test, VO2max – maximum oxygen uptake, BOMBT – backward overhead medicine ball throw test.

A one-factor ANOVA showed that mean velocities recorded for 25-, 50-, 75-, and 100-m swims were significantly different between the swimming styles ($p < 0.001$ in all cases) (Table 3). The post-hoc comparisons of mean swimming velocities recorded for particular distances within each style revealed that they were statistically significantly different from each other, excluding 75-m versus 100-m backstroke ($p > 0.05$) (Table 3). The differences were reflected in the regression slope values (Table 3). The largest decrease in swimming velocity with increasing distance occurred in the case of front crawl, and the smallest concerned backstroke. The values of the linear regression slopes were significantly different between the swimming styles ($p < 0.001$) (Table 3).

Table 4 summarizes Pearson's correlation coefficients between the results of the motor skills tests and mean swimming velocities recorded for different styles, adjusted by the Benjamini-Hochberg method. The results of the 50-m sprint test are statistically significantly correlated with the results of all swimming tests. Apart from the mean 75-m front crawl velocity, the results of all other swimming tests are significantly associated with the results of the 20-mSRT. The results of the abdominal muscle endurance and back muscle strength tests are significantly correlated with

Table 3. Velocities achieved by the swimmers (n = 28) during backstroke (BS), breast stroke (BRS), and front crawl (FC) swim tests and the linear regression slope values

Stroke	Swim velocity [m/s]				*F*	Slope	*F*
	25 m	50 m	75 m	100 m			
BS	1.341 ±0.113	1.317 ±0.114*	1.241 ±0.101***	1.232 ±0.100	43.185 $p < 0.001$	–0.040[aaa bb] ±0.026	18.619 $p < 0.001$
BRS	1.283 ±0.100	1.193 ±0.089***	1.151 ±0.099***	1.114 ±0.084***	127.450 $p < 0.001$	–0.055[aa] ±0.019	
FC	1.643 (0.170)	1.566 (0.144) ***	1.520 (0.190) ***	1.452 (0.117) ***	149.390 $p < 0.001$	–0.072 ±0.021	

**Compared with the previous velocity (*p < 0.05; **p < 0.01; ***p < 0.001), [a]compared with the FC velocity ([a]p < 0.05; [aa]p < 0.01; [aaa]p < 0.001), [b]compared with the BRS velocity ([b]p < 0.05; [bb]p < 0.01; [bbb]p < 0.001).*

Table 4. Pearson's correlation coefficients between the results of the motor skills tests and the results of the 25-, 50-, 75-, and 100-m swim tests (BS, BRS, and FC) (n = 28), adjusted for a false discovery rate of 0.1

Variable	50-m sprint		Variable	20-mSRT distance		Variable	30-s sit-ups		Benjamini-Hochberg-critical value
	r	*p*		*r*	*p*		*r*	*p*	
25 BS	–0.734	8.786×10^{-6} significant	25 BS	0.659	1.368×10^{-4} significant	25 BS	0.607	6.177×10^{-4} significant	0.008
25 BRS	–0.699	3.508×10^{-5} significant	25 BRS	0.634	2.902×10^{-4} significant	50 BS	0.452	1.583×10^{-2} significant	0.017
50 BRS	–0.686	5.627×10^{-5} significant	50 BRS	0.605	6.554×10^{-4} significant	50 BRS	0.431	2.197×10^{-2} significant	0.025
50 FC	–0.636	2.790×10^{-4} significant	100 BS	0.569	1.586×10^{-3} significant	100 BS	0.390	4.041×10^{-2} significant	0.033
50 BS	–0.628	3.477×10^{-4} significant	50 BS	0.545	2.728×10^{-3} significant	25 BRS	0.377	4.812×10^{-2} significant	0.042
100 BS	–0.565	1.725×10^{-3} significant	75 BS	0.542	2.882×10^{-3} significant	75 BS	0.375	4.959×10^{-2} significant	0.050
75 BS	–0.552	2.311×10^{-3} significant	100 BRS	0.455	1.489×10^{-2} significant	75 BRS	0.372	5.120×10^{-2} significant	0.058
25 FC	–0.537	3.188×10^{-3} significant	75 BRS	0.448	1.678×10^{-2} significant	50 FC	0.322	9.520×10^{-2} ns	0.067
100 FC	–0.528	3.856×10^{-3} significant	50 FC	0.434	2.095×10^{-2} significant	100 BRS	0.316	1.014×10^{-1} ns	0.075
100 BRS	–0.523	4.288×10^{-3} significant	100 FC	0.349	6.832×10^{-2} significant	100 FC	0.275	1.565×10^{-1} ns	0.083
75 FC	–0.468	1.208×10^{-2} significant	25 FC	0.327	8.916×10^{-2} significant	75 FC	0.221	2.587×10^{-1} ns	0.092
75 BRS	–0.453	1.538×10^{-2} significant	75 FC	0.293	1.297×10^{-1} ns	25 FC	0.202	3.015×10^{-1} ns	0.100

20-mSRT – 20-metre shuttle run test, BS – backstroke, BRS – breaststroke, FC – front crawl.

7 swimming velocities, and the results of the flexibility test with only 2 velocities (Table 4).

A multiple regression analysis of mean swimming velocities pointed out that almost all of them were best predicted by the results of the 50-m sprint run test; an exception was the mean 100-m backstroke velocity, which was best correlated with the results of the 20-mSRT (data not shown). Among the motor skills results, the analysis pointed to mean 25-m backstroke velocity (an independent variable) as the best predictor of participants' speed, cardiorespiratory fitness, and abdominal muscle endurance (dependent variables) (Table 5). Back muscle strength and flexibility (dependent variables) turned out to be the most strongly associated with mean 25-m front crawl velocity and mean 25-m breaststroke velocity, respectively

Table 4. Cont.

Variable	BOMBT		Variable	Sit and reach		Benjamini-Hochberg-critical value
	r	*p*		*r*	*p*	
25 FC	0.464	1.285×10^{-2} significant	25 BRS	0.484	9.098×10^{-3} significant	0.008
50 FC	0.449	1.648×10^{-2} significant	50 BRS	0.451	1.599×10^{-2} significant	0.017
75 FC	0.408	3.110×10^{-2} significant	100 BRS	0.384	4.344×10^{-2} ns	0.025
50 BRS	0.382	4.480×10^{-2} significant	75 BRS	0.331	8.486×10^{-2} ns	0.033
25 BRS	0.379	4.691×10^{-2} significant	50 FC	0.290	1.339×10^{-1} ns	0.042
50 BS	0.375	4.925×10^{-2} significant	25 FC	0.280	1.497×10^{-1} ns	0.050
100 FC	0.373	5.067×10^{-2} significant	75 BS	0.270	1.641×10^{-1} ns	0.058
25 BS	0.305	1.142×10^{-1} ns	75 FC	0.263	1.759×10^{-1} ns	0.067
100 BS	0.271	1.638×10^{-1} ns	100 FC	0.254	1.923×10^{-1} ns	0.075
75 BS	0.246	$2.068 \times 10^{-}1$ ns	100 BS	0.228	2.423×10^{-1} ns	0.083
100 BRS	0.245	2.097×10^{-1} ns	25 BS	0.196	3.171×10^{-1} ns	0.092
75 BRS	0.141	4.742×10^{-1} ns	50 BS	0.131	5.077×10^{-1} ns	0.100

BOMBT – backward overhead medicine ball throw test, BS – backstroke, BRS – breaststroke, FC – front crawl.

(Table 5). Because the results of the speed, endurance and abdominal muscle endurance tests had the same independent variable (mean 25-m backstroke velocity), the multiple regression analysis was repeated for mean 25-m backstroke velocity (as a dependent variable) and the results of the 3 tests (as independent variables). It showed that the best predictor of mean 25-m backstroke velocity was the result of the 50-m sprint run test (Table 5).

Discussion

According to a report published by the WHO in 2020 [4], an adequate level of physical activity is an essential element of a healthy lifestyle, but the role of additional physical activity understood as participation in a specific sport and its influence on the level of motor skills is still unclear. Therefore, this study aimed to determine whether peripubertal girls participating in swimming training and their non-training peers (controls) had different levels of motor skills, and whether the swimmers' performance in the motor skills tests and swimming tests involving different strokes and distances were correlated.

The swimmers were found to outperform the control group in speed, abdominal muscle endurance, strength of the back muscles, and flexibility. Their results on the speed, cardiorespiratory fitness, abdominal muscle endurance, and flexibility tests best correlated with 25-m backstroke velocity, back muscle strength with the 25-m front crawl velocity, and flexibility with the 25-m breaststroke velocity. The swimmers' performance on the 50-m sprint test was the most strongly associated with the 25-m backstroke velocity.

According to WHO recommendations [4] on the physical activity of children and adolescents aged 5–17 years, they should engage in 60 min of moderate-to-vigorous physical activity daily (420 min weekly). The control group in our study did not meet the recommendation because the only organized physical activity they participated in was 4 physical education (PE) classes per week at their schools (4 × 45 min = 180 min). The physical activity of the swimmers exceeded the level recommended by the WHO because, in addition to having 4 PE classes, they also had at least 5 swimming training sessions in a week (5 × 90 min = 450 min); as a result, their total weekly physical ac-

Table 5. The results of stepwise multiple regression analysis with backward elimination between dependent variables (the results of motor skills test) and independent variables (velocities in swimming tests)

Dependent variable	r^2	SEE	Independent variable	B ± SE of β	B ± SE of B	*P*-value
50 m sprint [s]	0.539 $p < 0.001$	±0.562	Intercept	–	16.240 ±1.288	< 0.001
			25 BS	–0.734 ±0.133	–5.273 ±0.957	< 0.001
20 mSRT – covered distance [m]	0.434 $p < 0.001$	±0.038	Intercept	–	2.643 ±0.088	< 0.001
			25 BS	0.659 ±0.148	0.291 ±0.065	
30s sit-ups [No. of repetitions]	0.368 $p < 0.001$	±2.808	Intercept	–	–1.594 ±6.431	ns
			25 BS	0.607 ±0.156	18.606 ±4.779	< 0.001
BOMBT [m]	0.215 $p < 0.05$	±0.052	Intercept	–	0.558 ±0.053	< 0.001
			25 FC	0.464 ±0.174	0.663 ±0.248	< 0.05
Sit and reach [cm]	0.234 $p < 0.01$	±6.474	Intercept	–	–18.180 ±16.107	ns
			25 BRS	0.484 ±0.172	35.278 ±12.516	< 0.01
25 BS	0.539 $p < 0.001$	±0.078	Intercept	–	2.278 ±0.171	< 0.001
			50 m dash	–0.734 ±0.133	–0.102 ±0.019	< 0.001

20mSRT – 20-metre shuttle run test, BOMBT – backward overhead medicine ball throw test, BS – backstroke, BRS – breaststroke, FC – front crawl.

tivity almost tripled that of the control group (180 min + 450 min = 630 min). The presumption that differences in the length of physical activity should be reflected in participants' performance on the motor skills tests was confirmed by the swimmers' greater speed and abdominal muscle endurance, stronger back muscles, and greater flexibility compared with the control group. Only cardiorespiratory fitness was comparable between the groups.

A review of studies conducted so far has shown that the influence of swimming training on the development of speed, strength, and flexibility and its health-benefiting effects in children and adolescents has been rarely investigated and that researchers tend to concentrate on factors that may help young swimmers become better competitive athletes. Consequently, this study's findings can only be supported by indirect evidence.

The significance of correlations between the results of the motor skills tests pointing to associations between participants' speed, cardiorespiratory fitness, abdominal muscle endurance, back muscle strength, and flexibility was consistent with the findings reported by other authors [24–26], confirming that the tests were correctly conducted. High correlations between swimmers' times recorded for different strokes and distances testify to the reliability of the swimming tests.

The success of competitive swimmers is determined by their somatic, biomechanical, and physiological characteristics [8]. Among the latter, energy production and neuromuscular properties are considered particularly important.

There is research evidence that muscle strength and power (the ability to develop strength in the water) are critical to swimming velocity, particularly over short distances [13]. It has been demonstrated that muscle strength increased by dryland strength training can improve sprint swimming performance [27], and that completing a maximum number of repetitions of a power exercise during explosive training over a specified time unit improves 50-m front crawl velocity [13]. Polat *et al.* [28] observed statistically significant improvement in the number of sit-ups completed by 12-year-old girls in 30 s after 6 months of swimming training. This implies that the swimmers in our study were stronger and faster than the controls because of regular swimming training.

Increased flexibility is thought to be necessary for a swimmer to make the best use of a swimming technique [29]. However, the results of studies are inconclusive. Jansson *et al.* [30] concluded that 12-year-old swimmers were not statistically significantly different in terms of flexibility, which they measured with the Beighton scale, from their untrained peers. Radlińska and Berwecki [31] reported that the competitive adult swimmers (males and females) in their study had greater mobility of the shoulder, knee, and ankle joints compared with the controls. Geladas *et al.* [32] observed a statistically significant negative association between shoulder joint flexibility and 100-m front crawl times in 12–13-year-old girls. Polat *et al.* [28] reported that 24 weeks of swimming training improved 12-year-old girls' flexibility as measured with the sit and reach test, and Yu *et al.* [33] observed that 12 weeks of periodic training significantly improved trunk flexion forward in 16-year-old swimmers. This implies that the swimmers in our study had more flexible back muscles compared with the control group, probably due to swimming training. Greater flexibility of the swimmers' back muscles was confirmed by their results in the BOMB test. It is known that muscle flexibility is related to the maximal muscle strength exertion angle: the strength of a more flexible muscle increases as it elongates and decreases when it contracts [24].

The swimmers and the control group in our study were comparable in cardiorespiratory fitness (the distances they completed during the 20-mSRT and their VO_2max values were similar). This finding was surprising because the swimmers' training program was designed based on the Long-Term Athlete Development approach, the focus of which is on developing athletes' aerobic capacity. The results of studies investigating whether engaging in additional physical activity can improve cardiorespiratory fitness are inconclusive. According to the studies reviewed by Baquet *et al.* [34], endurance training improves aerobic capacity in children and adolescents by just 5–6%, or 8–10% when only studies finding its effect to be significant are considered. In our earlier research on the influence of a 3-year swimming training program on prepubertal boys, a 2-factor ANOVA of the 20-mSRT results (factor I: controls-swimmers; factor II: time) showed that the main group effect was statistically significant, but measurements taken at successive time points did not reveal statistically significant differences between the 2 groups [35]. It is likely that a similar situation also occurred in this study (the swimmers performed statistically insignificantly better on the 20-mSRT), but whether it was really so cannot be confirmed without longitudinal studies. The lack of significant between-group differences in the level of endurance in our study could also be caused by a significant increase in the participants' body mass, mainly fat mass, following the pubertal growth spurt (this explanation is lent credence by the relative similarity of the groups' body mass index), or insufficient loads during swimming training.

The best measure of a swimmer's performance is velocity over a given distance [36]. The backstroke, breaststroke, and front crawl velocities we recorded in our study participants were similar to those reported for similar-age girls by other authors [37–39]. It has been shown that, regardless of the swimming distance, the front crawl is associated with the highest velocity, while the breaststroke is the slowest, probably because frontal water resistance in breaststroke is greater than in other styles [36, 40]. The results of our study are consistent with this finding. It needs to be noted, however, that while short-distance swimming performance mainly depends on muscle strength and the rate of muscle contractions, the ability to swim longer distances with maximum, constant speed is primarily determined by cardiorespiratory fitness (endurance), which makes it a legitimate target for motor training. The knowledge of how fast a swimmer can swim various distances, particularly information about the rate of velocity loss with increasing distance, helps identify which athlete's skills need improvement and whether he or she is predisposed to compete over short or longer distances in the future. In our study, changes in swimming velocity relating to the distance (25, 50, 75, and 100 m) are illustrated by a regression slope, which seems a helpful reference for swimming coaches. It shows that the greatest loss in swimming velocity over longer distances was recorded for the front crawl, and the smallest for the backstroke. The greatest velocity loss in the front crawl is intuitively understandable because it is the fastest of all styles studied. The smallest loss in swimming velocity observed for the backstroke can be explained in terms of the style involving a lower energy cost than the breaststroke [41].

The main source of energy for working muscles during 400-m and longer swimming tests is the aerobic system because research has shown that the swimmers' performance on the 400-m test is best predicted by their VO2max [42]. During swimming tests over shorter distances (< 400 m), the role of anaerobic processes significantly increases. Troup [43] estimated that in adults swimming 200 m front crawl, breaststroke and backstroke, anaerobic processes contributed 35, 37, and 30% of energy, respectively. Capelli *et al.* [41] estimated the proportion of anaerobic energy used by young males during a 50-yard (45.7-m) swim at 84.7% for front crawl and 72.9 and 82.6% for breaststroke and backstroke, respectively. De Mello Vitor and Böhme [44], who studied boys aged 12 –14 years, estimated that around 70% of the energy they used during a 100-m front crawl test came from anaerobic processes, a rate comparable with that reported for adult swimmers (66.8%). Unsurprisingly, the results of the swimming tests in our study best correlated with the results of the 50-m sprint run test, which is widely used to assess speed but also provides a reliable measure of anaerobic capacity [45]. The ability of the 20-mSRT to predict swimmers' performance on the 100-m backstroke test is probably related to the fact that breathing during breaststroke is easier compared with other swimming styles. The linear regression slope values calculated in this study serve as confirmation of the ratio of anaerobic to aerobic energy production, showing the greatest decrease in swimming velocity with increasing distance for front crawl, and the smallest for backstroke.

The multiple linear regression analysis of the results of the motor skills tests (dependent variables) in relation to swimming velocities (independent variables) showed that the mean velocity over 25 m backstroke was best correlated with the results of the 50-m sprint test, cardiorespiratory fitness, and abdominal muscle endurance. The motor skill variable showing the strongest association with velocity over 25 m backstroke was the result of the 50-m sprint test, again. The reason for this relationship is not clear, but a comparison of the velocities we recorded for each style with those reported by Cappelli *et al.* [41] suggests that it may be associated with the significantly smaller demand for aerobic energy in backstroke compared with other swimming styles.

The multiple linear regression analysis also demonstrated that the best predictors of explosive strength and back muscle flexibility were the velocities recorded for the 25-m front crawl and 25-m front breaststroke tests, respectively. An explanation of these 2 relationships seems to lie in the specificity of the patterns of movement required by the 2 swimming styles. A significant correlation between the 25-m front crawl velocity and the results of the BOMBT test is probably associated with the back muscles' work to stabilize the swimmer's position during the front crawl. Repeated strong contractions of the back muscles develop their strength and, consequently, their power, because strength is one of the components of muscular power. The association between the sit and reach test results and the 25-m breaststroke velocity is the most likely to be determined by greater flexibility of the lower back in backstroke swimmers, resulting from high-amplitude movements of the lumbar spine and the hip. A flexible lower back enables a swimmer to elevate higher during the pulling motion and create more coupling energy for both the pull and the following breaststroke kick.

The study has several limitations. Firstly, because of the small sample size, its results need to be interpreted with caution. Secondly, because all the girls participating in the study lived in the same Polish voivodeship, the results may not be valid for their peers living in other Polish regions. Thirdly, although the motor used tests are widely recognized and applied, further research using more precise tools for measuring human motor skills (speed, strength, endurance, and flexibility) is needed to confirm their outcomes.

Conclusions

The findings of the study can be summarized as follows. Girls aged 12–13 years, who participated in additional physical activity (swimming training), were faster than their untrained peers and surpassed them in abdominal muscle endurance, explosive strength of back muscles, and spine flexibility. However, despite swimming training's emphasis on developing athletes' aerobic capacity, both groups were similar in the level of cardiorespiratory fitness.

The 50-m sprint test results were shown to be the best predictor of mean front crawl, breaststroke, and backstroke velocities for swim distances of 100 m or shorter. Mean 25-m backstroke velocity proved to be the strongest predictor for speed, cardiorespiratory fitness, and abdominal muscle endurance; mean 25-m front crawl velocity for the explosive strength of back muscles; and mean 25-m front breaststroke velocity for flexibility.

The results of the study demonstrating that swimming training can stimulate the development of peripubertal girls' motor skills, which can be a helpful guideline for parents considering the best form of additional physical activity for their children. They can also support coaches in selecting children and adolescents for competitive swimming and serve as a reference in planning dryland training programs for young swimmers.

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Conflict of interest

The authors declare no conflict of interest.

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Address for correspondence

Ryszard Jarosław Zarzeczny PhD
Institute of Health Sciences
Jan Kochanowski University
Kielce, Poland
E-mail: ryszard.zarzeczny@ujk.edu.pl