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THE EVALUATION OF CRITICAL SWIMMING SPEED IN 12-YEAR-OLD BOYS

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ABSTRACT
Purpose. It has been suggested that the critical swimming speed (CSS) of young swimmers may be estimated by using two timed maximum exertion efforts at distances of 50 and 400 m. The aim of this study was to find out if the estimated CSS for a group of boy swimmers corresponds to the results obtained from a 12-min swim test and to examine if there was a difference whether these tests were completed using different swimming strokes. **Methods.** The study was carried out on 24 boys (age 12.2 ± 0.1 y, height 158.0 ± 1.8 cm, weight 47.7 ± 2.2 kg), all of whom were competing at the regional level. The participants were timed completing the 50 and 400 m distances at maximal effort, while the 12-min test was assessed by the total distance swum, all three trials performed in the front crawl and breaststroke. **Results.** The results found a close relationship between CSS determined by the 50 and 400 m distances and the distance covered during the 12-min test for both strokes (breaststroke r = 0.79, $p = 0.0000$; front crawl $r = 0.83$, $p = 0.0000$). There were no significant differences between CSS and the mean velocity of the 12-min swim test with swum in the front crawl (0.862 ± 0.027 m · s^{-1} and 0.851 ± 0.027 m · s^{-1}, respectively); however, CSS was significantly higher (p = 0.002) than the mean velocity found in the 12-min test in the breaststroke (0.769 ± 0.018 m · s^{-1} and 0.727 ± 0.022 m · s^{-1}, respectively). **Conclusions.** CSS estimated on the basis of the front crawl but not breaststroke is a good predictor of the average velocity of the 12-min swim test for young male swimmers.

Key words: swimming velocity, CSS, 12-min swim test, boys

Introduction

Swimming is a sport that has been widely accepted in the extracurricular sports programs of schools. However, a successful competitive swimming team requires a proper physical training program that would allow children not only to familiarize themselves with the technical skills needed in swimming but also properly stimulate the development of their cardiorespiratory (aerobic) fitness level.

Maximal oxygen uptake (VO_{2max}) and the anaerobic threshold are considered the most popular indicators used to assess an individual's aerobic capacity [1]. Traditionally, VO_{2max} has been interpreted as a measure of the maximal capacity of the cardiorespiratory system's ability to acquire oxygen and circulate it to working muscle, where muscles can extract and utilize oxygen in mitochondrial respiration in order to meet the energy needs of muscle contraction. The measure of VO_{2max} has, therefore, been invaluable in quantifying endurance fitness and the status of the cardiorespiratory and muscular systems for all individuals [2]. However, it was found that athletes with especially high aerobic capacity levels may show only slight changes in VO_{2max} during training [3]. Therefore, the most common solution in such cases is to measure anaerobic threshold, which is defined as the highest exercise intensity that can be maintained for a prolonged period of time without rapid blood lactate accumulation [3].

However, direct measurement of VO_{2max} and the anaerobic threshold are usually conducted in laboratory settings with the use of expensive equipment and well-trained staff. These limitations have spurred the growth of various predictive field tests that can be used to economically and accurately evaluate individual fitness levels.

In swimming, the 12-min swim test and a measure of critical swimming speed (CSS) are among two of the most popular noninvasive methods used for assessing the aerobic capacity of swimmers. Introduced by Cooper [4] the 12-min swim test classifies VO_{2max} based on the maximum distance that can be swum in 12 minutes. Several authors have confirmed that this test can be used to predict aerobic capacity [4–7]. CSS is estimated by measuring the intensity of exercise that can be theoretically maintained and continued without exhaustion [8]. It is expressed as the slope of a regression line between the covered swimming distance and the corresponding times it took achieve these distances [8, 9].

Although it has been proven that the measure of CSS is a practical and reliable tool for determining training speed and evaluating the endurance capacity of adult swimmers [8–11], its use as a measure in children

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is not yet well established. Denadai et al. [12] found that CSS calculated on the basis of swimming 50, 100, and 200 m underestimates swimming intensity that corresponds to a blood lactate concentration of 4 mM in children aged 10–12 years. However, Greco et al. [13] found that a swimming velocity associated with 4 mM of blood lactate was not different to CSS determined by 25, 50, and 100 m, though it was significantly higher than the CSS determined on the basis of the 100, 200, and 400 m distances. It was also found that the average speed during a 20- and 30-min maximal swim test in children aged 10–12 years was lower than the CSS determined on distances of 25, 50, and 100 m. Finally, Toubekis et al. [14] reported a significant relationship between CSS, determined by the swim times to complete 50, 100, 200, and 400 m and the swimming speed at the lactate threshold in a group of 12-year-old boys. Additionally, these authors suggested that CSS could be determined from only two distances – 50 and 400 m. Taking into account that (1) endurance capacity is better predicted by the anaerobic threshold than by an exercise intensity at a fixed value of 4 mM of blood lactate [3], (2) the anaerobic threshold is well-correlated with the fractional utilization of VO_{2max} [15], (3) and the average velocities in 20- and 30-min maximal swimming tests achieved by children are lower than the swimming speeds that correspond to a blood lactate concentration of 4 mM [13], the aim of this study was to find out if CSS estimated on the basis of two distances (50 and 400 m) corresponds to the results obtained during a standard 12-min swim test in a group of 12-year-old swimmers and, as a second aim, to examine if there were any differences in using the front crawl versus breaststroke.

Material and methods

Twenty-four 12-year-old boys were recruited for the study. All were regional-level swimmers and members of school sport clubs and had been practicing swimming for at least 2 years. Written consent was provided by the boys' parents, and the study was approved by the Bioethics Committee at the Jan Długosz Academy in Częstochowa. The anthropometric characteristics of the subjects are shown in Table 1.

Table 1. Characteristics of the participants (mean ± SE)

Variable	
Age (years)	12.2 ± 0.1
Body mass (kg)	47.7 ± 2.2
Height (cm)	158.0 ± 1.8
HR rest (beats · min^{-1})	80 ± 2
RR sys (mm Hg)	114 ± 2
RR diast (mm Hg)	71 ± 1

HR rest – resting heart rate; RR sys – resting systolic blood pressure; RR diast – resting diastolic blood pressure

The swimmers were subjected to two tests: swimming 50 and 400 m at maximal effort and then completing the 12-min swim test, with all three trials completed in the front crawl and breaststroke. The 50 and 400 m distance had been previously suggested to estimate CSS [14] and was completed by the participants at maximal effort as quickly as possible. The boys started with a push-off and the time taken to swim each distance was recorded using a manual chronometer. CSS was determined using the slope of the linear regression between the swimming distances (50 and 400 m) and the time (t_{50} and t_{400}) taken to swim these distances by the formula: CSS = (400 – 50) / (t_{400} – t_{50}) (as modified by Wakayoshi et al. [8])

For the 12-min swim test the swimmers were asked to swim for 12 minutes using rhythmic breathing and to see what distance they could cover within the allotted time. This swim test had also been previously used for aerobic training prescription [4–7]. The average swimming velocity in the 12-min swim test was calculated by dividing the covered distance by the total time.

All tests were administered in an indoor 25-m swimming pool and were performed at the beginning of the participants' practice session following a 5-min warm-up. The participants swam only one trial per day in random order to eliminate any possible effects of fatigue. Heart rate was measured immediately after completion of each test to test exercise intensity.

The results of the participants' swimming performance as well as post-exercise heart rates were subjected to two-way ANOVA with repeated measures followed by post-hoc analysis with the Newman-Keuls test. The relationship between CSS and the distance covered during the 12-min swim test was assessed by Pearson's product moment correlation coefficient. All calculations were made using Statistica v. 7.1 statistical software (Statsoft, USA). Significance level was set at $\alpha = 0.05$. All data was presented as mean ± standard error (SE).

Results

The calculated CSS determined by swimming the 50 and 400 m distances was significantly higher ($p = 0.0001$) for the front crawl (0.862 ± 0.027 m · s^{-1}) than for the breaststroke (0.769 ± 0.018 m · s^{-1}).

The distance covered in the 12-min test with the front crawl was longer ($p = 0.0001$) than the breaststroke. In addition, the mean velocity during the 12-min front

Table 2. Mean values (± SE) of the covered distance and velocity during the 12-min swim tests

Swimming stroke	Front crawl	Breaststroke
Distance (m)	612.8 ± 19.3	523.5 ± 15.7***
Velocity (m · s^{-1})	0.851 ± 0.027	0.727 ± 0.022***

comparison between front crawl and breaststroke:
*** $\alpha = 0.001$

Table 3. Mean values (± SE) of post-exercise heart rate

Swimming stroke	Front crawl	Breaststroke
50 m (beats · min^{-1})	155 ± 4	155 ± 5
400 m (beats · min^{-1})	179 ± 4***	171 ± 3**
12-min swim test (beats · min^{-1})	171 ± 4**	167 ± 4*

50 m (beats · min^{-1}) – heart rate immediately after 50 m swim test; 400 m (beats · min^{-1}) – heart rate immediately after 400 m swim test; 12-min swim test (beats · min^{-1}) – heart rate immediately after 12-min swim test; comparison in relation to 50 m for a given stroke;
* α = 0.05; ** α = 0.01; *** α = 0.001

crawl swim was faster ($p = 0.0001$) than with the breaststroke (Tab. 2).

The data showed that a close relationship existed between the distance covered during the 12-min swim test and CSS in the front crawl ($r = 0.83$, $p = 0.0000$; Fig. 1) as well as in the breaststroke ($r = 0.79$; $p = 0.0000$; Fig. 2). There was no significant difference between CSS and the mean velocity of the 12-min swim test in the front crawl. However, the CSS based on the breaststroke was significantly higher ($p = 0.002$) than the mean velocity in swimming the 12-min swim test with breaststroke (Fig. 3).

Post-exercise heart rates were significantly lower after completing the 50 m swim in the front crawl and breaststroke in comparison to the 400 m distance ($p = 0.0002$ and $p = 0.0090$, respectively) as well as during the 12-min swim tests in front crawl and breaststroke ($p = 0.0078$ and $p = 0.0280$, respectively). There were no differences in heart rates between the 400 m swims and 12-min swim tests for both strokes (Tab. 3).

Discussion

The aim of this study was to investigate if CSS established on the basis of two 50- and 400-m timed swim tests at maximum exertion corresponds with the results of a 12-min swim test and to examine the differences of using different strokes. Our study found that, in the 12-year-old boys, the attained CSS positively correlated with the distance covered in the 12-min swim test both in the front crawl as well as breaststroke. Moreover, the mean velocity attained in the 12-min swim test was not different to CSS when both were swum in the front crawl; however, this was not the case with the breaststroke.

The direct measurement of VO_{2max} and anaerobic threshold are considered the most accurate methods of assessing an individual's aerobic capacity. An improvement in these indices may predict that an athlete can exercise for a longer period of time at a given absolute exercise intensity or can exercise at a higher exercise intensity for a given duration [16]. In swimming, the direct measurement of VO_{2max} has been widely accepted as significant correlations were obtained between VO_{2max}

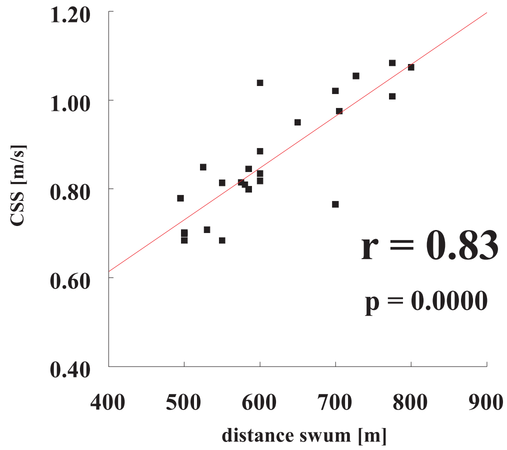

Figure 1. Relationship between distance covered during the 12-min swim test in front crawl and critical swimming speed (CSS) estimated from two timed front crawl maximum efforts at 50 and 400 m

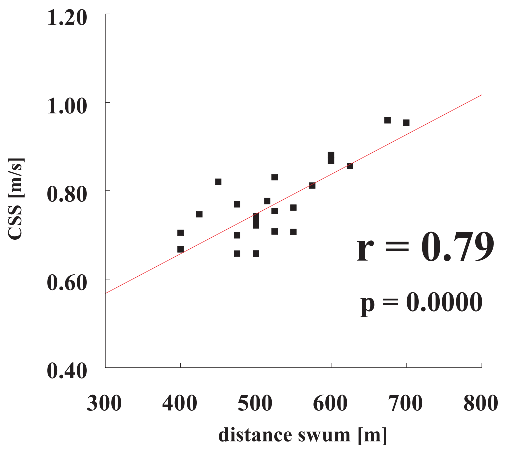

Figure 2. Relationship between distance covered during the 12-min swim test in breaststroke and critical swimming speed (CSS) estimated from two timed breaststroke maximum efforts at 50 and 400 m

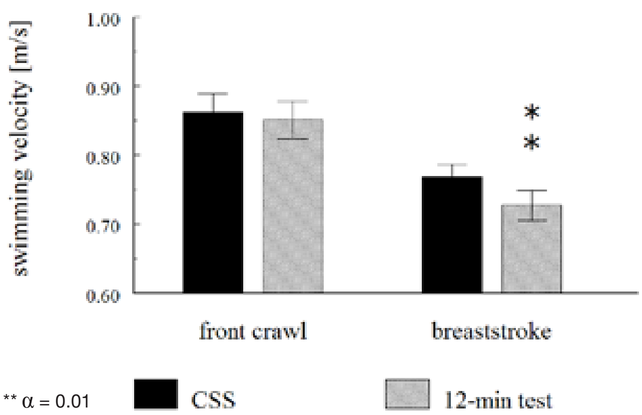

Figure 3. Comparison between critical swimming speed (CSS) estimated from two timed maximum efforts at 50 and 400 m and the mean velocity during the 12-min swim test for front crawl and breaststroke

and swimming performance [17–19]. However, it should be pointed out that although similar values of VO_{2max} were reported in swimmers during cycle ergometer exercise, treadmill running, or swimming [20], the best way of measuring swimmers' VO_{2max} values ought to be in conditions that best reproduce how the sport is naturally practiced [18, 21]. Therefore, several techniques have been developed in an attempt to directly measure VO_{2max} during swimming (free, tethered or flume swimming) [22] but, as mentioned earlier, direct measurements of endurance fitness levels involve considerable time, expense, and technical expertise and is impractical for testing large sample populations. To overcome these difficulties, attempts have been made to develop simple, indirect tests and indices that can predict swimming aerobic power and performance. Lavoie et al. [23] described a multistage swim test for competitive swimmers that correlated well ($r = 0.88$) with oxygen consumption up to maximal levels. However, its usefulness is limited to subjects with more variable swimming ability. Other examples of the methods used in the indirect estimation of VO_{2max} had been mentioned previously and include the 12-min swim test [4–7], critical swimming speed (CSS) [8, 9], or the average speed attained during a 20- or 30-min maximal test [10, 13, 24].

In our study, CSS was validated by the 12-min swim test, which classifies VO_{2max} based on 12 min of uninterrupted swimming performance. This classification was modified from the running data and not based on the relation of the 12-min swim's VO_{2max} [7]. Jackson et al. [6] found a correlation of 0.898 between the distance covered during a 12-min front crawl swim and the endurance and peak aerobic power results obtained from the time of completing a tethered, multi-stage swimming test until exhaustion. Huse et al. [25] reported that the 12-min swim distance had a moderate ($r = 0.47$) correlation with a maximal graded treadmill test in high-school male swimmers aged 13 to 17. On the other hand, Conley et al. [26, 27], using treadmill running and tethered swimming tests until exhaustion, noted relatively low correlations between oxygen consumption and 12-min swim test results in young men ($r = 0.38$ and $r = 0.40$, respectively) [14] as well as in young women ($r = 0.34$ and $r = 0.42$, respectively) [15]. It is difficult to explain such a discrepancy. Jackson and Coleman [28] pointed out that tests valid and reliable in one population may or may not be valid and reliable in other populations. Moreover, the well-established study by Magel et al. [29] clearly showed that training at mode-specific intensities can yield improvements in swimming VO_{2max} but not treadmill VO_{2max}. However, the most probable explanation may lay in swimming ability. It should be stressed that the 12-min swim test is highly skill-dependent [5, 7]; hence, a skilled swimmer with average cardiorespiratory fitness will be able to swim farther than a less experienced swimmer with higher cardiorespiratory fitness. Costill et al. [17] showed that recreational swimmers swim significantly slower than competitive swimmers in a 400-yard freestyle relay despite featuring almost identical oxygen consumptions, due in part to large difference in swimming efficiency. In fact, in Conley's study, all of the recruited subjects (young men and women aged 22 years) were recreational swimmers, in Jackson's study, trained college swimmers.

One can speculate that the validity of the 12-min swim test was verified largely in part by using only adult participants and had not been extensively explored in children. To our knowledge, there are no norms or studies that have validated this test for young children by a direct measurement of VO_{2max}. The only data on the subject were provided by Cooper [4], although the lowest age category that was used was 13–19 years old. This may be due to the low swimming ability of young children, as swimming is not as a natural motor act as walking or running; it is a skill a human has to learn. Lack of swimming experience and motivation are common problems when working in concert with young children, hence, these may be additional reasons that this test is less preferred by researchers and coaches. In our study, we selected subjects who practiced swimming in school sport clubs for at least two years and regularly competed in regional-level events. Although the subjects in the present study are not top-class swimmers, their CSS results in the front crawl ($0.86 \, m \cdot s^{-1}$) are comparable with those found by Greco et al. [13] in children aged 10–12 years ($0.89–0.92 \, m \cdot s^{-1}$). Moreover, even if a comparison is made with older boys (according to the above-mentioned values), the results obtained by our investigated subjects could still be considered 'fair' [4].

According to its definition, CSS is the exercise intensity that can be theoretically maintained and continued without exhaustion [8]. Anaerobic threshold holds a similar definition, and several studies have reported a close relationship between these two physiological variables [8–10, 12–14]. Post 12-min swim-test heart rates indicated that the values are close to what is usually found at the anaerobic threshold for children during ergocycle and treadmill exercises (c.a. 70% of predicted maximal heart rate) [30]. This finding may be a little bit perplexing especially when we take into consideration that this was the result of 12-min maximal swimming. However, the post-exercise heart rates obtained in our study should be interpreted with caution since heart rate values vary between those on land and in water even during exercise performed at a comparable intensity. It has been shown that maximal heart rate is lower by approximately 10–17 beats $\cdot$ min^{-1} during swimming compared with running or cycling [31, 32]. This may suggest that the post 12-min swim test heart rates obtained in the present study are slightly higher than one could expect for swimming at an intensity close to the anaerobic threshold. In fact, Dekerle et al. [33] reported that

CSS determined by four tests to exhaustion (95, 100, 105, and 110% of maximal aerobic speed) does not represent the maximal speed that can be maintained without a continuous rise of blood lactate concentration. Taking this finding into consideration, it is likely that during the 12-min swim test the heart rate gradually increased.

The effect of different environmental conditions may also account for the rather low maximal heart rates obtained during the 50-m swim by the participants. As had been mentioned above, heart rates during swimming are lower than for similar dry-land exercise [31, 32]. It has been suggested that a swimmer's horizontal position together with the influence of water pressure on the body as well as the 'dive reflex' can prevent the heart rate from increasing to such levels as in vertical, dry-land exercise even of the same intensity [31, 32, 34]. Considering that the time to complete the 50-m distance was relatively short in our study (40–50 s depending on the swimming style) and that the minimum distance usually used in other studies for determining VO_{2max} (and therefore assessing maximal heart rate) is 200 m [34–36], it is possible that the heart rate in the present study could not reach the maximal, age-predicted value.

It is difficult to explain the difference that was found between CSS and the mean velocity of 12-min breaststroke swimming. This may be caused by different levels of skill and ability, since the breaststroke is more technically demanding than the front crawl, and/or because of a difference in energy expenditure. Greco et al. [13] suggested that the lack of experience young swimmers have with long-distance tests may influence the relationship between CSS and the average velocity obtained in tests over longer distances. Another explanation for this disparity may be a shorter stroke length. Tsalis et al. [37], studying female swimmers during an interval training set (5 × 400 m), found that the stroke length of the fifth repetition was significantly shorter than the second repetition by young (13-year-old) swimmers and more so when compared with the first repetition by adult (19-year-old) swimmers. These authors suggested that this phenomenon may indicate the onset of early fatigue in young as well as adult swimmers. In addition, in a study by Thompson et al. [38], it has been found that adult male swimmers during 200-m breaststroke time trials significantly increased their stroke count as the trials progressed. Taking into account that energy expenditure is much higher in the breaststroke than the front crawl (0.79 and 1.29 kJ · m^{-1}, respectively) [22], it is possible that fatigue occurred earlier when swimming the breaststroke in the 12-min swim test.

Conclusions

1. Critical swimming speed determined from 50 and 400 m swims with the front crawl is a good predictor of the average velocity determined during the 12-min front crawl swim test based on a group of 12-year-old regional-level male swimmers.

2. Critical swimming speed attained during breaststroke in the 50 and 400 m distances may overestimate the average velocity of the 12-min breaststroke swim test.

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