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Research article

Shaping Physiological Indices, Swimming Technique, and Their Influence on 200m Breaststroke Race in Young Swimmers

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Abstract

The aim of this study was to investigate somatic properties and physiological capacity, and analyze kinematic parameters in the 200 m breaststroke swimming race. Twenty-seven male swimmers participated in the study. They were 15.7±1.98 years old. Their average height was 1.80 ± 0.02 m and lean body mass (LBM) was 62.45 ± 8.29 kg. Physiological exercise capacity was measured in two separate 90 sec. all-out tests, one for the arms and second for legs. During the tests total work of arm cranking (TWAR) and cycling (TWLG) as well as peak of VO_2 for arm ($VO_{2peak}AR$) and leg ($VO_{2peak}LG$) were measured. The underwater swimmers body movements were recorded during the all-out swimming 200m breaststroke speed test using an underwater camera installed on a portable trolley. The swimming kinematic parameters and propulsive or non-propulsive movement phases of the arms and legs as well as average speed (V200), surface speed (V200surface) and swimming speed in turn zones (V200turns) were extracted. V200surface was significantly related to the percentage of leg propulsion and was shown to have large effect on $VO_{2peak}LG$ in the Cohen analysis. V200turns depended significantly on the indicators of physiological performance and body structure: TWAR, VO_{2peak} LG and LBM, LBM, which in turn strongly determined the measured results of TWAR, TWLG, $VO_{2peak}AR$ and $VO_{2peak}LG$. The V200turns and V200surface were strongly associated with V200, 0.92, $p < 0.001$ and 0.91, $p < 0.001$ respectively. In each lap of the 200m swimming there was an increased percentage of propulsion of limb movement observed simultaneously with a reduction in the gliding phase in the breaststroke cycles.

Key words: Breaststroke swimming, physiological indices, lean body mass, kinematic indices.

Introduction

There are many factors determining high physical endurance in young swimmers. The influences of somatic indices are among them. Indices of physical fitness on swimming speed have been under examination for many years as these parameters, which with swimming technique, directly determine the ability of high performance swimming (de Mello Vitor and Silveira Böhme 2010; Geladas et al., 2005; Lätt et al., 2010; Morouco et al., 2011; Reis et al., 2010; Strzala and Tyka 2009).

Swimming technique, especially the breaststroke, requires a talented swimmer with years of training. In improving swimming results it is very useful to use the information from the movement technique analysis of the individual swimmer and the high level peer group and compare an individual with the results of the whole group. Breaststroke swimming and its relationship with the physical performance of the swimmers seems obvious, in the breaststroke, as in no other competitive swimming technique, effort is devoted not only to the production of propulsion, but also in overcoming the resistance of water in the recovery phases of upper and lower limbs. After recovery, the glide and relaxation time occurs within each cycle, but its duration from a bio-mechanical and swimming efficiency point of view is disadvantageous due to increasing inter-cyclic velocity variation (Leblanc et al., 2005). These cyclic circumstances related to glide in sprint breaststroke swimming are different, the propulsive and recovery phases occur almost continuously without gliding, but it is paid for by a faster growth of fatigue (Komar et al., 2014; Strzala et al., 2013).

Adjustment of movement technique to produce a large amount of power and to minimize the resistance is always at the centre of a swimmers interest (Leblanc et al., 2007; Seifert et al., 2010). Analysis of swimming technique strategies that adapt to rising fatigue during the race and its separate parts is of interest to and useful for coaches (Arrelano et al., 1994; Chatard et al., 2001; Strzala et al., 2005; Thompson et al., 2000).

Considering the above mentioned remarks, observations regarding the influence of a swimmers body structure, as well as their ability to perform aerobic (Lätt et al., 2010) and anaerobic work (Reis et al., 2010), on breaststroke swimming speed and on the shaping of swimming parameters at the distance of 200 meters (Thompson et al., 2000) are what is aimed to be obtained. In this race, high level components of aerobic and anaerobic sources are necessary in order to cope with the breaststroke. This technique is loaded with higher water resistance like in no other race swimming. This is due to a less economic underwater recovery of arms and legs, which crates drag (Chollet et al., 2004; Kolmogorov and Duplishecheva, 1992). Higher resistive recovery forces during recovery in conjunction with cyclical changes of trunk angle attack on incoming mass of water (Conceicao, 2013), increases neuromuscular fatigue (Conceicao, 2014).

The aims of this study were: (a) to examine the influence of selected indicators of somatic properties and physiological capacity on the swimming speed in the 200-

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meter breaststroke race, (b) analyze kinematic parameters of breaststroke swimming as well as assessing their impact on the speed in the 200-meter breaststroke race and (c) test the level of contribution of clear surface breaststroke and turning zones swimming in the 200-meter breaststroke race.

We may hypothesize that in our research group physiological capacity indices play a greater role than the selected breaststroke kinematic parameters which are usually related to the efficiency and economy of propulsion movements. We expect that in short course racing the swimming in turning zones may have a similar or stronger influence on the 200-meter results than in pure surface breaststroke.

Methods

Participants

The 27 male swimmers were recruited from two sports schools and the university swimming club and were 15.7 ± 1.98 years old. Their average height 1.80 ± 0.02 cm, body fat percentage (10.8 ± 2.48 %), body mass (70.03 ± 9.35 kg), and FINA score for the 200m breaststroke race was (399.3 ± 74.14 points). Their lean body mass (LBM) was calculated according Slaughter et al. (1988) after measurement of skin-fold thickness using Harpenden Skinfold Caliper (Sieber Hegner Maschinen AG, Switzerland) with constant pressure ($10 g\cdot mm^{-2}$) and body mass control (Sartorius, Germany). An informed consent form (approved by the Bioethics Commission in Cracow) was signed by either the participant or his parents. The swimmers specialized in the breaststroke as well as in individual medleys competed either at the regional or national level. All of them trained twice a day six times a week.

Laboratory and swimming tests

Physiological exercise capacity was measured in two separate 90 sec. all-out tests for the arms and legs. Both tests (arms test and separately legs test) were performed at least 3 days apart within one week. The arms test (90sAR) was performed in the sitting position, with the use of the 834E-Ergomedic ergometer, Monark (Sweden), the legs test was conducted (90sLG) on the 874E-Ergomedic cycle-ergometer, Monark (Sweden). The ergometer braking force was set individually for each subject at 7.0% of body mass in 90sLG and at 4.0% in 90sAR (Gastin and Lawson 1994; Strzala and Tyka 2009). Both the 90sAR and 90sLG tests were preceded by a 15-minute-long warm-up at an intensity of 50% VO_2max. Each athlete was instructed to receive the highest level of total work in arm cranking (TWAR) and cycling (TWLG) from the beginning to the end of the test, during which arm cranking and leg pedaling rate were freely chosen. During both 90 sec. all-out tests, gas exchange indices were calculated from breath-by-breath analysis, averaging in period of 15 seconds, using the 919ER MEDIKRO meter (Finland).

The all-out swimming 200m breaststroke speed test was carried out in a 25 meter swimming pool, applying FINA rules. The test was preceded by self-selected warm-up, similar to the one performed before a competition, comprising at least 1000-m using the breaststroke or other swimming techniques.

Underwater recordings

The underwater analysis of the swimmers' body movements as previously described by Strzala et al. (2013) were recorded using a Canon Legria HV40 (Japan) camcorder and an underwater camera, Sony Color Submergible Camera IP:68 (Japan). The camcorder was receiving a picture signal from an underwater camera. Video pictures were recorded at a sampling rate of 50Hz. The camcorder and underwater camera were installed on a portable trolley, which moved along the swimming pool border and parallel to the swimmer, providing a side-shot. The trolley operator maintained the lens of the underwater camera between two perpendicular lines of the swimmer's fingertips of the straightened arms in the front and toes of the stretched legs in the back. The underwater camera was mounted to the lower arm of the trolley and submerged in water about 1 meter below the surface and approximately 5 meters from the swimmer's lane.

Video analysis of breaststroke swimming

The analysis of the video recording involved selecting propulsion and non-propulsion phases of each pair of limbs from the breaststroke cycle: *Arm total propulsion phase* (AP) was determined to be from the beginning of the arm movement toward the outside with the hands twisted out in pronation (First Arm Propulsion phase Begining -FAPB), through the catch and backward arm pull, with the hands then moving inwards until the beginning of the forward hand movement (First Arm Propulsion phase End - FAPE), ($t_{AP} = t_{FAPE} - t_{FAPB}$). *Arm total recovery phase* (AR) was determined to be from the end of the first AP phase (FAPE) until the beginning of the second AP (SAPB), ($t_{AR} = t_{SAPB} - t_{FAPE}$), (Strzala et al., 2013).

Leg total propulsion phase (LP) was determined after bending the legs at the hip and knees, the phase begins with the ankles moving backwards (First Leg Propulsion phase Begining -FLPB), ($t_{LP} = t_{FLPE} - t_{FLPB}$) through the knee straightens till the closure of feet approximation (First Leg Propulsion phase End - FLPE). *Leg total recovery phase* (LR) was determined from the end of the first LP phase (FLPE) till the beginning of second LP (SLPB), ($t_{LR} = t_{SLPB} - t_{FLPE}$).

The collected data was selected on the percentage of the execution time of the respective phases in the breaststroke cycle were used to calculate two indexes: *Glide or Overlap* (Chollet et al., 2000; Strzala et al., 2013) - the inter-cyclic glide or overlap of the propulsive movement of the upper limbs on the propulsive movement of the lower limbs of the previous cycle, as a certain percentage of the movement cycle of the upper and lower limbs. If the propulsive phases overlapped then the inter-cyclic index was positive, when the glide phase occurred then the index was a negative value. *TTG* (Seifert and Chollet 2005) - total time gap is the sum of the different time gaps between the propulsive movement of the arm and leg, which include the above mentioned glide and intra-cyclic gap between the propulsive phases produced by the upper and lower limbs.

Table 1. **Lean body mass (LBM), physiological indices achieved in 90-s all-out work capacity tests: total work (TWAR) and peak level of oxygen uptake $VO_{2peak}AR$ of arm cranking and total work (TWLG) and peak level of oxygen uptake $VO_{2peak}LG$ of cycling, and their partial correlations (when controlled for age) with speed (averages): V_{200}, V_{200}surface and V_{200}turns.**

indices	LBM (kg) 62.5 (8.3)	TWAR (kJ) 19.3 (4.6)	VO_2peakAR ($l{\cdot}min^{-1}$) 3.23 (.44)	TWLG (kJ) 35.9 (5.8)	VO_2peakLG ($l{\cdot}min^{-1}$) 3.88 (.50)
LBM (kg)	-	.79 **	.51 **	.86 **	.60 **
V_{200} ($m{\cdot}s^{-1}$)	.32	.36	.25	.22	41 *
V_{200}surface ($m{\cdot}s^{-1}$)	.17	.24	.29	.08	.37
V_{200}turns ($m{\cdot}s^{-1}$)	.38 *	.39 *	.19	.32	.41 *

* $p < 0.05$, ** $p < 0.01$

The above mentioned analysis during the all-out swimming test was conducted in 10 m splits in surface swimming, in every second lap of the 200 meters distance – in the sections between the 35th to 45th meter, then between the 85th to 95th meter, the 135th to 145th meter and finally between the 185th to 195th meter. The duration of the race Δt_i and the times of the separate sectors were measured with a stopwatch with the accuracy of 0.01 s. Surface swimming time in 10 m sectors measured in each pool was used to calculate average swimming speed (V_{200}), surface swimming speed (V_{200}surface) and average swimming speed in turn zones (V_{200}turns), which consisted of 5 approaching phases to the wall, a turn and 10 moving away phases from the wall (Haljand, 2014). The following parameters were used to assess the swimming technique during each analysed 10m-long swim (i = 2, 4, 6, 8):

1) Swimming speed: $V_i = 10m / \Delta t_i$, [$m{\cdot}s^{-1}$];

2) Stroke rate (SR_i): calculated as the reciprocal of the arithmetical average of the duration of three analysed swimming cycles: $SR_i = 1/T_i$, [$cycle{\cdot}min^{-1}$];

3) Stroke length (SL_i), calculated as the average speed to SR_i ratio: $SL_i = V_i/SR_i$ [m].

Results of the swimming kinematic parameters SR and SL as well as the coordination indices described above were calculated based on three full movement cycles, which were identified following the 10 meter sector of every second 25 meter pool, as mentioned above.

Statistical analysis

The normality, homoscedasticity and independency of data assumptions were examined respectively with Kolmogorov-Smirnov, the Levene and Durbin-Watson tests. Descriptive statistics of means and standard deviations were calculated for all variables. One-way Anova was used then planned comparisons or Tukey post-hoc tests were used to describe the shape of swimming technique variables in the following segments of swimming on the 200m breaststroke.

The partial correlations, controlled for age, were conducted between the swimming speeds: V_{200}, V_{200}surface, V_{200}turns and the respective somatic and physiological indices. The same analyses were conducted between V_{200}surface and propulsion and non-propulsion phases, coordination indexes (TTG, Glide or Overlap) and basic stroke kinematics (SR, SL). All tests were conducted with STATISTICA ver.10 software (StatSoft, Inc). The significance level was set at $p < 0.05$. Using data from the analysis of partial correlations between TWAR and V200 as well asVO_2peak LG and V_{200}surface, when controlled for age, it was possible to additionally calculate Cohen effect-size (f^2).

Results

Swimming speed in the 200m (V_{200}) race was 1.22 ± 00.8 ($m{\cdot}s^{-1}$), surface swimming speed (V_{200}surface) in sectors between 10th to 20th meters of each successive pool of 200 m reached 1.09 ± 00.8 ($m{\cdot}s^{-1}$), while the breaststroke turn zone speed (V_{200}turns) result was the highest 1.27 ± 0.07 ($m{\cdot}s^{-1}$) powered by push of the each turning wall with stroke, during which the swimmer may be submerged. The physiological index levels achieved in the 90 sec. all-out anaerobic work capacity tests influenced the swimming speed. In testing, the relationship between indicators TWAR and V_{200} as well as between $VO_{2peak}LG$ and V_{200}surface (Table 1), the partial correlations (when controlled for age) were supplemented with Cohen (f^2) calculations. In both cases, the resulting effect-size indexes were large, the first value being $f^2 = 0.75$ and $f^2 = 0.56$ in the second case. It was then noted that V_{200}turns was significantly dependent on TWAR and $VO_{2peak}LG$. LBM index influenced significantly V_{200}turns (0.38, $p < 0.05$) and strongly interplayed with all physiological variables (Table 1).

Variants of surface pool swimming showed variations of surface pool swimming ($F = 4.24$, df = 7.208, $p < 0.001$), the results of Tukey's post-hoc test showed that the 1st lap was statistically different ($p < 0.001$), (Figure 1, left). Speed in successive turns was varied; however the statistical differences were between the first and the third, fourth, fifth, sixth and seventh turn (Tukey test $p < 0.001$). In spite of this a cubic trend was established for the curve ($F = 7.54$, df = 6.182, $p < 0.001$) (Figure 1, right). The V_{200}turns and V_{200}surface were strongly associated with V_{200}, 0.92, $p < 0.001$ and 0.91, $p < 0.001$ respectively.

Basic stroke kinematics SR and SL complement each other in successive measurements. SR decreased on the second 50m than increased on the third and fourth 50m, conversely shaped the SL indices, however, their diversity was not statistically significant (Figure 2).

The TTG index of the breaststroke cycle non-significantly decreased, while the percentage of arm propulsion in the cycle (AP) increased, but non-significantly. The less dispersed variable of LP increased with statistical significance in a linear trend ($F = 29.82$, df = 1.104, $p < 0.001$) (Figure 3). A scatter chart shows the Glide or Overlap coordination movement index in which individual cases were the most dispersed, the value of the index was similar in the first part of the 200m, then increased,

Table 2. **Averages (±SD) of propulsion (AP, LP) and recovery (AR, LR) phases of the arm and leg, coordination indexes: Glide or Overlap, TTG and basic kinematics SR, SL of breaststroke swimming cycle and their partial correlations with surface swimming speed – V_{200}surface ($m \cdot s^{-1}$) when controlled for age.**

AP (%)	AR (%)	LP (%)	LR (%)	Glide or Overlap (%)	TTG (%)	SR ($cycle \cdot min^{-1}$)	SL (m)
32.2 (6.1)	67.8 (6.1)	24.1 (5.2)	75.9 (5.2)	-14.1 (10.3)	43.8 (8.6)	32.2 (3.54)	1.99 (.24)
.14	,.14	.39 *	-.39 *	.28	-.33	.24	.34

* $p < 0.05$

but without significance (Figure 4).

There was a statistically significant effect between the indicators of swimming techniques listed in Table 2, it is between V 200surface and LP, LR indices.

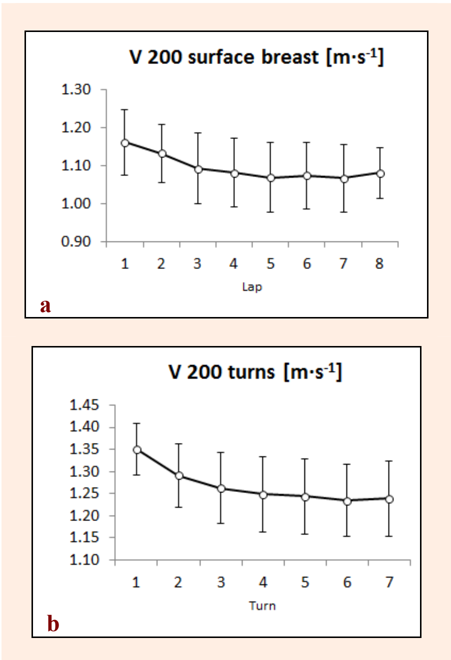

Figure 1. **Surface breaststroke swimming speed (V200) under the 200m (a), swimming speed in each turn (V200turn) zone (b).**

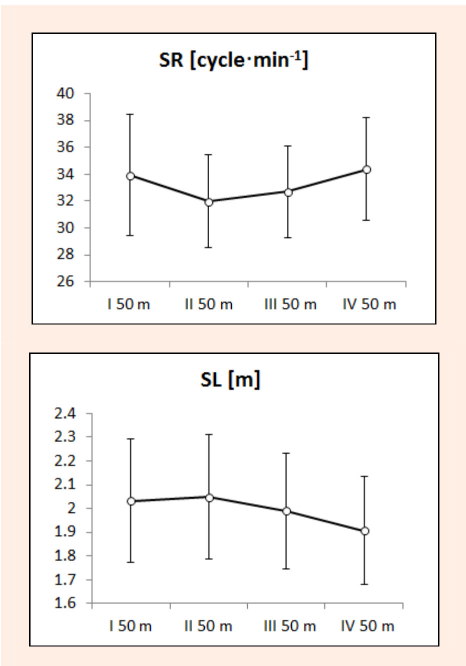

Figure 2. **Basic stroke kinematics stroke rate (SR) and stroke length (SL) under the 200m breaststroke.**

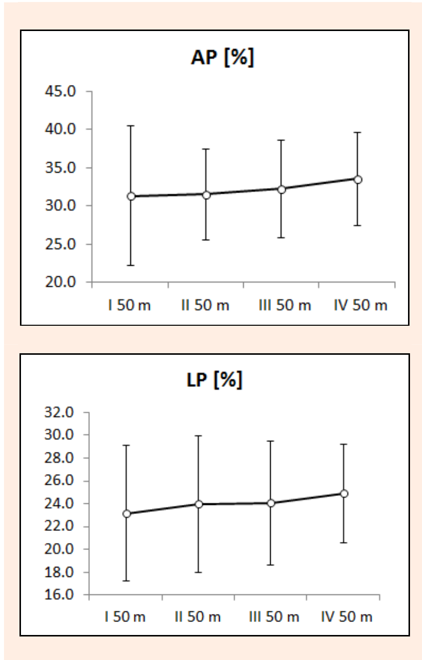

Figure 3. **Arm total propulsion phase -AP and leg total propulsion phase -LP measured under 200m.**

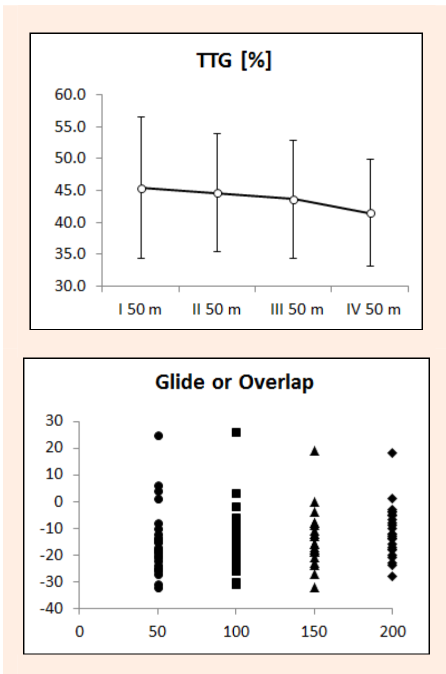

Figure 4. **Stroke indexes TTG and Glide or Overlap measured under 200m.**

Discussion

The main aim of this study was to examine the selected indicators of somatic properties and physiological capacity, and analyze kinematic parameters of breaststroke swimming as well as assessing their impact on the breaststroke swimming speed.

In our observations the V_{200} was moderately dependent on VO_2peakLG, moreover, separate V_{200}turns depended on VO_2peakLG and on LBM and TWAR. The body's functional capacity has an important impact on achieving good breaststroke swimming results in the young swimmer. Reis et al. (2010) researched the combination of aerobic fraction on energy release, peak blood lactate post-exercise and VO_2 elicited at the swimming velocity corresponding to 2 $mmol \cdot L^{-1}$ explained optimum season event performance for the 200 m breaststroke. Peak level of VO_2 obtained in the all-out tests lasting for approximately one minute can be a good predictor of a swimmer's physical endurance during their efforts (Brickley et al., 2006) even at a distance of 100 meters, as produced by mechanical work achieved using aerobic power (besides anaerobic capacity), which has a significant contribution of up to 54% in an effort lasting 90 seconds (Serresse et al., 1988). According to Withers et al., (1991) the rate of aerobic metabolism in maximal efforts lasting 30-s, 60-s and 90-s increases from 28% through 49% to 64%. The level of VO_2 in the last 30 seconds of maximal effort lasting 90 seconds may exceed 90% of VO_2max (Carey and Richardson, 2003), a level of even 98,7% was observed in the research of Withers et al. (1991). Lätt et al. (2010) reported similar results to ours, with a 3.51 $l \cdot min^{-1}$ VO_2 measured during maximal front crawl swimming at a distance of 100 meters, with a similar level of statistical association (partial correlation) to swimming results, although peak VO_2 has been found with higher correlations with 100-m speed (r = 0.787) in adult swimmers (Rodriguez et al., 2003). In studies of Lätt et al., (2010) a slightly higher level of dependence of swimming efficiency with LBM was reported, this index in our observation strongly determined the level of both TWAR and TWLG as well as VO_{2peak}AR, on the other hand VO_{2peak}LG, LBM and TWAR influenced V_{200}turns with statistical significance.

In this research V_{200}turns was strongly correlated with V_{200}, which is caused by the fact that swimming in the turn zones is one of the most important components at the distance of 200 meters, particularly in the short course. In short courses it can occur that up to 40% of the total event time is spent turning (Thayer and Hay, 1984), currently it is similar, although the swimming speed during turns has increased due to improvements in swimming technique and accordance with the rules of the execution of additional dolphin kick. The dependence noted by us was very strong, and swimming in the turn zones played a more important role than mentioned before, particularly within the (5m + 10 m) 5m distance of approaching the wall and 10m departure phase from the wall (Haljand, 2014). In other research Blanksby et al. (1998) noted that swimmers crossed the distance (5m + 5m), which gives 20% of the distance of 50 meters in 18.26 % of the mean 50 m breaststroke time. From the stepwise regression equation results they could state that it was advantageous for "…a taller swimmer who pivoted rapidly on the wall, generated a high peak horizontal velocity, and traveled an optimal distance underwater before surfacing at a relatively fast velocity" when attempting to achieve the best turn zone performance. Keskinen et al. (2007) points out that increased velocity after each turn in the front crawl has a period of relative inactivity during which the swimmer has time for recuperation. We have identified other findings which have shown that in breaststroke swimming this effect is even greater (Craig, 1986). Whereas in the, approximately, 10 m underwater displacement this relative inactivity during one arm stroke, single dolphin kick and the first arm stroke followed by a breaststroke kick is higher. In the research of Thompson et al. (2000) conducted on international top level elite breaststroke swimmers, there were moderate interrelationships reported between turning time (7.5 m+ 7.5 m) and 200 m time (-0.54, $p < 0.01$), however it was in a long course with three turns, where the velocity decreased in each turn but there was statistically insignificant difference between the second and third turns. In our observations a statistically significant cubic trend was noted for the curve representing the turn zones speed, and movement efficiency during turns depended on the swimmers' physical efficiency TWAR, VO_2peak and LBM.

Another important result of this study was the ability to swim fast on the surface was positively and significantly associated with the percentage time of propulsion generation -LP in the breaststroke cycle, which is interesting; the non-propulsive phase –LR of the legs, including gliding, was negatively correlated to V_{200}surface. The ability to perform efficient propulsive leg movements brings the greatest propulsive benefit in every single cycle in the breaststroke amongst all styles (Kippenhan, 2001; Maglischo 2003; Mason et al., 1989; Strzala et al., 2012; Vilas-Boas 1994) analysed that swimmers accelerated their bodies for a longer time with their arms than they did with their legs and our results are in agreement with this. The kick is clearly the dominant propulsive force in the breaststroke, because swimmers accelerate the body forward much more strongly with their legs than arms, even though peak velocities are similar during other phases of the of the stroke (Maglischo, 2003).

In our observation we did not find significant dependence between percentage of propulsive arm movement and V_{200}surface. A more detailed division into phases, for example: catch, outsweep, and insweep, could provide a better idea of the shape of these phases (Payton and Bartlett, 1993; Strzala et al., 2013; Tourny, 1992).

The shape of the basic kinematic indicators SR and SL in the four segments of distance in our young swimmers were similar to those top level elite breaststroke swimmers (Hellard et al., 2008; Thompson et al., 2000, 2004;) and, although their values were lower, they overlapped even more with increasing distance, i.e. as SL decreased, SR increased on the 3rd and 4th 50m sectors of the total 200m. In the above mentioned analyses a statistically significant dependence between SL and V200 (0.36) was noted (Thompson et al., 2000). The data from their further study (Thompson et al., 2004) and later study by the Hellard team (2008) provided evidence that increases in both stroke rate and length cause an increase in swimming velocity in national and international 200 m breaststroke races. We agree with this statement, especially in the case of young swimmers who need master their efficiency by improving stroke length (Wakayoshi, 1995) and stroke rate (Yanai, 2001). We understand the importance of gliding ability (Barbosa et al., 2012; Leblanc et al., 2010) especially in longer 200m distance, but remember that this phase is only resistive. There is additional indication that true improvement in performance is generally achieved by prioritizing training and a swimmer's competency for increasing three key variables: mid-pool swimming velocity, turn times and start time (first 15 m), but coaches should always compare their swimmers' performance in each of these elements against their relative ranking before making a final decision on where to place training emphasis (Thompson et al., 2004).

The dependence between Glide, Overlap or TTG and V_{200}surface being statistically insignificant, shows the tendency of faster swimmers to limit the non-propulsive glide phase, which makes our results closer to those of Leblanc et al. (2007), where better swimmers reached 22% glide in comparison with less skilled (no recreational) who achieved more than 27%. Changes in the coordination indices in the following 50th m was related mainly to a decrease in glide phase, which is well recognized as a differential in shaping the movement cycles between sprinting and swimming a longer distance (Komar et al., 2014). For longer distances increasing propulsive force in the breaststroke cycles on the consecutive laps is achieved by an increase in SR, which correlates strongly with the Glide or Overlap, AP and LP indices (Strzala et al., 2013) and occurs with increasing fatigue (Conceicao et al., 2014). This happens gradually and proportionally to the loss of power, such as loss of power accompanied by our swimmers, or other athletes, in such all-out test as 90 sec. TWLG and TWAR.

In conclusion the above mentioned results indicate that the V_{200} was directly dependent on two indicators of physiological performance VO_{2peak}LG and TWAR (f^2 = 0.54), however, after splitting the 200m breaststroke race for the most important components – surface (V_{200}surface) and – turning zones (V200turns) swimming showed the increasing significance of the physiological properties of the swimmers organism. V200turns in young swimmers depended significantly on indicators of physiological performance and body structure: TWAR, VO_{2peak}LG and LBM, LBM which in turn strongly determined the measured results of TWAR, TWLG, VO_{2peak}AR and VO_{2peak}LG. Whereas, V200surface depended on VO_{2peak}LG with large Cohen effect-size (f^2 = 0.75) and was significantly relative to the percentage of the leg propulsion - LP. During the successive laps of the 200m breaststroke swimming there was an increased percentage of propulsion production in the breaststroke cycles, occurring simultaneously with a reducing gliding phase. In addition, the indicators shaping: SL, SR, TTG, Glide or Overlap with increasing fatigue indicates a decrease in efficacy in propulsive movements.

Conclusion

The collected data indicates a significant role of the properties of the body and physical endurance indicators, which was particularly highlighted by their influence on the main component, V200turns, in the 200m breaststroke in the short course race. This knowledge may be an indicator for achieving better performance through its implementation in our or other swimmers.

References

Arellano, R., Brown, P., Cappaert, J. and Nelson, R.C. (1994) Analysis of 50-, 100-, and 200-m freestyle swimmers at the 1992 Olympic games. *Journal of Applied Biomechanics* **10**, 189-199.

Barbosa, T.M., Costa, M.J., Morais, J.E., Moreira, M., Silva, A.J. and Marinho, D.A. (2012) How informative are the vertical buoyancy and the prone gliding tests to assess young swimmers' hydrostatic and hydrodynamic profiles? *Journal of Human Kinetics* **32**, 21-32.

Blanksby, B.A., Elliott, B.C., McElroy, K. and Simpson, J.R. (1998) Biomechanical factors influencing breaststroke turns by age group swimmers. *Journal of Applied Biomechanics* **14**, 180-189.

Brickley, G., Dekerle, J., Hammond, A.J., Pringle, J. and Carter, H. (2007) Assessment of maximal aerobic power and critical power in a single 90-s isokinetic all-out cycling test. *International Journal of Sports Medicine* **28**, 414-419.

Carey, D.G. and Richardson, M.T. (2003) Can aerobic and anaerobic power be measured in a 60–second maximal test? *Journal of Sports Science and Medicine* **2**, 151-157.

Chatard, J.C., Girold, S., Caudal, N., Cossor, J. and Mason, B. (2001) Analysis of the 200m events in the Sydney Olympic Games. In: *Proceedings of swim sessions: XIX International Symposium on Biomechanics in Sports,* University of San Francisco, San Francisco, CA. Eds: Blackwell, J.R. and Sanders, R.H. 261-264.

Chollet, D., Chalies, S. and Chatard, J.C. (2000) A new index of coordination for the crawl: description and usefulness. *International Journal of Sports Medicine* **21**, 54-59.

Chollet, D., Seifert, L., Leblanc, H., Boulesteix, L. and Carter, M. (2004) Evaluation of Arm-Leg Coordination in Flat Breaststroke. *International Journal of Sports Medicine* **25**, 486-495.

Conceicao, A., Silva, A.J., Barbosa, T., Karsai, I. and Louro, H. (2014) Neuromuscularfatigue during 200 m breaststroke. *Journal of Sports Science and Medicine* **13**, 200-210.

Conceicao, A., Silva, A.J., Boaventura, J., Marinho, D.A., Lauro, H. (2013) Wave characteristics in breaststroke technique with and without snorkel use. *Journal of Human Kinetics* **39**, 185-194.

Craig, A.B. (1986) Breath holding during the turn in competitive swimming. *Medicine and Science in Sports and Exercise* **18**, 402-407.

De Mello Vitor, F.and Silveira Böhme, M.T. (2010) Performance of young male swimmers in the 100-meters front crawl. *Pediatric Exercise Science* **22**, 278-287.

Gastin, P.B. and Lawson, D.L. (1994) Variable resistance all-out test to generate accumulated oxygen deficit and predict anaerobic capacity. *European Journal of Applied Physiology and Occupational Physiology* **69**, 331-336.

Geladas, N.D., Nassis, G.P. and Pavlicevic, S. (2005) Somatic and physical traits affecting sprint swimming performance in young swimmers. *International Journal of Sports Medicine* **26,** 139-144.

Haljand, R. (2014) *Model of breaststroke start technique.* Available from URL: http://www.swim.ee /models/_breast_swim1.html

Hellard, P., Dekerle, J., Avalos, M., Caudal, N., Knopp, M. and Hausswirth, C. (2008) Kinematic measures and stroke rate variability in elite female 200-m swimmers in the four swimming techniques: Athens 2004 Olympic semi-finalists and French National 2004 Championship semi-finalists. *Journal of Sports Sciences* **1**, 35-36.

Keskinen, O.P., Keskinen, K.L. and Mero, A.A. (2007) Effect of pool length on blood lactate, heart rate, and velocity in swimming. *International Journal of Sports Medicine* **28**, 407-413.

Kippenhan, B.C. (2001) Influence of lower extremity joint motions of the effectiveness of the kick in breaststroke swimming. In: *Proceedings of swim sessions: XIX International Symposium on Biomechanics in Sports,* University of San Francisco, San Francisco, CA. Eds: Blackwell, J.R. and Sanders, R.H. 48-52.

Kolmogorov, S.V. and Duplishcheva, O.A. (1992). Active drag, useful mechanical power output and hydrodynamic force coefficient in different swimming strokes at maximal velocity. *Journal of Biomechanics,* **25**, 311-318.

Komar, J., Sanders, R.H., Chollet, D. and Seifert, L. (2014) Do qualitative changes in inter-limb coordination lead to effectiveness of aquatic locomotion rather than efficiency? *Journal of Applied Biomechanics* **30(2),** 189-196.

Lätt, E., Jürimäe, J., Mäestu, J., Priit, P., Rämson, R., Haljaste, K., Keskinen, K.L., Rodriguez, F.A. and Jürimäe, T. (2010) Physiological, biomechanical and anthropometrical predictors of sprint swimming performance in adolescent swimmers. *Journal of Sports Science and Medicine* **9**, 398-404.

Leblanc, H., Seifert, L. and Chollet, D. (2010) Does floatation influence breaststroke technique? *Journal of Applied Biomechanics* **26**, 150-158.

Leblanc, H., Seifert, L., Baudry, L. and Chollet, D. (2005) Arm–leg coordination in flat breaststroke: a comparative study between elite and non-elite swimmers. *International Journal of Sports Medicine* **26**, 787-797.

Leblanc, H., Seifert, L., Tourny-Chollet, C. and Chollet, D. (2007) Intra-cyclic distance per stroke phase, velocity fluctuations and acceleration time ratio of a breaststroker's hip: a comparison between elite and non-elite swimmers at different race paces. *International Journal of Sports Medicine* **28**, 140-147.

Maglischo, E.W. (2003) *Swimming fastest*. Human Kinetics. Champaing, Illinois (US). 244-245.

Mason, B.R., Patton, S.G. and Newton, AP. (1989) Propulsion in breaststroke swimming. In: *Proceedings of the VII International Symposium on Biomechanics in Sport*, Footscray Institute of Technology, Melbourne, Australia. Ed: Morrison, W.E. 257-267.

Morouco, P., Neiva, H., Gonzalez-Badillo, J.J., Garrido, N., Marinho, D.A. and Marques, M.C. (2011) Associations between dry land strength and power measurements with swimming performance in elite athletes: a pilot study. *Journal of Human Kinetics* **Special issue,** 105-112.

Payton, C.J and Bartlett, R.M. (1995) Estimating propulsive forces in swimming from three-dimensional kinematic data. *Journal of Sports Sciences* **13**, 447-454.

Reis, V.M., Barbosa, T.M., Marinho, D.A., Policarpo, F., Reis, A.M., Silva, A.J. and Baldari, C. (2010) Physiological determinants of performance in breaststroke swimming events. *International SportMed Journal* **11**, 324-335.

Rodriguez, F.A., Keskinen, K.L., Keskinen, O.P. and Malvela, M. (2003) Oxygen uptake kinetics during free swimming: A pilot study. In: *Biomechanics and Medicine in Swimming IX*.: Publications de l'Universite de Saint-Etienne. Saint-Etienne. Ed: Chatard, J.C. 379-384.

Seifert, L. and Chollet, D. (2005) A new index of flat breaststroke propulsion: comparison between elite men and elite women. *Journal of Sports Sciences* **23**, 309-320.

Seifert, L., Leblanc, H., Chollet, D. and Delignieres, D. (2010) Inter-limb coordination in swimming: effect of speed and skill level. *Human Movement Sciences* **29**, 103-113.

Serresse, O., Lortie, G., Bouchard, C. and Boulay, M. (1988) Estimation of the contribution of the various energy systems during maximal work of short duration. *International Journal of Sports Medicine* **9**, 456-460.

Slaughter, M.H., Lohman, T.G., Boileau, R.A., Horswill, C.A., Stillman, R.J., Van Loan, M.D. and Bemben, D.A. (1988) Skinfold equations of body fatness in children and youth. *Human Biology* **60**, 709-723.

Strzala, M., Kręzalek, P., Kaca, M., Glab, G., Ostrowski, A., Stanula, A., and Tyka A. (2012) Swimming speed of the breaststroke kick. *Journal of Human Kinetics* **35**, 133-139.

Strzala, M., Kręzalek, P., Glab, G., Kaca, M., Ostrowski, A., Stanula, A. and Tyka, A.K. (2013) Intra-cyclic phases of arm-leg movement and index of coordination in relation to sprint breaststroke swimming in young swimmers. *Journal of Sports Sciences and Medicine* **12**, 690-697.

Strzala, M. and Tyka, A. (2009) Physical endurance, somatic indices and swimming technique parameters as determinants of front crawl swimming speed at short distances in young swimmers. *Medicina Sportiva* **13**, 99-107.

Strzala, M., Tyka, A., Zychowska, M. and Woznicki, P. (2005) Components of physical work capacity, somatic variables and technique in relation to 100 and 400m time trials in young swimmers. *Journal of Human Kinetics* **14**, 105-116.

Thayer, A.L. and Hay, J.G. (1984) Motivating start and turn improvement. *Swimming Technique* **20**, 17-20.

Thompson, K.G., Haljand, R. and MacLaren, D.P. (2000) An analysis of selected kinematic variables in national and elite male and female 100-m and 200-m breaststroke swimmers. *Journal of Sports Sciences* **18**, 421-431.

Thompson, K.G., Haljand, R. and Lindley, M. (2004) A comparison of selected kinematic variables between races in national to elite male 200m breaststroke swimmers. *Journal of Swimming Research* **16**, 6-10.

Tourny, C., Chollet, D., Micallef, J.P. and Macabies, J. (1992) Comparative analysis of studies of speed variations within a breaststroke cycle. In: *Swimming Science VI*. Ed: MacLaren, D., Reilly, T. and Less, A. E & FN SPON, London. 161- 166.

Vilas-Boas, J.P. (1994) Maximum propulsive force and maximum propulsive impulse in breaststroke swimming technique. In: ISBS – Conference Proceedings Archive, *XII International Symposium on Biomechanics in Sports.* Eds: Barabas, A. and Fabian, G. International Society of Biomechanics in Sports, Budapest-Siofok, Hungary. 303-310.

Wakayoshi, K., D'acquisto, L.J., Cappaert, J.M. and Troup, J.P. (1995) Relationship between oxygen uptake, stroke rate and swimming velocity in competitive swimming. *International Journal of Sports Medicine* **1**, 19-23.

Withers, R.T, Sherman, W.M., Clark, D.G., Esselbach, P.C., Nolan, S.R., Mackay, M.H. and Brinkman, M. (1991) Muscle metabolism during 30, 60, and 90 s of maximal cycling on an air-braked ergometer. *European Journal of Applied Physiology and Occupational Physiology* **63**, 354-362.

Yanai, T. (2001) Rotational effect of buoyancy in front crawl: does it really cause leg to sink? *Journal of Biomechanics* **34**, 235-243.

Key points

- This study investigated the influence of the selected indicators of somatic properties and physiological capacity as well kinematic and coordination parameters on breaststroke swimming.
- In this observations the body's functional capacity have an important impact on achieving good breaststroke swimming results, the V_{200} was moderately associated on VO_2peakLG, moreover, separate V_{200}turns depended with VO_2peakLG and on LBM and TWAR.
- The speed of surface breaststroke swimming - V_{200}surface similarly as V_{200}turns had a very strong influence on the end result of V_{200} , 0.91, $p<0.001$ and 0.92, $p<0.001$ respectively.
- The ability to swim fast on the surface (V_{200}surface) was positively and significantly associated with the percentage time of propulsion generation -LP in the breaststroke cycle.

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