

Physical Endurance and Swimming Technique in 400 Metre Front Crawl Race

by

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The aim of the observation was to examine the relationships between endurance indices and technique parameters on 400 m front crawl swimming. 26 swimmers were examined (16.1±1.09 years. Basic body variables (BH 177.5±8.07 [cm], BM 65.4±9.40 [kg]) and maximal oxygen uptake during arm cranking or leg cycling (3.14±0.54 and 3.82±0.53 [l.min⁻¹] respectively) were measured. The examination was conducted during 400 metre swimming (average speed 1.42±0.07 [m.s⁻¹]) beginning from water at a 50 m pool. Stroke rate (SR), stroke length (SL), propulsion (PL, PS) and non-propulsion phases (E, R) as well as index of coordination (IdC) for arms were measured. Leg movement quantity (LQ), was counted from the same shots as arms. There was a significant dependence of 400 m swimming speed on PL+PS level, IdC and SR (r=0.69, 0.50, 0.50 respectively) characterizing athletes technique. Front crawl swimming technique parameters were analyzed during four successive 100m segments of the 400 m distance. In spite of reduced stroke length, the increased stroke rate enabled swimmers to maintain speed in successive 100 metre segments or even accelerate, (especially in the last 100 m). The relation between SL and LQ was statistically significant r=0.41, p=0.04 and influenced stroke length. The correlation between SR and LQ was negative, close to statistical significance r= -0.36, p=0.07. Moreover, correlations between AR, WLLTAR, TWAR and V400 were insignificant and reached an average level (r=0.28-0.36).

Key words: swimming, stroke parameters, oxygen uptake, anaerobic threshold

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Introduction

400 m freestyle swimming using front crawl technique has been performed for over a hundred years. The first race at the distance of 440 yards took place at the Olympic Games in St. Louis. Leading specialists in front crawl swimming at shorter (Pieter van der Hoogenband and Ian Thorpe) and long distances (Grant Hackett and Yuri Prilukov) compete additionally at middle distance race. Complex examination of the prominent competitors enables sport scientists to determine the most important factors limiting performance at 400m. Empirical studies in the field of sport swimming are focused mainly on research analyzing the effects of applying different swimming techniques in short and long distance races on the swimmers' speed, as well as the role of aerobic and anaerobic endurance indices. Some authors point out the essential role of the anaerobic component (Sharp et al. 1982, Keskinen et al. 1989), while others suggest, that aerobic efficiency, is the most important factor (Obert et al. 1992, Wakayoshi et al. 1995). Others stress the importance of such factors as swimmers morphological and structural properties (Avlonitou et al. 1997, Grimston et al. 1986, Seifert et al. 2007). They play an important role in the hydrodynamic formation of swimming technique, and they are focused on during front crawl training (Berger et al. 1999, Toussaint et al. 1992, 2004, 2005, Kolmogorov et al. 1992, 1997).

The aim of this observation was to examine the relationships between physical endurance indices and technique parameters in 400 m front crawl swimming.

Materials and methods

26 swimmers aged from 15 to 18 years were examined. They signed a written informed consent. The research project received an approval of the Bioethics Commission in Cracow (No 292/KBL/OIL/2004 from 17th November 2004).

On the basis of the data collected during anthropometric measurements, the following variables were estimated: somatotype (using the method introduced by Carter-Heath 1990), percentage of body fat (PF) and lean body mass (LBM) (using the Slaughter et al. 1988 formula). Total body length (BTL) was measured while the subjects were lying on their back with their upper extremities extended above the head, and ankles plantar-flexed. Arm span of abducted arms was measured between the right and left arm from the fingertips. The measurements were performed using appropriate anthropometric instruments (Sieber Hegner Maschinen AG, Switzerland) and Harpenden-type foldmeter of constant pressure (10 g cm⁻²).

Upper limb tests (and TWAR) were conducted in a sitting position on an ergometer adapted for arm cranking (843E-Ergomedic, Monark, Sweden). Lower limb tests were conducted on a cycloergometer ER 900 Jaeger (Germany) and TWLG on a cycloergometer 874E-Ergomedic (Monark, Sweden). During the anaerobic 60s TWLG test the ergometer breaking resistance was set at 7.5% of BM, and during the 60s TWAR – 4.5% of BM (Bar-Or 1987, Lutostawska 1995). The graded exercise test evaluating was preceded by a three minute warm-up (WU) at intensity of approximately 45% of , after which every three minutes the resistance was increased by 30W. The intensity of the exercise during WU at was 150W or 120W depending on the swimmers' age and endurance level. The tests were preceded by WU at the intensity of 90 or 60W also depending on the age and endurance level, and every 3 minutes the resistance was gradually increased by 18 and 12W respectively. Graded exercise was continued until volitional exhaustion at a pace of 70 rpm at LG and 60rpm at AR. Breathing exchange variables were measured using a 919ER Medikro (Finland) apparatus. In the last 30 seconds of each segment load in AR and LG a capillary blood samples were taken to determine lactate concentration (La) using a Minifotometer Plus Dr Lange (Germany). The research procedure adopted by the authors enabled them to determine simultaneously, both the anaerobic threshold (AT) using Dmax technique (Cheng et al. 1992) and maximal oxygen uptake (AR and LG).

The field tests were conducted during 400 m swimming beginning from water at a 50 m pool. The parameters used for assessing swimming technique were measured at the end of each 100 m segment of the distance (between 75 and 90m, excluding the 5 metre zone before the turn). Duration of the race and the intermediate time of covering particular distances were measured using a stop watch with a precision of 0.01s. Swimmers' movements were recorded with a rapid shutter speed GRV 9800 JVC (Japan) video camera at a frequency of 50 shots per second. The recordings were executed from a side view about 1 m below the water surface. Two complete upper limb cycles were analyzed.

Since the arm movements in the front crawl are cyclic, the cycles were separated and divided into phases in the recorded movement. The identification of the intracyclic phases was conducted according to the Chollet method (2000) (Fig. 1)

Cycles were divided into phases according to characteristic events during hand and arm movement. Each phase was specified according to its role in accelerating the swimmer's body (propulsion or non-propulsion phase). The first is the entry phase (E – Entry, non-propulsion) – from the entry of the hand into the water till the beginning of its backward movement. Then there comes the

first propulsion phase (PL – Pull) – from the end of the entry phase till the moment when the arm is vertically raised above the humeral joint. Then, the second propulsion phase (PS – Push) – from the vertical position of the arm till the arm release from the water. The cycle ends with the non-propulsion phase (R – Recovery) – from the hand's release from the water to its next entry into the water.

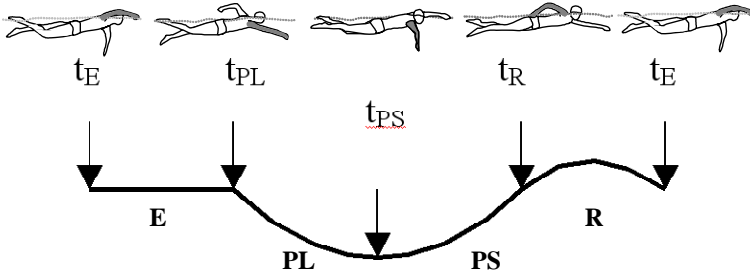


Fig. 1

Front crawl upper extremity intracyclic phases division scheme

The following parameters were used to assess swimming technique during each analyzed 20m long swim ($i=1,2,3,4$):

- swimming speed: $V_i = 20m / \Delta t_i$
- stroke rate (SR $_i$), calculated as the reciprocal of the arithmetical average of duration of two analyzed swimming cycles: $SR_i = 1/T_i$
- stroke length (SL $_i$), calculated as the average speed to SR $_i$ ratio: $SL_i = V_i / SR_i$

The swimming cycles of both arms are typically phase-shifted. Depending on the chosen extremities coordination method, such a shift results in the occurrence of periods without any propulsion (when none of the extremities is in the propulsion phase) or periods with double propulsion (when both extremities are in the propulsion phase). To assess the upper extremities cooperation in body propulsion a parameter called index of coordination (IdC $_i$) is used. It is expressed as percentage of cycle duration:

$$IdC_i = \frac{t_R^{k1} - t_{PL}^{k2}}{T_i} * 100\%$$

where: t_R^{k1} – beginning of R phase for the first arm,

t_{PL}^{k2} – beginning of PL phase for the second arm,

T_i – duration of swimming cycle,

IdC has a positive value when propulsion phases interfere, but when there is a pause between them it takes negative value.

Legs movement quantity (LQi), counted from the same shots as arms movements, were qualified as six-beat kick, corresponding to six complete alternating immersion and/or emersion movements in one upper extremities movement cycle, and four- and two-beat kick, for four and two leg movements in one arm movement cycle respectively.

To determine the relationship between speed, endurance and somatic or swimming technique variables, partial correlations were estimated, controlling for age. Pearson correlation coefficients were calculated to evaluate the relation between technique parameters of upper (SL, SR) and lower (LQ) extremities. Normal data distribution was tested, to confirm their formation similar to normal Gauss-Laplace curve. Analysis of variance for repeated measures (ANOVA) was used to examine differences in four consecutive segments of 400m distance for each measured parameter of swimming technique. All tests were conducted with STATISTICA 6.1 software (StatSoft, Inc). The significance level was set at $p < 0,05$. Descriptive data were presented as mean and standard deviation.

Results

Swimmers' basic biometric data, such as age, body height (BH), body mass (BM), lean body mass (LBM), arm span (AS) and total body length (TBL) are shown in Table 1. Eleven of the studied 26 athletes had an ectomorphic body structure, while the rest (15 swimmers) had a mezomorphic body type.

Table 1

Swimmers' body structure and endurance indices

Parameters	Age [years]	BH [cm]	BTL [cm]	AS [cm]	BM [kg]	LBM [kg]
$\bar{x} \pm SD$	16.1 \pm 1.09	177.5 \pm 8.07	245.5 \pm 12.98	182.4 \pm 10.28	65.4 \pm 9.40	58.7 \pm 8.05
Parameters	TWAR [kJ]	TWLG [kJ]	$\dot{V}O_2$ max AR [lmin ⁻¹]	$\dot{V}O_2$ max LG [lmin ⁻¹]	WL _{LT} AR [W]	WL _{LT} LG [W]
$\bar{x} \pm SD$	284.4 \pm 55.36	468.8 \pm 76.75	3.14 \pm 0.54	3.82 \pm 0.53	116.0 \pm 28.2	192.7 \pm 34.12

Blood lactate concentration after anaerobic exercise using upper extremities (TWAR) reached an average of 12.6 \pm 1.73 mmol.l⁻¹, while in the leg test (TWLG) it was significantly higher: 14.1 \pm 1.46 mmol.l⁻¹ ($p < 0.01$). During the third minute of recovery after the 400 m swimming race, blood lactate concentration (La) amounted to 11.2 \pm 2.03 mm.l⁻¹.

Table 2

400 metre front crawl swimming technique parameters

parameters	V[ms ⁻¹]	SR[cklmin ⁻¹]	SL[m]	IdC[%]	PL+PS[%]	E+R[%]	
$\bar{x} \pm SD$	1.42±0.07	39.6±4.41	2.13±0.23	-5.9±6.55	43.1±6.39	56.9±6.39	
parameters	E[%]	PL[%]	PS[%]	R[%]	LQ2 [n]	LQ4 [n]	LQ6 [n]
$\bar{x} \pm SD$	33.0±8.69	16.7±3.27	26.4±4.00	24.0±3.91	11	7	8

Partial correlation coefficients show statistically significant correlations between maximal oxygen capacity and V400. Anaerobic endurance indices were correlated with V400 tenuously or indifferently. Anaerobic threshold power results were close to statistical significance (WLLTAR) (0.36, $p < 0.07$). Body mass (BM) and LBM were statistically significantly correlated with V400, as well as AS and BTL indices with V400.

Table 3

Selected partial correlations between swimmer's body morphological and functional indices, swimming technique parameters with age control and 400 metre swimming speed.

Statistically significant correlations are marked with a star ($p < 0.05^*$, $p < 0.01^{**}$)

n=26	$\dot{V}O_{2,max}$ AR [lmin ⁻¹]	$\dot{V}O_{2,max}$ LG [lmin ⁻¹]	WL _{LT} AR [W]	WL _{LT} LG [W]	TWAR [kJ]	TWLG [kJ]	BTL [cm]	AS [cm]
V[ms ⁻¹]	0.23	0.14	0.36	0.34	0.29	0.35	0.45*	0.50*
n=26	SR [cklmin ⁻¹]	SL [m]	IdC [%]	PL+PS [%]	E+R [%]	LQ [cykl]	BM [kg]	LBM [kg]
V[ms ⁻¹]	0.50*	-0.24	0.50*	0.69**	-0.69**	-0.28	0.42*	0.45*

No significant relationships were shown by the attempt to correlate the endurance indices (AR and LG) with front crawl swimming technique parameters influencing the V400 speed. The strongest correlation (0.37, $p < 0.07$) was claimed between AR and PL+PS.

Table 4

Front crawl swimming technique parameters during four successive segments of the 400 m distance

n=26	V[ms ⁻¹]	SR [cklmin ⁻¹]	SL[m]	IdC [%]	PL+PS [%]	E+R [%]
I 100 $\bar{x} \pm SD$	1.49±0.08	39.2±4.7	2.21±0.27	-6.6±7.0	41.9±6.8	58.1±6.8
II 100 $\bar{x} \pm SD$	1.40±0.08	39.0±4.9	2.16±0.25	-5.9±6.9	42.8±7.1	57.2±7.1
III 100 $\bar{x} \pm SD$	1.38±0.07	39.1±4.7	2.07±0.22	-6.3±7.3	42.8±6.9	57.2±6.9
IV 100 $\bar{x} \pm SD$	1.41±0.07	41.3±4.0	2.07±0.24	-5.0±6.3	44.7±6.0	55.3±6.0

400 m swimming speed and technical parameters showed a statistically significant diversity for each of the consecutive 100m segments of the distance. In each segment swimming speed had a square trend (Table 4). Variance analysis with repeated measurements ($F= 236.49$, $df=1.25$, $p< 0.001$) showed that the highest value of V_{400} was reached during the first 100 m of the distance, and then it decreased during the next two 100 metre long segments, and after that, during the last segment, it increased once again. Such changes in swimming speed were reflected by modifications in the front crawl swimming technique.

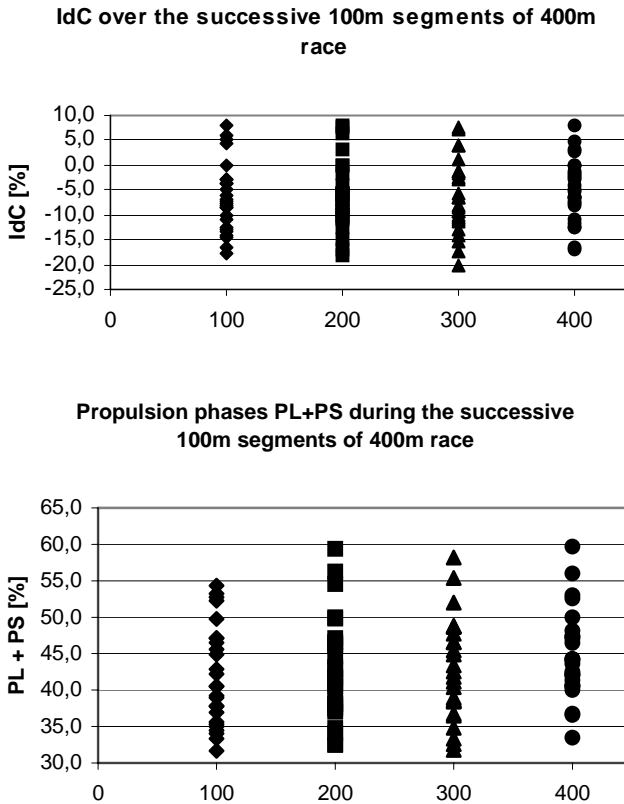


Figure 2

Index of coordination (IdC) (top) and propulsion phases PL+PS (bottom) during the upper extremities movement cycles in the examined swimmers' during four segments of the 400 m race

The highest SL values were obtained at the first 100 m long segment and then decreased linearly ($F=41.81$, $df=1.25$, $p<0.001$). During the second segment SR dropped, and then in the third and fourth one it increased (square trend $F=16.33$, $df=1.25$, $p<0.001$). Propulsion phases increased linearly ($F=16.87$, $df=1.25$, $p<0.001$). Such change in technique parameters (PL+PS, IdC and SR) allowed the swimmers to increase their speed during the last segment of the 400 m distance.

Selected swimming technique parameters with the largest diversity in the group of sportsmen (IdC and PL+PS) are presented in figure 2. Linear correlation between stroke rate, stroke length and LQ of each arm movement cycle were also estimated. The relation between SL and LQ was statistically significant $r=0.41$, $p=0.04$ and influenced stroke length. The correlation between SR and LQ was negative, close to the statistical significance $r=-0.36$, $p=0.07$.

Discussion

Statistical analysis of data showed, that there was a significant dependence of 400 m swimming speed with PL+PS level, IdC and SR characterizing upper extremities movement technique. Similar correlations were observed at the distances of 12.5 and 25 metres by Chollet et al. (2000) and Seifert et al. (2007). In those studies the swimmers covered marked segments with speed adequate to sprint and long distance, with minimized fatigue. Keskinen and Komi (1993) examined such dependences among 400 m front crawl swimmers covering the distance with increasing speed. The reference data are in accordance with our results. They show that the best athlete during successive segments reduced the non propulsive phase contribution in order to increase the propulsive phase contribution. Such modifications in the movement cycle structure were connected with an increase of fatigue and intended to minimize the drop of locomotion speed. Movement technique changes were possible by using such swimming strategy. In spite of reducing stroke length, the increased stroke rate enabled swimmers to maintain the speed of successive 100 m segments or even to accelerate (especially at the last 100 m). Could this mean that some swimmers specialized in medium distance front crawl swimming are able to modify movement cycle structure consciously as fatigue increases? Such an assumption might be supported by the fact that in each separate upper extremities movement cycle reducing SL and increasing SR were performed in order to reduce swimmer's centre of gravity speed fluctuations during one movement cycle. Decline in speed in a movement cycle is caused by producing less propulsion during E and PL phase than in PS and existence of lag time ($IdC\%>0$) while

generating propulsion using upper extremities. The longer is the lag time, the lower the stroke rate.

Therefore an appropriate adjustment of technique parameters (SL and SR) during the race contributes to reduced physical effort, energy expense and in effect to maintenance or even increased swimming speed. Some research results may confirm this phenomenon (Pelayo et al.1996, Dekerle et al.2005, Strzała et al. 2005, 2007). These results need verification through biomechanical analysis of a group of elite swimmers. The correlation between particular front crawl swimming technique parameters (especially SR and swimming speed) has already been a focus of this research team (Strzała et al. 2005). The results confirmed the remarks of Grimston et al. (1986) on high prediction of somatic indices' correlations with middle distance swimming results. After analyzing upper extremities movement cycle kinematic structure in front crawl swimming, the opinion, that increasing the percentage of arm movement cycles propulsion phases is convergent to movement coordination change and IdC increase, must be accepted. It occurs through reducing the lag between propulsion phases in upper extremities movement cycle, and consequently improving swimmer's arm movement efficiency (Chatard 1990a). Increasing IdC level might be convergent to the ability to reduce less hydrodynamically effective leg propulsion movements. Holmer's (1974), Chatard's et al. (1990b) results show three to four times lower leg movement efficiency compared to upper extremities. Deschodt et al. (1999) observed only a 10% leg work contribution in human locomotion during sprint front crawl swimming at 25 m. Zamparo et al. (2005) postulated that except from sprint front crawl swimming, leg movements are the main determiner of "un-optimal" hydrodynamic efficiency and should be reduced to swimmer's body stabilizing and ensuring better propulsion transfer from arms. The hypothesis about a higher physiological cost of front crawl swimming technique with intensified leg work than of their lower contribution while swimming, has been positively verified by the authors. It has been shown that SR is strongly positively correlated with V400, but negatively with LQ. This may indicate that greater leg movement contribution decreases mean 400 metre front crawl swimming speed. According to Secher et al. (2006) this may be explained by specific cardiovascular reactions for simultaneous work of upper and lower extremities and only upper extremities movements. In the first case a significant decrease in upper extremities muscles blood circulation was observed, mainly because of blood vein constriction and increasing circular resistance. These authors suggest that this was caused among others by higher sympathetic, lower blood circulation pressure via upper extremities (ml.min⁻¹.mmHg⁻¹) and lower myoglobin oxygen saturation in working skeletal mus-

cles (Volianitis 2002). Anaerobic glycolysis intensification is a consequence of upper extremities muscles insufficient oxygenation, which may lead to an increase in lactate concentration in muscles and body fluids. Volianitis et al. (2003) and Secher et al. (2006) explain these metabolic changes by restricted availability of HbO₂. On the other hand moderate leg work engagement prevents increasing hydrogen ion (H⁺) concentration, by increased ability of active lower extremities muscles to metabolize lactate. The results of a negative relation between LQ and SR tend towards a hypothesis which implies that, a high energy cost of leg work in propulsion may reduce upper extremities propulsion efficiency. This does not directly support reducing already trained leg coordination in upper extremities movement cycle but may imply intentional reduction their intensity by reducing the mobility range.

Wakayoshi et al. (1995) in a similar research noted a high dependency of SR on $\dot{V}O_2$, which was not confirmed by this observation. In this paper it is stated that not only SR, but also interdependent IdC and PL+PS did not significantly correlate with $\dot{V}O_2$. The results did not indicate any direct relations between the indices most important for swimming speed technique such as SR, IdC, PL+PS and endurance variables in arm exertions. Although correlations between AR, WLLTAR, TWAR and V400 were insignificant and reached an average level ($r=0.28-0.36$), it seems that this information is important for coaches and 400 m free style swimmers.

The knowledge of swimming technique's influence on the effectiveness and speed of front crawl swimming at long distances should create a possibility to optimize the training process for both coaches and athletes. During a race, depending on the level of global fatigue, it will be possible to modify swimming technique parameters in a controlled way. This is sometimes observed in case of elite long distances swimmers.

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