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Components of Physical Work Capacity, Somatic Variables and Technique in Relation to 100 and 400m Time Trials in Young Swimmers

by

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The most important components determining sport results of competitive swimmers include somatic, physiological and psychological properties. The main objective of this work was to identify the main factors determining sport results of elite polish freestyle swimmers at 100 and 400 meters. The research material included 16 male swimmers between the age of 15-17 (16,3 ± 0,73 years) with a 4-5° of biological development according to Tanner (1963) and training experience of 8-9 years. All athletes were subjected to 3 laboratory tests. A aerobic capacity test with graded intensity performed until volitional exhaustion and two anaerobic 60s tests conducted with lower (CE) and upper (SE) limbs. Swimming trials were also conducted in a 25m pool at 100 and 400m. On the basis of the conducted research it can be concluded that the results in the 100m freestyle are primarily determined by anaerobic capacity of upper and lower limbs as well as body height and lean body mass. At 400m the influence of somatic features is smaller. Once again the results are mainly affected by anaerobic capacity as well as stride rate.
Key words: *swimming, work capacity, somatic variables*

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Introduction

The most important components determining sport results of competitive swimmers include somatic, physiological and psychological properties that allow to apply proper technique. They also determine the rate and range of adaptive changes to work performed in the water environment of different intensity. The time of swimming races vary from 20-60s at the sprint distances (50-100m), through 2-4min at middle distances (200-400m) up to 15min during the longest race (1500m). This requires significant energy expenditure through all metabolic pathways. Particular distances also require the modification of technique because of different energy demand. On the basis of literature review one can state that certain anthropometric, physiological and structural variables such as: (length and width indexes), (body composition), (aerobic and anaerobic capacity) influence technique and sport results in swimming (Holmer 1974). The results of these observations point to dominant factors influencing sport results in swimming yet the data is often contradictory thus the authors attempted to verify them. The main objective of this work was to identify the main factors determining sport results of elite polish freestyle swimmers at 100 and 400 meters.

Material and methods

The research material included 16 male swimmers between the age of 15-17 (16,3 ± 0,73 years) with a 4-5° of biological development according to Tanner (1963) and training experience of 8-9 years, coached according to the same program of Sports Championship School in Oswiecim. Of the 16 tested subjects, 9 were mesomorphs and 7 ectomorphs (Carter-Heath 1990). Body Fat content (BF) and lean body mass (LBM) were evaluated according to Slaughter et all 1998 (Table 1). All athletes were subjected to 3 laboratory tests. A aerobic capacity test with graded intensity performed until volitional exhaustion and two anaerobic 60s tests conducted with lower (CE) and upper (SE) limbs. Swimming trials were also conducted in a 25m pool at 100 and 400m. The graded exercise test was performed on an ergocycle 900E Jaeger (Germany) which was preceded by a 3min warm-up at the intensity of 45% VO_2max. The load was increased every 3min by 30W and the exercise was stopped when the subject could not maintain 60rev • min^{-1} at a particular load. Gas exchange variables such as oxygen uptake (VO_2) and CO_2 (VCO_2) exhalation were evaluated every 30s with the use of 919ER MEDIKRO apparatus (Finland). During the last 30s of each load arterialized blood was drawn in which the concentration of lactate (LA) was evaluated with a Miniphotometer (dr Lange).

The anaerobic tests were performed on an 834E Ergomedic cycle (Monark-Sweden) in case of lower limbs and on a Biometer swim ergometer for upper limbs (Germany). The tests were preceded by a 15min warm-up conducted at intensity of 50% VO2max (?) a varied intensity (Tyka 1995). Total work (TW) was the main variable registered. In the CE test the resistance was individualized (7,5% BW) according to Bar-Or (1987). In the SE test the resistance was applied with the procedures of Swaine (2000). Time trials at 100 and 400m were conducted from the water at race pace. The time was measured by hand on a stopwatch with the accuracy of 0,01s. Frequency of arm movements (SR) was measured twice during each pool length during the 100m trial and at the 2, 4, 6, 8 10, 12 and 16th length of the pool. The stride length (SL) was evaluated during the middle 15m of each pool length excluding the 5m after and before the turn. During each time trial and the recovery phase heart rate (HR) was registered with a Polar monitor (Finland). The concentration of lactate was evaluated enzymatically in the 3rd min of recovery. Basic descriptive statistics were applied and correlation coefficients were calculated. Tests of significance of differences and ANOVA with repeated measures were used (Statistica 6,0).

Results

The analyzed group of swimmers varied in regard to body height (BH) and body mass (BM) as well as fat content (BF) and lean body mass (LBM). They also differed significantly in the level of maximal oxygen uptake (VO_2max), the level of lactate threshold (WL_{LT}) and its percentile value of maximal power (% MWL_{LT}) as well as results of total work output during the 1min tests for the lower and upper limbs (SE) and (CE) (table 1). The dispersion of results in the 100 and 400m trials and variables characterizing swimming technique (MV, SR, SL) was rather small. During both swim trials at 100 and 400m freestyle the 3 variables related to technique were analyzed: MV, SL, SR (Fig. 1 A, B, C, D, E, F). To evaluate the dynamics of these variables the analysis of variance with repeated measures and the analysis of its trend were used.

At 100m the average swim velocity had a square trend (F=190,61 df=1,15 p<0,001) and was highest during the first 25m, than it decreased significantly during the second and third pool length (Fig 1A). During the 400m trial the swim velocity had a similar trend (F=343,73 df=1,15 p<0,001) Fig 1D. In the 400m trial arm movement frequency decreased significantly until the middle of the distance (square trend F=62,6 df=1,15 p<0,001) and than rose from the 10th pool length until the finish, reaching maximal frequency at the last pool length

(41,6 ckl • min^{-1}) (Fig E). In the 100m trial SR decreased directly at each pool length (F=54,4 df=1,15 p<0,01)

Table 1

Basic statistical description of analyzed variables

variable	BH [cm]	BM [kg]	PF [%]	LBM [kg]	VO_{2max} [l·min^{-1}]	VO_{2max} [ml·min^{-1}]	$\%MWL_{LT}$ [%]	WL_{LT} [W]
$\bar{x}$, SD	177±6.50	65.6±7.60	9.4±3.20	59.3±6.30	3.64±0.34	55.6±5.00	71.1±4.70	208.1±25.60
min-max	168-190	53.6-76.4	5.1-16.3	50.1-69.1	3.17-4.28	45.8-63.4	63.9-80.3	180-240
variable	MV100 [m·s^{-1}]	MV400 [m·s^{-1}]	SL100 [m]	SR100 [ckl·min^{-1}]	SL400 [m]	SR400 [ckl·min^{-1}]	TW-SE' [kJ]	TW-CE' [kJ]
$\bar{x}$, SD	1.68±0.06	1.47±0.07	1.92±0.17	49.9±4.50	2.09±0.20	39.9±4.50	1.86±0.56	28.30±3.09
min-max	1.58-1.82	1.31-1.58	1.62-2.31	40.5-57.2	1.75-2.47	31.5-48.9	1.02-2.69	23.37-34.01

Table 2

Correlation coefficients between chosen somatic and physiological traits with swim variables at 100 and 400 m.

		WL_{LT} [W]	VO_{2max} [l·min^{-1}]	LBM [kg]	TW-SE'	TW-CE' [kJ]	MV100	MV400 [m·s^{-1}]	SL100	SL400 [m]	SR100	SR400 [ckl·min^{-1}]
BH	[cm]	0.41	0.54*	0.73**	0.30	0.58*	0.55*	0.27	0.29	0.14	-0.11	-0.12
BM	[kg]	0.34	0.68*	0.95**	0.26	0.83**	0.38	-0.26	0.41	0.23	-0.25	-0.23
LBM	[kg]	0.53*	0.76**	-	0.28	0.85**	0.57*	0.16	0.41	0.22	-0.20	-0.19
VO_{2max}	[l·min^{-1}]			0.83**	0.15	0.73**	0.30	0.06	0.45	0.28	-0.33	-0.29
WL_{LT}	[W]				0.02	0.51*	0.17	0.02	0.16	0.04	-0.06	-0.06
TW-SE'	[kJ]					0.26	0.70**	0.51*	-0.41	-0.01	0.28	0.25
TW-CE'	[kJ]						0.53*	0.22	0.54*	0.41	-0.37	-0.29

Significant correlation * p< 0.05, ** p<0.001

Fig 1B, while SL was highest during the second pool length (1,94m) and had a cubic trend (F=8,07 df=1,15 p=0,01) Fig C. During the 400m trial stride length was highest during the beginning of the race (2,14m) and decreased throughout the race in a linear trend (F=24,3 df=1,15 p<0,001) Fig F. The heart rate (HR) values immediately after the 100 and 400m trials equaled respectively 173 ± 6,5bts • mm^{-1} and 181 ± 5,9 bts • min^{-1}. After the SE and CE anaerobic capacity test it reached values of 162 ± 8,5 bts • min^{-1} and 185 ± 5,7 bts • min^{-1}. The lactate concentration (LA) following the lower limb test (CE) equaled 10,5 ± 1,5 mmol • l^{-1} and was 40% higher than that reached in the upper limb test (SE) reaching a value of 6,8 ± 1,9 mmol • l^{-1}. The LA concentration after the 100m trial equaled 8,8 ± 1,9 mmal • l^{-1} and was significantly greater (p<0,5) than the value obtained after the 400m swim trial (7,5 ± 2,3 mmol).

Table 3

Relationships between arm movement frequency (SR) and swim velocity (MV) as well as between MV and stride length (SL) at 100 and 400m.

Variable	100 m				400m			
SR [ckl·min^{-1}]	**1**(25)	**2**(25)	**3**(25)	**4**(25)	**4**(25)	**8**(25)	**12**(25)	**16**(25)
correlation	**0.30**	**0.29**	**0.29**	**0.22**	**0.61***	**0.54***	**0.47**	**0.50***
MV [m·s^{-1}]	**1**(25)	**2**(25)	**3**(25)	**4**(25)	**4**(25)	**8**(25)	**12**(25)	**16**(25)
correlation	**0.10**	**0.03**	**0.05**	**0.32**	**-0.22**	**-0.09**	**0.08**	**-0.01**
SL [m]	**1**(25)	**2**(25)	**3**(25)	**4**(25)	**4**(25)	**8**(25)	**12**(25)	**16**(25)

Significant correlation * p< 0.05

From the considered somatic, physiological and technique variables (table 2) the highest relationships were observed between LBM, BM and TW-CE (r=0,85 and 0,83) as well as between VO_2max and LBM and BM (r=0,76 and 0,68). Body height showed a high relationship with VO_2max(r=0,54), and LBM (r=0,73) while MV showed a significant relationship with TW-SE (r=0.70), TW-CE (r=0.51) and BH (r=0,55). Maximal velocity (MV) at 400m showed significant relationships only with TW-SE (r=0,51 p<0,05). The anaerobic capacity (TW-CE) showed a significant relationship only with one variable of swimming technique which was SL at 100m (r=0,54). During the 100m swim trial MV showed a positive but insignificant relationship with SR and SL at all 4 pool lengths (Table 3). At 400m a significant relationship between MV and SR was registered at the 4th, 8th and 16th pool length. Additionally the swimmers were divided into two groups upon maximal velocity reached at both distances. An attempt was made to determine factors differentiating the faster and slower swimmers. In these groups the significance of differences was established between TW-SE, TW-CE and SR 400. The tested swimmers differed significantly in particular groups (p<0,05) in relation to TW-SE what indicates a dominant role of anaerobic capacity in reaching elite level at 100 and 400m. Also an high relationship was observed between results of 100 and 400m trials (r=0,81 p<0,01)

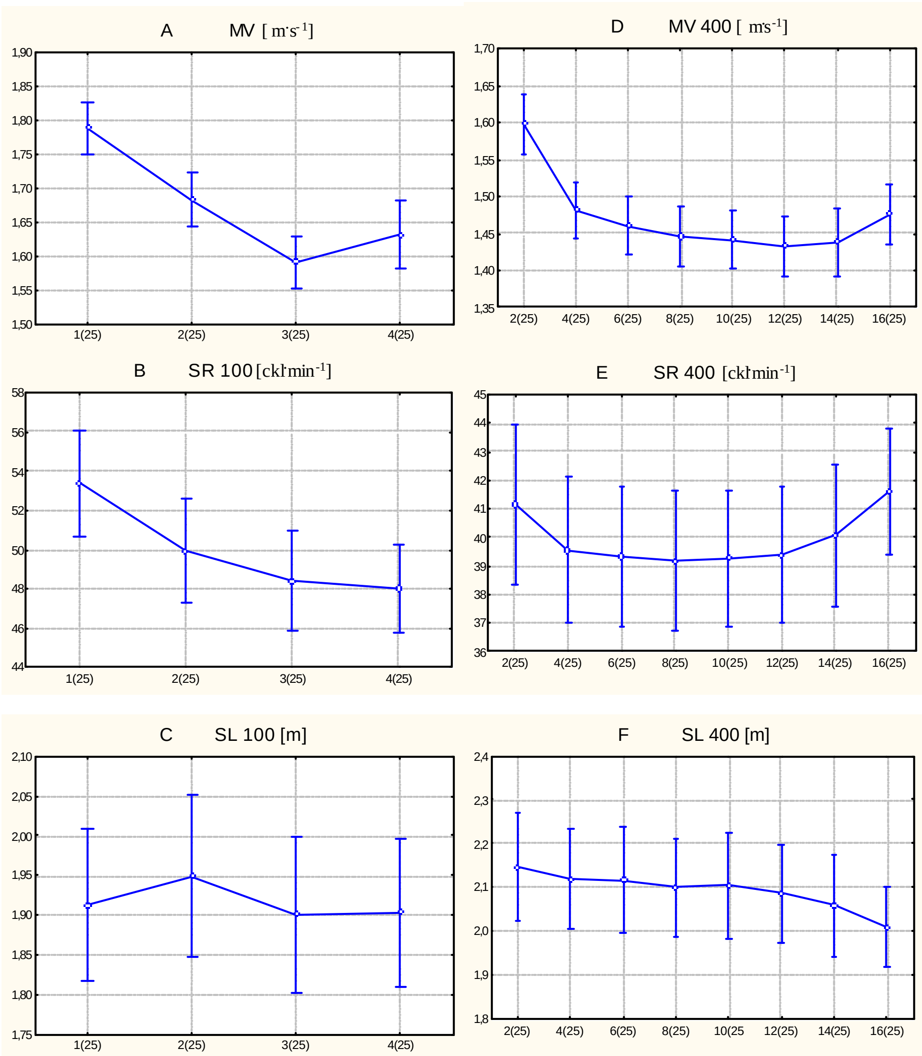

Fig. 1. *Dynamics of particular swim variables (A – MV at 100m, B – SR at 100m, C – SL at 100m, D – MV at 400m, E – SR at 400m, F – SL at 400m.*

Discussion

Elite swimmers specializing in the sprint (50-100m) are general taller and have a greater muscle mass what allows them to generate greater power under anaerobic conditions (Chatard 1990, Keskimen et al 1989). These scientists also recorded significant relationships between 100m craul times and body height (r=0,73) arm span (r=0,71) and body mass (r=0,72). On the other hand (Grimoton et al 1986) showed significant relationships between body dimensions and craul results over distances from 50 to 1000 yards. On the contrary (Pelayo et al 1990) and (Siders et al 1993) did not find such correlations between MV at 100 and 400m craul races and body height, arm span and foot length. The same authors also showed no effect of BH and LBM on results at 100m. This fully justifies the undertaken research with the top polish youth swimmers. The obtained results confirmed a significant influence of BH on MV at both 100 and 400m races yet the correlation was higher at the shorter distance. Total work output (TW) obtained in the 1min anaerobic test with the upper limbs (SE) highly correlated with results of the 100 and 400m trials (r=0,70 and r=0,51). The results of the lower limb anaerobic test (SE) showed a significant, yet smaller correlation with 100m swim times (r=0,53) and very small insignificant relationship with times at the longer distance (r=0,22). Additionally the work output in the upper limb test (SE) was significantly greater ($p<0,05$) in the group of better swimmers. A smaller relationship of TW-CED with 400m times than with 100m indicates a decreased role of lower limbs at longer distances. The research of (Holmer 1974) and (Chatard et al 1990) proved that leg work in the 400m craul is 3-4 times less efficient than arm work. Additionally because of the greater muscle mass, the legs consume more oxygen creating a significantly higher energy cost. This does not indicate that swimmers who engage arms more than legs in propulsion in the craul reach better results. According to Chatard et al 1990 a more significant use of the legs in the craul requires a greater aerobic and anaerobic energy output what allows higher, better sport results, yet the athlete must have a very high level of physical work capacity. In sprint swimming the anaerobic component constantly rises since the propulsion is related to the force generated by the athlete in the water. With the rise in swimming speed the resistance increases (Keskinen et al 1992) and is also affected by the body dimensions of the swimmer (Kalmolgorov et al 1992). The forces to overcome in the water are significantly smaller in long distance swimmers than in sprinters (Chatard 1990). Hollander et al 1986 indicate that the forces created in the water during swimming are proportional to the square of swimming velocity. The energy expenditure in elite sprint swimmers is less dependent on the aerobic component. According to Costill et al 1992 in highly trained swimmers the energy contribution in the 100m craul sprint is as follows: anaerobic-alactic 25%, anerobic-glycolytic 65% and 10% aerobic.

The maximal oxygen uptake (VO_2max) evaluated on an ergocycle equaled 3.64 $l \cdot min^{-1}$ and did not show significant correlations with results of the 400 and 100m craul time trials. College swimmers evaluated by Costill et al (1985) immediately after a 400 yard race showed similar oxygen uptake values (3.7 l•min^{-1}) and significant yet small relationships of MV and VO_2max (r=0.43). Chatard et al (1990c) on the other hand registered higher values of oxygen uptake in swimmers of the same age (4.4 l•min^{-1}) and a high, significant relationship of this variable with MV at 400 yards (r=0.80). During a graded swim test in a hydrodynamic canal Wakayoshi et al (1992) registered significantly greater values of VO_2max ((4.73 l•min^{-1}) which showed a minor, yet inverse relationship with 400m times. Other authors do not show significant differences in VO_2max values in swimmers of the same age and sports level (Magel et al 1967, Bonen et al 1980, Rodriguez 2000).

The obtained values of the anaerobic threshold (WL_{LT}) evaluated according to Stegmann et al (1981) did not show significant relationships with MV at 100 and 400m.

The analysis of MV, SR and SL dynamics registered in successive pool lengths during the time trials at 100 and 400m allowed for a deeper inquiry. For example, MV at 100m decreased during the first 3 lengths of the pool and rose during the last most important length, primarily do to the increase in the length of the arm movement cycle. A very minor decrease in SL (1.04%) in the second part of the race indicates a high level of technical preparation. Chollet et al (1997) registered a decrease of 1.6% in SL in national level French swimmers while Pai et al (1984) recorded a 1.5% drop in SL during the second part of the 100m race in American swimmers. Swimming technique may be related to glycolytic capacity, what is confirmed by significant correlations between TW-CE and SL100 (0.54, $p<0.05$). Such a relationship indicates that a more effective work of a swimmers lower limbs create good conditions for arm work. This allows the swimmer to perform arm cycle movements (SL).

The velocity at 400m decreased in subsequent pool lengths, until the last 100m when the velocity once again increased do to a greater SR (41.6 cykl•min^{-1}). Throughout the 400m distance values of MV and SR showed significant relationships Table 3). At 400m the observed decrease in SL and a increase in SR was connected to the reduction in power output per each arm movement cycle (Pelayo et all 1996). Such changes in MV, SR and SL were also registered by Craig et all (1985) in the USA national team and by Keskinen et all (1993) in well trained swimmers from Finland. A significant correlation of SR and MV at 400m in elite swimmers may indicate a possibility to modify stride rate during particular phases of the race.

The relationship of MV and SL in the 400m time trial at the 4th, 8th and 16th length of the pool was negative and statistically not significant. Similar results were obtained by Keskinen et all (1993). Such results may indicate that stride length in elite 400m swimmers is not the dominant factor influencing sport results in this event, yet coach opinions very in this aspect. The decisive factor, determining results of the 400m time trial in this study was the stride rate (SR), what was also observed by Keskinen(1993).

The SR registered in this research was lower than that observed by Craig (1985) and Chatard (1990c) in swimmers with better personal records. From the considered somatic, physiological and technical variables, of great importance seems the high relationship between anaerobic capacity (TW) of the upper limbs and MV. A significant influence of anaerobic capacity on MV at 100 and 400m distances was also registered by Sharp et al (1982) who obtained the following correlation coefficients (r=0.86 at 100m and r=0.76 at 400m). The values of MV at 100 and 400m were highly correlated what indicates a significant influence of swimming speed on results at 400m.

The values of anaerobic threshold (LT) obtained in the ergocyle test did not show significant relationships with considered variables (MV, SL, SR) of swimming technique. It seems that the evaluation of WL_{LT} during a swim test, under natural conditions would allow to detect a more significant relationship between the analyzed variables.

On the basis of the conducted research it can be concluded that the results in the 100m freestyle are primarily determined by anaerobic capacity of upper and lower limbs as well as body height and lean body mass. At 400m the influence of somatic features is smaller. Once again the results are mainly affected by anaerobic capacity as well as stride rate.

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