

Research article

Can blood gas and acid-base parameters at maximal 200 meters front crawl swimming be different between former competitive and recreational swimmers?

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Abstract

The aim of the present study was to ascertain whether maximal 200 m front crawl swimming strategies and breathing patterns influenced blood gas and acid-base parameters in a manner which gives advantage to former competitive swimmers in comparison with their recreational colleagues. Twelve former competitive male swimmers (the CS group) and nine recreational male swimmers (the RS group) performed a maximal 200 m front crawl swimming with self-selected breathing pattern. Stroke rate (SR) and breathing frequency (BF) were measured during the swimming test. Measures also included blood lactate concentration ([LA]) and parameters of blood acid-base status before and during the first minute after the swimming test. The CS group swam faster than the RS group. Both groups have similar and steady SR throughout the swimming test. This was not matched by similar BF in the CS group but matched it very well in the RS group ($r = 0.89$). At the beginning of swimming test the CS group had low BF, but they increased it throughout the swimming test. The BF at the RS group remained constant with only minor variations throughout the swimming test. Such difference in velocity and breathing resulted in maintaining of blood P_{O_2} from hypoxia and P_{CO_2} from hypercapnia. This was similar in both groups. [LA] increased faster in the CS group than in the RS group. On the contrary, the rate of pH decrease remained similar in both groups. The former competitive swimmers showed three possible advantages in comparison to recreational swimmers during maximal 200 m front crawl swimming: a more dynamic and precise regulation of breathing, more powerful bicarbonate buffering system and better synchronization between breathing needs and breathing response during swimming.

Key words: Swimming, freestyle, breathing, blood gas, acid-base status.

Introduction

The swimming activity, in relation to dry land activities, is strictly technique-dependent breathing (Holmér et al., 1974). Breathing in swimming is synchronised with swimming strokes. In all swimming techniques except in backstroke, expiration takes place under water and, accordingly, against greater resistance than in air. Furthermore, breathing frequency (BF) has to be in accordance with the stroke rate (SR). Swimmers could also manipulate with different breathing patterns during front crawl swimming. Usually, they take breaths every second stroke cycle. However, they could reduce BF with taking breath every fourth, fifth, sixth or eighth stroke cycle. Reduced breathing patterns are often used during the final part of

the competition races, when swimmers try to finish as fast as possible.

Despite limitation of the pulmonary ventilation (V_E) during front crawl swimming, arterial oxygen saturation was maintained high, indicating sufficient supply of oxygen to working muscle (Holmér et al., 1974). On the contrary, impaired V_E during front crawl swimming seemed to interfere with elimination of carbon dioxide (Magel and Faulkner, 1967; Ušaj, 1999). The dramatic increase of V_E and consequently the decrease of arterial partial pressure of carbon dioxide (P_{CO_2}) are well documented phenomena during intense cycle ergometer exercise (Stringer et al., 1992). However, the increase of V_E during front crawl swimming did not result in significant decrease of P_{CO_2} (Ušaj, 1999). P_{CO_2} frequently increased during high and/or maximal front crawl swimming reaching the limit of hypercapnia. It may be assumed that for preventing hypercapnia the pulmonary ventilation is limited by relatively slow breathing cycles during high and/or maximal intensity front crawl swimming.

Furthermore, durations of breathing phases during front crawl swimming changed as a function of skill level (Lerda and Cardelli, 2003). Considering that, it could be questioned whether different performance level swimmers (competitive, former competitive and recreational level) reached different values of blood gas and acid-base parameters during maximal front crawl swimming. It is known that competitive swimmers are able to precisely regulate their velocity and BF during maximal front crawl swimming so as to create the appearance of critical acidosis only at the end of swimming (Štrumbelj et al., 1999). With increased V_E they could reduce magnitude of changes in blood gas parameters (to protect against severe hypercapnia and hypoxia) and minimize disorders in acid-base (acidosis) and electrolyte status. According to that, it could be assumed that competitive swimmers throughout a high intensity competitive training may improve gas exchange regulation to be more precise and effective. In addition, it is questionable if recreational swimmers also adjusted their breathing to high metabolic demands during maximal front crawl swimming as efficient as competitive swimmers. Recreational swimmers are well-skilled, however, they do not have experience with this kind of demands. Considering that highly trained competitive swimmers are usually difficult to persuade to participate in experiments, former competitive swimmers were measured in the present study. According to experiences of former competitive swimmers and swimming coaches it could be suggested that expecting adaptations of competitive swimming training still lasted one or two years

after finishing competitive career (on condition that swimmers did not stop exercising completely). Therefore, the aim of the present study was to ascertain whether maximal 200 m front crawl swimming strategies and breathing patterns influenced blood gas and acid-base parameters in a manner which gives advantage to former competitive swimmers in comparison with their recreational colleagues.

Methods

Subject

Twelve former competitive male swimmers (CS group; age: 23 ± 2 years, height: 1.81 ± 0.06 m, body mass: 77.2 ± 8.3 kg) and nine recreational level male swimmers (RS group; age: 16 ± 2 years, height: 1.80 ± 0.08 m, body mass: 69.4 ± 7.4 kg) volunteered to participate in this study. Former competitive swimmers had more than eight years of competitive swimming experience and they finished their swimming careers at least two years ago. During the competitive careers they were mostly middle-distance specialists (200 – 400 m) at national level. Therefore, they were adapted on high and maximal intensity training, which was practiced mainly twice per day for a several years. After finishing their competitive careers, they still practiced swimming three times per week to remain in good physical fitness. Recreational swimmers have been trained for at least five years. They had never more than three training sessions per week. The intensity of their training has been sub maximal. The goal of their training was mainly to improve swimming technique. Therefore they were well-skilled swimmers, without experiences with competitive and maximal intensity swimming.

Procedures

Swimmers warmed up with some flexibility exercise on land and 800 m swimming at lower intensity. Then, they finished it with one maximal 25 m front crawl swimming. Following warming up, swimmers performed maximal 200 m front crawl swimming. Each swimmer swam alone. They were instructed to swim as fast as possible without any predefined swimming strategy. They chose their own patterns of velocity, SR and BF during swimming. The swimming test was performed in a 25 m indoor pool with a water temperature of 27 °C.

Measurements

Swimming time per each 25 m distances was measured by using digital CASIO stopwatch (Casio Electronics Co., London, United Kingdom). The swimming test was filmed from the side using video camera (DCR-TRV 410E, PAL standard recorder, Sony, Tokyo, Japan) operating at 25 Hz. Velocity for each 25 m was calculated by dividing the time with 25 m. The measures of stroke parameters were taken from videotapes. The elapsed time for five complete one arm stroke cycles during about 12 m section of each pool length was measured to calculate SR (stroke cycles \times s⁻¹). BF was calculated by dividing the number of breaths with the time, which were both measured during the swimming test. SR and BF were measured for each 25 m.

Measures of blood parameters included lactate concentration ([LA]), partial pressure of blood O₂ (P_{O₂}) and CO₂ (P_{CO₂}) and pH before and during the first and third minute after the swimming test. Capillary blood samples (60 – 80 μ l) were taken by micro puncture from a hyperemied earlobe. Blood samples for measuring [LA] were diluted in a LKM41 lactate solution (Dr. Lange, Berlin, Germany) and analysed using the MINI8 (Dr. Lange, Berlin, Germany) photometer. Blood samples for measuring P_{CO₂}, P_{O₂}, and pH were collected in heparinized glass capillaries and introduced into the blood gas analyser ABL5 (Radiometer, Copenhagen, Denmark).

Observations

Different swimming strategies during high intensity swimming may influence on metabolic parameters in a different manner (Thompson et al., 2004). Considering that, the subjects within each group were divided into sub-groups according to their pattern of velocity. The individual data of velocity for every 25 m were plotted against distance. The plot velocity/distance for each subject was examined visually to select subjects with a similar pattern of velocity within each group. The main criterion for group selection was a change (increase or decrease) of velocity at final 50 m. After this selection, the majority within each group represented the CS and RS group, respectively. The swimmers in each testing group who used a different pattern of velocity (the CSa and RSa group; as mentioned in the following chapter, the swimmers in these groups increased their velocity during the final 50 m) were analyzed and compared with the CS and RS group separately.

Calculations

In order to describe the changes of velocity, SR and BF during the swimming test the data of these parameters were fitted by linear interpolation for each subject. Considering that velocity and SR significantly changed after the first 50 m during 200 m front crawl event (Sidney et al., 1999) the linear regression model was used without the data measured at the first 25 m. Therefore the pattern of velocity was described individually by using a linear model:

$$v_s = v_{50} - b \times s \text{ (m/s)} \quad \text{(Equation 1)}$$

where v_s is velocity at distance s (v_{50} is velocity at 50 m distance), b represents the slope coefficient of regression line or rate of velocity decrease ($\Delta v/s$) and s is the selected distance (m). The same method was used for estimating the patterns of SR and BF.

The rate of [LA] increase that occurred during the swimming test (RLA) was additionally calculated for each subject by using the following equation:

$$RLA = \frac{\Delta[LA]}{t} \quad \text{(Equation 2)}$$

where $\Delta[LA]$ is the difference between [LA] measured during the first minute after and before the swimming test and t is the time (t) needed for completing the swimming test. The result was expressed as a change of [LA] per minute (mmol \cdot l⁻¹ \cdot min⁻¹). The same method was used for calculating the rate of pH decrease that occurred during the swimming test (RpH).

Statistical analyses

The results were presented as average values and standard deviations (SD). Normal distribution for each variable was tested using Kolmogorov Smirnov test. The independent *t* test was used to compare the data between groups. For statistical analysis of blood parameters the ANOVA for repeated measurements was carried out using swimming level (former competitive – recreational) and swimming test (before – during the first minute after) as factors (between and within factors, respectively). The Pearson's coefficient was computed to test linear correlation between SR and BF during the swimming test. A 95% level of confidence was accepted for all comparisons. All statistical parameters were calculated using the statistics package SPSS (SPSS Inc., Chicago, United States of America) and the graphical statistics package Sigma Plot (Jandel, Tübingen, Germany).

Results

Most of the former competitive and recreational swimmers continuously decreased their velocity during 200 m distance. These swimmers made up the CS group (ten former competitive swimmers) and the RS group (six recreational swimmers). However, two former competitive swimmers and three recreational swimmers dramatically increased their velocity during the final 50 m. Therefore, these swimmers made up the CSa and RSa group, respectively. Because of an acceptable number of subjects only the data of the CS and RS group were statistically analysed in full.

After the selection, the pattern of velocity became more homogenous: from the first 50 m, where velocity was the highest (except in the starting phase), it continuously decreased to the end of swimming (Figure 1). There were significant differences in velocity at every 50 m between the CS and RS group.

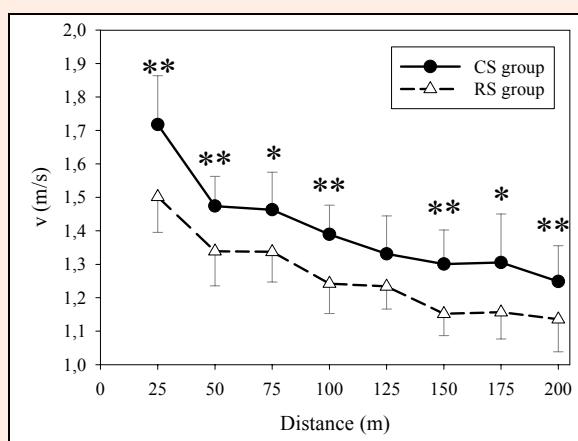


Figure 1. Comparisons of velocity (*v*) during maximal 200 m front crawl swimming between the CS (circles) and RS (triangles) group. * and ** denote $p < 0.05$ and 0.01 respectively between the groups.

When individual data of velocity were fitted by a linear model, then v_{50} showed clear difference between both groups (Table 1). However, the rate of velocity de-

crease through the swimming test was similar in both groups.

Table 1. Average values (\pm SD) of the pattern of velocity (*v*), stroke rate (SR) and breathing frequency (BF) during the swimming test calculated from individual regression lines.

	CS group	RS group
v_{50} ($\text{m}\cdot\text{s}^{-1}$)	1.57 (.1)	1.42 (.11) *
$\Delta v/s$ ($\text{m}\cdot\text{s}^{-1}\cdot 100 \text{ m}^{-1}$)	.16 (.72)	.16 (.69)
SR ₅₀ (Hz)	.71 (.1)	.7 (.1)
$\Delta\text{SR}/s$ ($\text{Hz}\cdot 100 \text{ m}^{-1}$)	-.03 (.05)	-.01 (.03)
BF ₅₀ (min^{-1})	25 (7)	36 (5) **
$\Delta\text{BF}/s$ ($\text{min}\cdot 100 \text{ m}^{-1}$)	2.92 (3.81)	.19 (.95)

* and ** denote $p < 0.05$ and 0.01 respectively between the groups.

There were no significant differences in SR during maximal 200 m front crawl swimming between the CS and RS group (Figure 2). Furthermore the patterns of SR did not differ between both groups (Table 1).

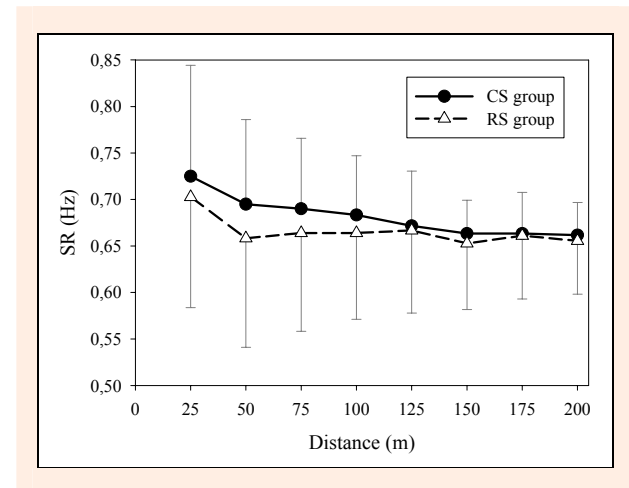


Figure 2. Comparisons of stroke rate (SR) during maximal 200 m front crawl swimming between the CS (circles) and RS group (triangles). There were no significant differences between groups.

There was a significant difference in BF₅₀ between the CS and RS group (Table 1). All swimmers in the RS group maintained their BF close to steady fluctuations or they increased it very slightly throughout the swimming test (Figure 3). On the contrary, there was much variability in the pattern of BF in the CS group (as shown in Table 1 there was a high standard deviation in $\Delta\text{BF}/s$ calculated at this group).

A comparison of BF and SR during the swimming test showed a clear difference between both groups (Figure 4 on the left and on the right). Significant correlation existed between SR and BF in the RS group ($r = 0.89$, $p \leq 0.01$). On the contrary, BF independently changed from SR in the CS group ($r = 0.01$, $p \geq 0.05$).

Parameters of blood-gas (Po_2 and Pco_2), acid-base status (pH) and lactate concentration ([LA]) obtained before and in the first and third minute after the swimming test are given in Table 2 (the CS group) and Table 3 (the RS group).

As shown in Table 2 and Table 3 Po_2 and Pco_2 did not change significantly during the swimming test. There were no significant differences between both groups in these two parameters. During the swimming test [LA] and

pH were significantly increased and decreased ($p \leq 0.01$), respectively. Changes reached similar values at both groups. However, these similar changes occurred at different velocities, therefore at shorter periods of time in the CS group. According to this, the RLA was significantly higher ($4.9 \pm 0.9 \text{ mmol}\cdot\text{l}^{-1}\cdot\text{min}^{-1}$) in the CS group than in the RS group ($4.0 \pm 0.6 \text{ mmol}\cdot\text{l}^{-1}\cdot\text{min}^{-1}$) ($p \leq 0.05$) (Figure 5 on the left). On the contrary, there were no significant differences in RpH between groups ($-0.08 \pm 0.03 \text{ min}^{-1}$ in the CS group and $-0.09 \pm 0.02 \text{ min}^{-1}$ in the RS group) (Figure 5 on the right).

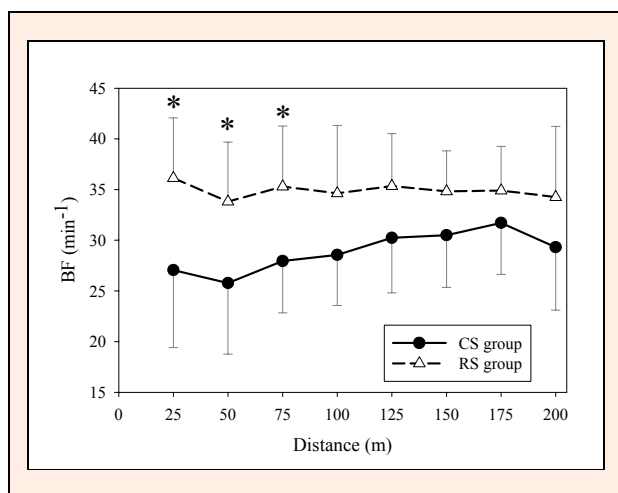


Figure 3. Comparisons of breathing frequency (BF) during maximal 200 m front crawl swimming between the CS (circles) and RS group (triangles). * denote $p < 0.05$ between the groups.

The data obtained from the CSa and RSa group are presented in the Table 4. These data were not statistically analysed by inferential procedures. Two swimmers in the CSa group decreased their velocity during the first 100 m, but they dramatically increased it at the end of the swimming test. According to final results, they were the fastest swimmers. They had a similar BF during the swimming test as swimmers in the CS group. They also increased their BF throughout the swimming test in a similar pattern as other former competitive swimmers. However, they swam with the lowest SR. Despite of the highest velocity they maintained their blood gas parameters within the same limits as their colleagues in the CS group (Table 4). Acid-base and [LA] parameters changed in a similar manner and magnitude as in the CS group. Three swimmers in the RSa group decreased their velocity through the first 100 m and then increased it at the last 50 m. However, their average velocity was not higher than in the RS group. They swam with lower SR and BF than the RS group. Their Pco_2 showed a clear tendency to be higher after the swimming test than before it (Table 4).

Discussion

The aim of the present study was to ascertain whether maximal 200 m front crawl swimming strategies and breathing patterns influenced blood gas and acid-base parameters in a manner which gives advantage to former competitive swimmers in comparison with their recreational colleagues. As expected, the CS group swam maximal 200 m front crawl swimming significantly faster than the RC group (Table 1). There were no significant differences in SR during the swimming test between both groups (Figure 2). However, high standard deviations calculated in this stroke parameter at both groups showed large variation between swimmers in the pattern of SR during the swimming test. Some swimmers decreased it, in others it remained constant and for a few others, SR increased as the swimming test progressed. Results of some previous studies (Chatard et al., 2003; Kjendlie et

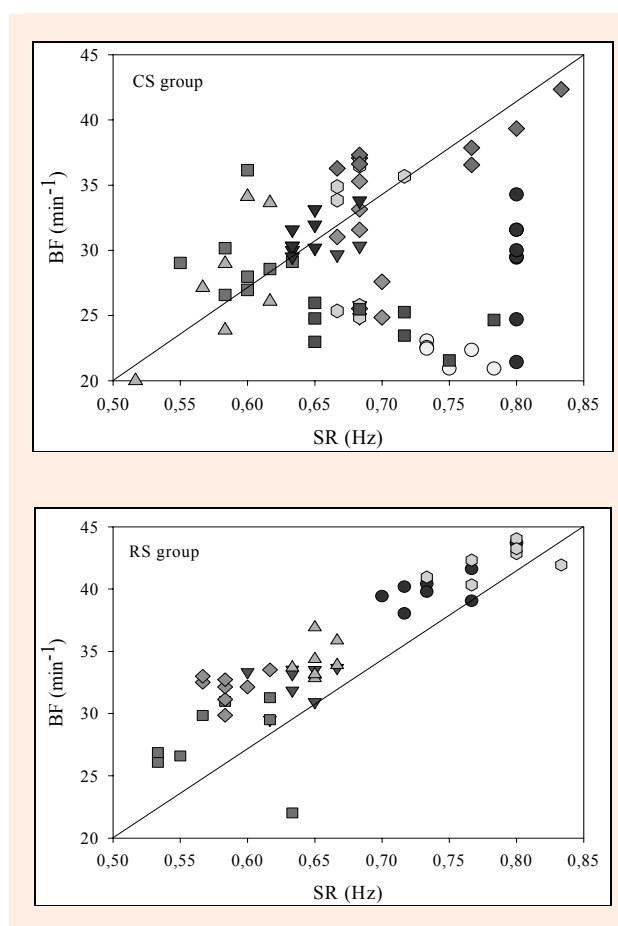


Figure 4. Individual relationships between BF and SR during the swimming test in the CS group (top) and RS group (bottom, $r = 0.89$, $p \leq 0.01$). Equal symbols represent the data measured in the same subject at different distances.

Table 2. Average values (\pm SD) of blood parameters and differences between measurements during the first minute after the swimming test and measurements before the swimming test (Δ) in the CS group.

	Before	After (1st min)	After (3rd min)	Δ
Po_2 (kPa)	11.8 (1.2)	12.7 (1.1)	16.2 (2.6)	.8 (1.2)
Pco_2 (kPa)	5.1 (.2)	5.1 (.5)	3.9 (.7)	.0 (.4)
pH	7.38 (.07)	7.21 (.06)	7.18 (.05)	-.18 (.07) **
[LA] (mmol/l)	2.5 (1.0)	14.2 (1.7)	15.6 (1.9)	11.7 (1.9) **

** denote $p < 0.01$ between the values measured before and during the first minute after the swimming test.

Table 3. Average values (\pm SD) of blood parameters and differences between measurements during the first minute after the swimming test and measurements before the swimming test (Δ) in the RS group.

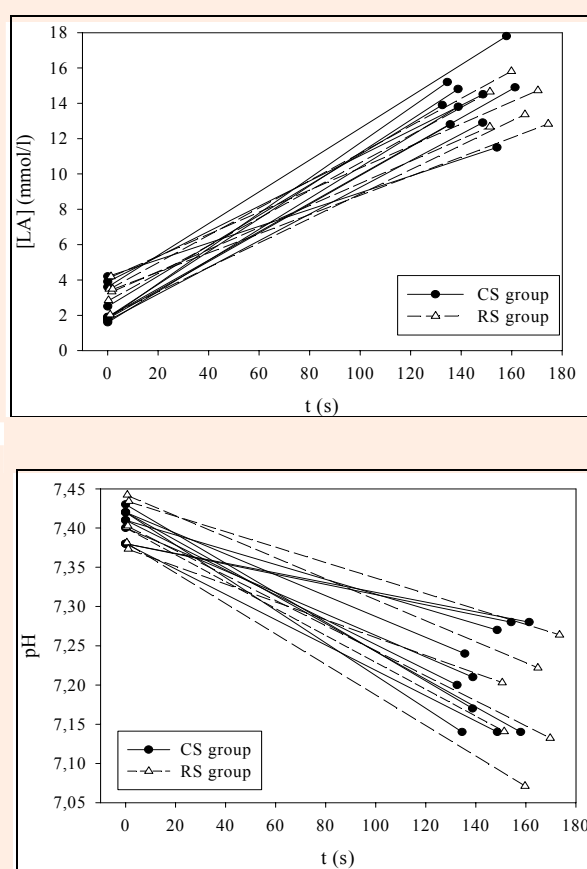
	Before	After (1st min)	After (3rd min)	Δ
Po ₂ (kPa)	11.0 (1.7)	11.0 (1.1)	13.7 (2.6)	.0 (1.7)
Pco ₂ (kPa)	4.8 (.4)	5.2 (.6)	4.2 (.4)	.4 (.5)
pH	7.40 (.03)	7.17 (.07)	7.13 (.07)	-.23 (.06) **
[LA] (mmol/l)	3.1 (.7)	13.8 (1.3)	15.1 (1.4)	10.7 (1.3) **

** denote $p < 0.01$ between the values measured before and during the first minute after the swimming test.

al., 2006; Sidney et al., 1999) also did not show consistent pattern of SR during different competition races. In addition, swimming velocity is product of SR and stroke length. Considering that, it could be assumed that the CS group had longer stroke length than the RS group. According to Keskinen (1993), this could be primarily due to higher swimming efficiency in the CS group in comparison with the RS group. However, this could be only an assumption, considering that clean velocity was not calculated in present study. The measurements of velocity should be taken over a distance of 15 m in order to ignore the changes in velocity at start and turns.

Despite a higher velocity former competitive swimmers (the CS and CSa group) swam with a lower BF in the first half of the swimming test than the RS group. In addition, they increased their BF in the second half of the swimming test probably to maintain the breathing dependent blood gases in a certain range where they did not stimulate the breathing too intensively. These results were in accordance with the results of Štrumbelj et al. (1999) who also obtained similar Pco₂ values before and after maximal 400 m front crawl swimming at competitive swimmers. Therefore, in contrast to expectations, the former competitive swimmers maintained their parameters influenced by breathing successfully in the certain range, away from hypercapnia and/or hypoxia despite of maximal intensity swimming. They achieved better regulation of blood gas and pH parameters by more dynamic regulation of velocity and breathing. The RS group seemed to reach a similar goal too, however, at lower swimming velocities. The rate of velocity decrease through the 200 m distance was similar in the CS and RS group. However, three recreational swimmers (the RSa group) used a different pattern of velocity as in the RS group. Swimmers in the RSa group increased their velocity during the final 50 m; however, they were not the fastest among recreational swimmers. Furthermore, the RSa group also swam with the lowest SR and BF with clear consequences: their Pco₂ changed more dramatically and differently as in other groups despite their similar pH and [LA]. It seemed that they were not adapted for a precise and dynamic regulation of breathing during

maximal effort. In trying to answer the question whether the former competitive swimmers would show any advantage to recreational swimmers according to their breathing it seemed that the former competitive groups of swimmers (the CS and CSa group) developed a more precise and dynamic regulation of breathing during maximal 200 m front crawl swimming than the recreational group of swimmers (the RS and the RSa group). Former

**Figure 5.** The individual changes of [LA] (top) and pH (bottom) during the swimming test in the CS group (the slopes of solid lines) and in the RS group (the slopes of dashed lines).**Table 4.** Average values (\pm SD) of blood parameters and differences between measurements during the first minute after the swimming test and measurements before the swimming test (Δ) in the CSa and RSa groups.

	CSa group				RSa group			
	Before	After (1st min)	After (3rd min)	Δ	Before	After (1st min)	After (3rd min)	Δ
Po ₂ (kPa)	11.3 (.9)	12.2 (.4)	13.7 (.7)	.9 (.6)	10.6 (.4)	10.8 (.5)	13.3 (.1)	.2 (.1)
Pco ₂ (kPa)	4.9 (.5)	4.8 (.3)	4.3 (.1)	-.1 (.8)	4.6 (.3)	5.3 (.2)	4.3 (.2)	.7 (.1)
pH	7.42 (.03)	7.25 (.01)	7.19 (.02)	-.17 (.05)	7.43 (.01)	7.23 (.02)	7.23 (.03)	-.21 (.03)
[LA] (mmol/l)	1.7 (.3)	11.5 (.2)	12.9 (.9)	9.8 (.5)	2.6 (.9)	11.9 (1.7)	11.9 (1.4)	9.3 (.8)

competitive swimmers started with a low BF because they did not need to breathe frequently. However, they increased their BF dramatically when they needed to. They acquired this pattern of BF through many years of intense training and competitions. On the contrary, recreational swimmers did not show this pattern. Their BF matched their SR (Figure 4 on the right). This pattern enabled a successful regulation of blood gases in the RS group. Furthermore, swimmers in the RSa group used the lowest BF without additional corrections during the swimming test. These conditions probably resulted in an increase of their P_{CO_2} . Cardelli et al. (1999) obtained similar differences in pattern of BF during maximal 100 m front crawl between more and less expert swimmers. They suggested several physiological and biomechanical interpretations for such conditions. However, we argued against their conclusion that avoiding too strong oxygen deficit is the reason for earlier use of a high breathing frequency at less expert swimmers in comparison with more expert swimmers. Results of the preset study suggested that elevated P_{CO_2} rather than lower P_{O_2} was the main stimulus for higher breathing frequency during the swimming test at the RS group than at the CS group.

In our study the high velocity was accompanied by an increased [LA] and decreased pH during the swimming test. The values of [LA], measured during the first and third minute after the swimming test, indicate the maximality of the swimming exercise. These results were close to results of Bonifazi et al. (1993) who measured [LA] after competition. Between the CS and RS group there were no significant differences in the values of [LA] and pH measured after the swimming test as well as in the changes of these parameters during the swimming test. However, the changes of [LA] and pH during the swimming test happened in a shorter period of time in the CS group in comparison with the RS group. Considering that, we also compared the rates of [LA] increase and pH decrease between both groups. The rates of [LA] increase were higher in the CS group and lower in the RS group. However, the rates of pH decrease were similar in both groups. This indicates that the CS group had probably more sensitive, dynamic and powerful regulation of the bicarbonate buffering system. This regulation mainly depends on breathing. This seemed to be one of advantages of the CS group.

Additionally, the pattern of BF at the CS group (initially low and increased during the swimming test) showed a probably better integrative adaptation of this group to higher swimming velocities by using several mechanisms, as follows. First, lower BF during swimming is partly compensated with larger tidal volumes (Peyrebrune et al., 2003; Town and Vanness, 1990; West et al., 2005). Larger tidal volumes may represent a larger initial reserve for increasing pulmonary ventilation during maximal swimming. This was probably realized during the second half of the swimming test by using a higher BF at the CS group. We assume that former competitive swimmers (the CS and CSa group) can achieve this goal at faster swimming because of a larger vital capacity of lungs and consequently larger tidal volume during swimming. Second, a lower BF during swimming may have

some biomechanical advantage for a swimmer's performance. Lerda et al. (2001) analysed the interactions of breathing and arm actions in the front crawl. They found that breathing while swimming increased the discontinuity in the propulsive action of the arms. This greater continuity, in addition to the improved gliding position of the body obtained in a front crawl without breathing could result in greater swimming efficiency by reducing energy cost (Chatard et al., 1990) and hydrodynamic resistance (Kolmogorov and Duplisheva, 1992). These facts could enable faster swimming when lower BF is used (Pedersen and Kjendlie, 2006).

These were characteristics that may represent possible advantage factors of the CS group. However, it can not be concluded that the RS group is not adequately adapted for front crawl swimming. The RS group was training for at least five years, never more than three training sessions per week. The main goal of their training was to improve their swimming technique. Therefore, they trained at a lower intensity of swimming without any reduced breathing frequency and preparations for competitions. Consequently, they became adapted to such a type of training and not to maximal effort during 200 m front crawl swimming. On the contrary, the CS group was better adapted to maximal effort during 200 m front crawl swimming. Their training program often included a higher and maximal intensity of swimming and preparations for competitions. They also frequently trained with reduced breathing frequency. This kind of training (also often referred to as hypoxic training or controlled breathing frequency training) adapts swimmer to swim with fewer breaths (Kapus et al., 2005). Adaptation to hypercapnia and respiratory acidosis could also be the result of such training (Dicker et al., 1980; Kapus et al., 2003; Town and Vanness, 1990).

Presented differences between both groups were mostly related to more powerful energetic processes and to more dynamic and precise regulation of breathing in the CS group. This adaptation could be realized only by an intense and long period of swimming training at selected (not all) subjects. Therefore, this was the reason why there were age differences between both groups in the present study. For a swimmer it is not possible to reach the international level and to adapt in such a manner that corresponds to the CS group in a short period of time of training. On the contrary, the adaptations characteristic of the recreational level can be obtained in a much shorter time.

Conclusion

The former competitive swimmers showed three possible advantages in comparison to recreational swimmers during maximal 200 m front crawl swimming: a more dynamic and precise regulation of breathing, more powerful bicarbonate buffering system and better synchronization between breathing needs and breathing response during swimming.

Acknowledgments

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References

- Bonifazi, M., Martelli, G., Marugo, L., Sardella, F. and Carli, G. (1993) Blood lactate accumulation in top level swimmers following competition. *Journal of Sports Medicine and Physical Fitness* **33**, 13-18.
- Cardelli, C., Chollet, D. and Lerda, R. (1999) Analysis of the 100-m front crawl as a function of skill level in non-expert swimmers. *Journal of Human Movement Studies* **36**, 51-74.
- Chatard, J.C., Collomp, C., Maglischo, E. and Maglischo, C. (1990) Swimming skill and stroking characteristics of front crawl swimmers. *International Journal of Sports Medicine* **11**, 156-161.
- Chatard, J.C., Girold, S., Caudal, N., Cossor, J. and Mason, B. (2003) Analysis of the 200m events in the Sydney Olympic Games. In: *Biomechanics and medicine in swimming 9*. Ed: Chatard, J.C. 1th edition. Saint-Etienne: Laboratoire de Physiologie and Service de Exploration Fonctionnelle Cardio-respiratoire et de Medecine du Sport. 261-264.
- Dicker, S.G., Lofthus, G.K., Thornton, N.W. and Brooks, G.A. (1980) Respiratory and heart rate responses to controlled frequency breathing swimming. *Medicine and Science in Sport and Exercise* **1**, 20-23.
- Holmér, I., Stein, E.M., Saltin, B., Ekblom, B. and Astrand, P.O. (1974) Hemodynamic and respiratory responses compared in swimming and running. *Journal of Applied Physiology* **37**, 49-54.
- Kapus, J., Ušaj, B., Kapus, V. and Štrumbelj, B. (2003) Influence of reduced breathing during intense front crawl swimming on some respiratory and metabolic values in blood. *Kinesiologia Slovenica* **9**, 12-17.
- Kapus, J., Ušaj, B., Kapus, V. and Štrumbelj, B. (2005) The influence of training with reduced breathing frequency in front crawl swimming during a maximal 200 meters front crawl performance. *Kinesiologia Slovenica* **11**, 17-24.
- Keskinen, K.L. (1993) *Stroking characteristics of front crawl swimming*. 1th edition. University of Jyväskylä, Finland.
- Kjendlie, P.L., Hajland, R., Fjørtoft, O. and Stallman, R.K. (2006) Stroke frequency strategies of international and national swimmers in 100m races. In: *Biomechanics and medicine in swimming 10*. Eds: Vilas-Boas, J.P., Alves, F., Marques, A. 1th edition. Porto: Portuguese Journal of Sport Sciences. 52-54.
- Kolmogorov, S.V. and Duplisheva, A. (1992) Active drag, useful mechanical power output and hydrodynamic force coefficient in different genders and performance levels. *Journal of Biomechanics* **25**, 311-318.
- Lerda, R. and Cardelli, C. (2003) Breathing and propelling in crawl as function of skill and swimming velocity. *International Journal of Sports Medicine* **24**, 75-80.
- Lerda, R., Cardelli, C. and Chollet, D. (2001) Analysis of the interactions between breathing and arm actions in the front crawl. *Journal of Human Movement Studies* **40**, 129-144.
- Magel, J.R. and Faulkner, J.A. (1967) Maximum oxygen uptakes on college swimmers. *Journal of Applied Physiology* **22**, 929-938.
- Pedersen T. and Kjendlie P.L. (2006) The effect of breathing action on velocity in front crawl swimming. In: *Biomechanics and medicine in swimming 10*. Eds: Vilas-Boas, J.P., Alves, F., Marques, A. 1th edition. Porto: Portuguese Journal of Sport Sciences. 75-77.
- Peyrebrune, M., Robinson, J., Lakomy, H. and Nevill, M. (2003) Effects of controlled frequency breathing on maximal tethered swimming performance. In: *Biomechanics and medicine in swimming 9*. Ed: Chatard, J.C. 1th edition. Saint-Etienne: Laboratoire de Physiologie and Service de Exploration Fonctionnelle Cardio-respiratoire et de Medecine du Sport. 289-294.
- Sidney, M., Delhay, B., Baillon, M. and Pelayo, P. (1999) Stroke frequency evolution during 100-m and 200-m events front crawl swimming. In: *Biomechanics and Medicine in Swimming VIII*. Ed: Keskinen, K.L., Komi, P.V., Hollander, A.P. 1th edition. Jyväskylä: University of Jyväskylä, Gummerus Printing. 71-75.
- Stringer, W., Casaburi, R. and Wasserman, K. (1992) Acid-base regulation during exercise and recovery in humans. *Journal of Applied Physiology* **72**, 954-961.
- Štrumbelj, B., Ušaj, A., Kapus, V. and Bednarik, J. (1999) Some factors influencing performance on 400 meters freestyle swimming. In: *Sport kinetics*. Eds: Strojnik, V., Ušaj, A. 1th edition. Ljubljana: University of Ljubljana, Faculty of Sport. 379-382.
- Thompson, K.G., MacLaren, D.P.M., Lees, A. and Atkinson, G. (2004) The effects of changing pace on metabolism and stroke characteristics during high-speed breaststroke swimming. *Journal of Sport Sciences* **22**, 149-157.
- Town, G.P. and Vanness, J.M. (1990) Metabolic responses to controlled frequency breathing in competitive swimmers. *Medicine Science in Sport and Exercise* **22**, 112-116.
- Ušaj, A. (1999) The characteristics of acidosis after maximal front crawl swimming on 400 m. In: *Sport kinetics*. Eds: Strojnik, V., Ušaj, A. 1th edition. Ljubljana: University of Ljubljana, Faculty of Sport. 398-401.
- West, S.A., Drummond, M.J., VanNess, J.M. and Ciccolella, M.E. (2005) Blood lactate and metabolic responses to controlled frequency breathing during graded swimming. *Journal of Strength and Conditioning Research* **19**, 772-776.

Key points

- Training programs for competitive swimmers should promote adaptations to maximal efforts.
- Those adaptations should include high and maximal intensity swims with controlled breathing frequency (taking breath every fourth, fifth, sixth or eighth stroke cycle for front crawl swimming).
- Such training will improve breathing regulation in order to impose a better synchronization between breathing needs and breathing response during maximal swimming.

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