INVITED CONTRIBUTION

ENERGETICS IN COMPETITIVE SWIMMING AND ITS APPLICATION FOR TRAINING

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Competitive swimming events consist of different distances from 50m to 1500m. Since the exercise intensity and the relative importance of aerobic and anaerobic energy processes vary depending on the exercise time (and thus swimming distance), training regimen should be developed in accordance to time dependent metabolic profile. To understand the time dependent metabolic profile of arm stroke (A), leg kick (K) as well as whole body (S) swimming, the accumulated O_2 uptake (AOU) and the accumulated O_2 deficit (AOD) were determined at six different water flow. The AOU increased linearly with exercise time in all strokes, and the increased rate of AOU in A and K corresponded to 70, and 80% in S, respectively. The AOD in A and S significantly increased until 2-3min of exercise time, while the AOD in K more rapidly increased and the AOD at 30 s was not significantly different from those at 1 min and 2-3min. These results concerning time dependent metabolic profile in A, K, and S, would give a helpful information to plan training successfully to improve the metabolic capacity for each stroke.
Training effects of a moderate–intensity continuous training (CT) and a high-intensity intermittent training (IT), which are the most popular training regimens in competitive swimming, on $\dot{V}O_2$max and maximal accumulated O_2 deficit (MAOD) were evaluated. After the training, $\dot{V}O_2$max increased significantly in both training modes. On the other hand, MAOD did not increase significantly in CT, but in IT. These results indicate that CT can improve only aerobic power but that adequate IT can improve both aerobic power and anaerobic capacity.
Aerobic and anaerobic energy release in supramaximal swimming lasting 2-3 min were determined under different levels of hypobaric hypoxic condition. The exercise intensity (water flow rate) decreased with decrease in atmospheric pressure. During the exhaustive swimming, rate of aerobic energy release diminished with increase in hypobaric hypoxia, while not only AOD but also rate of anaerobic energy release throughout the exercise were unaffected despite the decreased O_2 demand caused by diminished exercise intensity due to hypobaric hypoxia.
Furthermore, the effects of high-intensity exercise training under a normal condition (C) and hypoxic conditions (H) on metabolic capacity were examined. After the training, $\dot{V}O_2$max significantly increased in both N and H, and no significant difference was observed in the increase ratio of $\dot{V}O_2$max between C and H. MAOD also significantly increased in both groups, however, the increase ratio of MAOD was significantly higher in H than C. The results suggest that the hypoxic training would be favorable for the improvement of the ability to supply anaerobic energy such as MAOD rather than $\dot{V}O_2$max.

Key Words: metabolic profile, specific training effect, energy dynamics, hypoxic training.

INTRODUCTION

Competitive swimming events consist of different distances from 50m to 1500m, and it takes approximately 23 seconds to 14 minutes 30 seconds to complete swimming those distance events. The required energy to swim a certain distance is supplied by aerobic and/or anaerobic energy processes, however, the relative importance of each energy process and also exercise intensity vary depending on the exercise time (and thus swimming distance) (Medbø 1989, Ogita 1996, 1999, 2003). Therefore, it is considered that coaches and swimmers should understand metabolic profile of each swimming distance event, what is more required for the swimmer, and how to strengthen the weak point, in order to develop effective and distance specific training program. By doing so, the performance could be improved more successfully.
This paper is summarized concerning to energetics in competitive swimming and its application for training. In particular, I would like to focus on following 4 topics using some of the recent our results; 1) metabolic profile corresponding each distance event, 2) specificity of training effect to various training program, 3) energetics during swimming under a normal and hypoxic conditions, and 4) new idea of hypoxic (high-altitude) training.

TIME DEPENDENT METABOLIC PROFILE

The propulsion during whole body swimming is generated by the action of both arms and legs. Therefore, daily swimming training is conducted not only by whole body swimming but also by arm stroke or leg kicking only, because it has been considered that to strengthen metabolic capacity in local muscles would improve more effectively whole body swimming performance. Therefore, if time dependent metabolic demands of arm stroke (A), leg kick (K) as well as whole body (S) swimming are clarified, the knowledge would provide an important implication for specific training of each distance event. So, the aerobic and anaerobic energy release were determined the at six different intensities, which were estimated to cause exhaustion in 15 s, 30 s, 1 min, 2-3 min, 4-5 min, and 8-10 min simulating from 25m sprint to 800m.

Aerobic and anaerobic energy release

The AOU increased linearly with exercise time in all strokes (Fig. 1). This means that the longer the duration (and thus the distance), the larger the total amount of aerobic energy release. Also, the increased rate of AOU related to exercise duration was the highest in S, and those in A and K corresponded to 70 and 80% of that in S, respectively. The ratio was similar to those when $\dot{V}O_2$max among strokes was compared (A: 2.80 $l \cdot min^{-1}$, K: 3.34 $l \cdot min^{-1}$, S: 3.92 $l \cdot min^{-1}$). Therefore, it is suggested that the increased rate of AOU is highly dependent on the magnitude of $\dot{V}O_2$max, supporting a general concept that a higher maximal aerobic power can be a more beneficial to accomplish a good performance for the endurance swimmer.
With increasing duration, the AOD in A and S significantly increased until 2-3min of exercise, and the AOD gradually decreased when the exercise duration was longer than 4-5min (Fig. 1). The AOD at 30s was not significantly different from those at 1 min and 2-3min. Several studies used running and cycling have also reported that the AOD reached maximal levels with exercise bouts lasting 2-3 min (Medbø 1988. Medbø 1989). Actually, it was revealed that the anaerobic ATP production estimated by lactate production and PCr break down was the highest in 2-3 min exhaustive exercise (Medbø 1993). These findings indicate that both the ATP-PCr system as well as the lactate producing system are stressed maximally with 2-3 min exhaustive exercise. Therefore, it is suggested that the

anaerobic energy system is recruited maximally in 200m swimming event, and consequently maxima AOD (MAOD) is recognized as an important factor determining the performance of this event.
On the other hand, the AOD in K increased more rapidly, and reached almost maximal levels in 30 s (>90% of maximal AOD). In addition, this level was observed in bouts lasting up to 2-3 min. Therefore, it is implies that the anaerobic energy release in K is different from the other strokes and that the swimmer can induce a maximal stimulus for the anaerobic energy process in leg muscles by maximal leg kicks of 50 m to 200 m. Consequently, this stimulus would induce the improvement of the anaerobic capacity in K, due to an increase in buffering capacity of leg muscles *per se*.

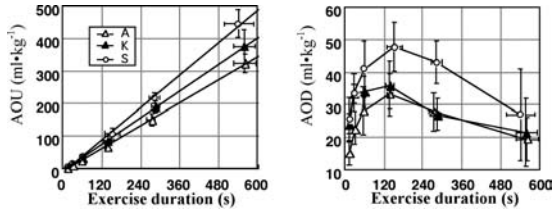

Fig. 1. The accumulated O2 uptake (AOU) and deficit (AOD) in relation to exercise duration in arm stroke (A), leg kicking (K), and whole swimming (S). (Ogita 2003)

Relative contribution of aerobic and anaerobic energy processes
The relative importance of anaerobic energy process in three strokes decreased from 78-85% for 15 s to 50 % for 1min, 30% for 2-3min where the anaerobic energy supply was at a maximum. Furthermore, it was only ~5% for 8-10min duration (Table 1). In general, short lasting exhaustive bout is recognized as so called "anaerobic exercise". However, our results reveal that even in exercise bout of 15s, the aerobic energy supply covered at least 15-20% of energy demand, while it covered more than 65% in 2-3 min bouts. Therefore, the contribution of the aerobic energy process even in short lasting bout should not be neglected. Also, the relative contribution of the aerobic and the anaerobic energy system was almost equal for 1 min exercise bouts. This suggests that both energy processes should be strengthened to improve the performance in 100m and 200m event.

Table 1. Accumulated O2 demand, uptake, deficit for exhausting bouts of different durations during A, K, and S.

		durations (s)	water flow rate (m•s-1)	accumulated O2 demand (l)	accumulated O2 uptake (l)	accumulated O2 deficit (l)	accumulated O2 deficit/ accumulated O2 demand (%)	O2 demand (%V̇O2max)
15s	A	14.4±0.4	1.49±0.05 **##	1.28±0.21 **##	0.27±0.07 **	1.02±0.24 **##	78.4±7.9	190±20#
	K	14.2±1.4	1.39±0.08 **	1.91±0.34	0.26±0.07	1.64±0.21	85.9±6.2	243±23
	S	15.5±1.4	1.69±0.06	2.08±0.43	0.36±0.03	1.73±0.45	82.1±6.3	205±32
30s	A	30.7±2.4	1.42±0.04 **##	2.38±0.39 **##	0.83±0.16 **	1.54±0.34 **##	64.4±7.9	166±17#
	K	30.0±1.5	1.09±0.05 **	3.18±0.34	0.92±0.24	2.26±0.20	71.3±6.2	191±17
	S	29.7±1.8	1.59±0.05	3.36±0.30	1.08±0.13	2.28±0.38	67.4±6.3	175±23
1min	A	58.3±2.4	1.33±0.04 **##	3.77±0.55 **#	1.85±0.19 **##	1.91±0.51 **#	50.0±8.2	138±12
	K	61.5±3.7	0.95±0.05 **	4.51±0.32 **	2.19±0.28 **	2.32±0.31	51.3±6.2	133±13
	S	61.3±3.4	1.45±0.04	5.50±0.59	2.72±0.28	2.78±0.59	50.1±7.3	138±14
2-3min	A	137.8± 8.1	1.21±0.03 **##	6.96±0.61 **##	4.71±0.36 **#	2.25±0.44 **	32.2±4.9	109±6
	K	138.7±10.8	0.88±0.05 **	8.28±1.16 *	5.84±0.90	2.44±0.49 *	29.5±5.1	107±6
	S	152.3±22.7	1.31±0.04	10.58±1.33	7.35±1.14	3.23±0.51	30.7±4.7	107±9
4-5min	A	272.7±12.2	1.15±0.04 **##	12.24±1.49 **##	10.36±1.16 **	1.88±0.40 **##	15.3±7.9	96±6
	K	284.6±11.2	0.84±0.05 **	14.81±1.72	12.98±1.28	1.82±0.53	12.1±6.2	93±4
	S	282.7±17.7	1.25±0.02	17.71±1.30	14.79±1.09	2.92±0.45	16.5±6.3	96±4
8-10 min	A	560.0±33.6	1.12±0.05 **##	23.34±1.91 **#	22.02±2.02 **##	1.32±0.45 **#	15.7±8.2	90±7
	K	557.9±33.2	0.81±0.06 **	26.96±3.08 **	25.51±3.51 **	1.45±0.70	15.6±6.2	87±2
	S	540.4±44.9	1.22±0.03	32.03±2.97	30.21±2.84	1.83±0.96	15.7±7.3	91±3

** P<0.01 vs S * P<0.05 vs S, ## P<0.01 vs K # P<0.05 vs K A : arm stroke, K : leg lick, S : whole body stroke

Exercise intensity
The relative exercise intensities expressed as %V̇O2max in relation to exercise duration longer than 1 min were comparable among A, K and S, and corresponded to 135%V̇O2max for the 1 min bout, 105-110%V̇O2max for the 2-3 min bout, and 95-100%V̇O2max for the 4-5 min bout. These results indicate that the 400m event is competed at almost 100%V̇O2max level, and that the shorter distance events are done at supramaximal intensities. This finding points out that the anaerobic training should be very important for most swimmers. In addition, in the 15 s and 30 s bout, the intensity in K was much higher than those in A and S (15 s : K 240%, A 190%, 30 s : K 190%, A 165% V̇O2max), and the intensities in S were intermediate between A and K (Table 1). Therefore, when the training consists of 25 m or 50 m sprints, it should be heeded that the exercise intensity expressed as %V̇O2max differ between A, S and K.
Conventionally, the magnitude of the training effect on metabolic capacity depends on the exercise intensity (Fox 1975). In other words, in order to improve the total metabolic capacity, adequate exercise intensity, taxing both aerobic and anaerobic energy processes, must be set. Therefore, the reported metabolic profiles (i.e. aerobic and anaerobic energy release and their relative contributions, relative exercise intensity and so on) in relation to exercise time in A, K, and S, gives helpful information to plan training successfully.

EFFECTS OF TRAINING MODES (OR INTENSITY) ON V̇O2max AND MAOD
Metabolic capacity has been considered to be one of important determinants of swimming performance. Therefore, the swimming training should be designed to improve the ability to release energy both aerobically and anaerobically. The most popular training regimens in competitive swimming are an intermittent (interval) training and a continuous (endurance) training. In general, the success of the training effect can and should be evaluated not only by an exercise performance but also by metabolic capacity such as V̇O2max and MAOD. So, we compared the specific training effect of different training protocols: a moderate-intensity endurance training and high-intensity intermittent training.
In this study, continuous training (CT) was performed at the intensity of 70%V̇O2max for 60 min•session^{-1}, on the other hand, intermittent training (IT) consisted of 7-8 sets of 20-s exercise at an intensity of 170% V̇O2max with a 10-s rest between each bout. Both trainings were done 5 days a week for 6 weeks.

The effect on V̇O2max and MAOD
After the training, V̇O2max increased from 53 to 58 ml•kg^{-1}•min^{-1} in CT, and 48 to 55 ml•kg^{-1}•min^{-1} in IT (Fig. 2). On the other hand, MAOD did not increase significantly in CT, but it increased by 28% in IT (Fig. 2). These results indicate that CT at moderate- intensity can improve aerobic power but not MAOD and that IT at high-intensity can improve both V̇O2max and MAOD simultaneously.

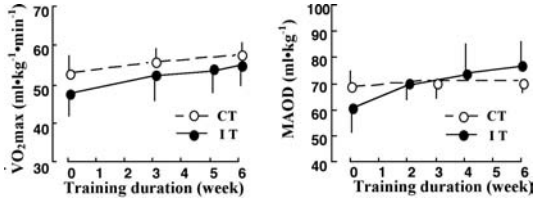

Fig. 2. Effect of moderate-intensity continuos training (CT) and high-intensity in termittent training (IT) on V̇O2 max and maximal accumulated O2 deficit (MAOD) (Tabata 1996).

These results suggest that CT at moderate-intensity is not intense enough training to improve anaerobic power. In fact, it has been proved that the used IT training protocol can tax maximally stimulus not only to aerobic but also to anaerobic energy process but that CT at moderate intensity does not (Tabata. 1996). As previously suggested, the greater stimulus to aimed energy system, the larger improvement of metabolic capacity. Accordingly, for short to middle distance swimmers who are proposed to be strengthened both energy processes, IT at high intensity must be more adequate training mode compared to CT at moderate intensity.

ENERGETICS IN SUPRAMAXIMAL SWIMMING UNDER HYPOXIC CONDITIONS

It has been well documented that $\dot{V}O_2$max reduces with decrease in atmospheric pressure, i.e. O_2 fraction. In addition, several investigations have shown that hypoxia results in slower O_2 uptake kinetics during exercise (Engelen 1996, Hughson 1995). Since steady-state $\dot{V}O_2$ during submaximal exercise is identical between normoxic and hypoxic conditions, this means that AOD is greater in hypoxia than in normoxia (Knuttgen 1973, Linnarson 1974). Indeed, a greater reduction in muscle phosphocreatine levels and greater increases in blood and muscle lactate concentrations have been observed during submaximal exercise in hypoxia compared with normoxia (Knuttgen 1973, Linnarson 1974).

On the other hand, there are few studies that investigated the effect of anaerobic energy release during exercise, especially supramaximal bout, on hypoxia. As mentioned in the first section, to improve MAOD as anaerobic capacity is very important for most swimmers. So, we attempted to clarify the aerobic and anaerobic energy release during supramaximal exhaustive swimming lasting 2-3 min, where anaerobic energy process is recruited maximally, under different hypoxic conditions (a normal condition; 999hPa, 800 m; 912hPa, 1600 m; 836hPa, and 2400 m above sea level; 751hPa).

$\dot{V}O_2$max in each condition

$\dot{V}O_2$max was significantly reduced as atmospheric pressure decreased. Compared to mean values of $\dot{V}O_2$max at sea level (4.28±0.53 l•min^{-1}), values were at 96% for 800 m (4.11±0.49 l•min^{-1}), 88% for 1600 m (3.76±0.44 l•min^{-1}), and 85% for 2400 m (3.63±0.44 l•min^{-1}).

Aerobic and anaerobic energy release during supramaximal exhaustive swimming

Mean water flow rate in the supramaximal swimming diminished significantly with decreased atmospheric pressure. However, when O_2 demand estimated from water flow rate was expressed as a percentage of $\dot{V}O_2$max, no significant differences were observed (Table 2). This means that even though absolute exercise intensity in hypoxic condition decreased due to a decrease in $\dot{V}O_2$max, the swimmers could swim relatively at the same intensity.

Table 2. Exercise duration, water flow rate, accumulated O2 demand, uptake, deficit, for supramaximal axhausting bout lasting 2-3 min.

		Sea level	800m	1600m	2400m
Exercise durations	(min)	2.26 ± 0.15	2.23 ± 0.13	2.27 ± 0.14	2.34 ± 0.24
Water flow rate	(m•s^{-1})	1.25 ± 0.03	1.23 ± 0.02 *	1.21 ± 0.02 *#	1.19 ± 0.02 *#$
Relative exercise intensity	%VO2max)	110 ± 7	111 ± 7	117 ± 11	115 ± 12
Accumulated O2 demand	(l)	10.67 ± 1.62	10.28 ± 1.97	10.02 ± 1.82	9.73 ± 1.98
Accumulated O2 uptake	(l)	7.30 ± 1.09	7.04 ± 1.11	6.88 ± 1.33	6.56 ± 1.15
Accumulated O2 deficit	(l)	3.36 ± 0.74	3.24 ± 0.92	3.14 ± 0.55	3.17 ± 0.99
Accumulated O2uptake/ Accumulated O2 demand	(%)	68.5 ± 4.7	68.5 ± 4.2	68.6 ± 2.3	67.4 ± 5.7
Accumulated O2 deficit / Accumulated O2 demand	(%)	31.5 ± 4.7	31.5 ± 4.2	31.4 ± 2.3	32.6 ± 5.7

* Indicates a significant difference vs normal condition (P<0.05).
# Indicates a significant difference vs 800 m above sea level (P<0.05)
$ Indicates a significant difference vs 1600 m above sea level (P<0.05)

VO_2 during the supramaximal swimming quickly increased at the beginning of exercise and almost reached a plateau within 2 min in all conditions (Fig. 3). However, mean VO_2 determined every 30 s as well as VO_2peak decreased with increasing hypoxia, and thus AOU tended to decrease with increased altitude (although no significant differences were identified) (Table 2). Also decrease in VO_2peak under hypoxic conditions was quite comparable to the decrease in $\dot{V}O_2$max under each hypoxic condition. Therefore, VO_2 during supramaximal exercise also appears to be directly affected by the level of hypobaric hypoxia throughout the exercise.

Conversely, changes in O_2 deficit determined every 30 s during the bout were quite comparable in all conditions (Fig. 3). Consequently, no significant differences were observed in MAOD between the conditions. This implies that the rate of anaerobic energy release during exercise is strongly associated with relative physiological stress regardless of inspiratory O_2 fraction, although underlying mechanisms remain unclear.

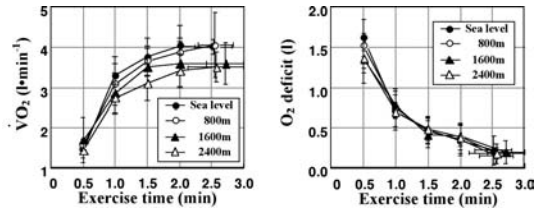

Fig. 3 Time course of Vo2 and O2 deficit measured every 30 s during supramaximal swimming under normal (sea level) and hypobaric hypoxic conditions corresponding to 800 m, 1600 m and 2400 m above sea level. (Ogita 2000)

Our results suggest that during supramaximal swimming, rate of aerobic energy release diminished with increase in hypobaric hypoxia, while not only AOD but also rate of anaerobic energy release throughout the exercise were unaffected despite the decreased O_2 demand caused by diminished exercise intensity due to hypobaric hypoxia. If so, hypoxic condition such as high altitude might be a better condition to tax easily a greater stimulus to anaerobic energy process regardless of the decrease in absolute exercise intensity.

ALTITUDE TRAINING – AEROBIC OR ANAEROBIC?

As altitude acclimatization occurs, hemoglobin concentration and thus arterial oxygen content increases. This physiological adaptation would expect also to increase maximal oxygen transport to active muscles during exercise. Therefore, training at altitude has been primarily performed for the purpose of improving $\dot{V}O_2$max, and thus, endurance exercise performance. However, according to the evidence that the higher the training stimulus to the aerobic or anaerobic energy process, the greater the increase in metabolic capacity (Fox 1975, Tabata 1996), the metabolic stimulus to the aerobic process under hypoxic conditions is lowered due to the reduction in $\dot{V}O_2$max, compared to that under normoxia (Levine 1992). Conversely, the capacity to supply anaerobic energy (MAOD) would not be limited by hypoxia (Medbø 1988, Ogita 2000). In addition, rate of anaerobic energy release during supramaximal swimming is unaffected by hypoxia despite the reduction in absolute exercise intensity. Furthermore, Weyand (1999) reported that sprint performance lasting ≤ 60 s was unaffected by hypoxia, even though aerobic power during hypoxia was significantly lower than that under normoxia, suggesting that reductions in aerobic energy during hypoxic sprints would be compensated by an increased rate of anaerobic energy release. All this suggests that anaerobic energy can achieve maximal release at a lower exercise intensity compared to that under normoxia, or may be more rapidly released when exercise is performed at the same absolute intensity as normoxia. In other words, hypoxic training can readily create the same or greater stimulus on the anaerobic energy process, and thus could more effectively improve MAOD as anaerobic capacity. Several investigations have actually reported increased MAOD after high-altitude training (Mizuno 1990, Ogita 1999), which would be associated with improvements in muscle buffering capacity (Mizuno 1990).

To examine above hypothesis, 12 well-trained college male swimmers were matched for physical fitness level into two groups and then randomized to control group (C) and hypoxic training group (H). C had training under a normal condition and H performed under hypoxic conditions that simulated atmospheric pressure of 1600m and 2400m above sea level. Both groups conducted three types of high intensity intermittent or endurance training; 1) a 2-min bout at OBLA separated by 15-s recovery were repeated 15 times, 2) a 2 min bout at 50% $\dot{V}O_2$max and a 3 min bout at 100% $\dot{V}O_2$max were continuously repeated 5 times, 3) a 20-s bout at 170% $\dot{V}O_2$max separated by 10s recovery was conducted at least eight sets or more. Training 1) and 2) were done in the hypobaric condition corresponded to 1600m above sea level, and training 3) was done in 2400m above sea level. The training was done 2 sessions daily, 5 days a week for 3 weeks. Before and after the training period, $\dot{V}O_2$max and MAOD, and swimming performance in 100m and 200m free style were determined.

The effect on $\dot{V}O_2$max and MAOD

After the 3 weeks of training, mean values of $\dot{V}O_2$max increased significantly 56 to 62 ml •kg^{-1}•min^{-1} in C, and 56 to 63 ml •kg^{-1}•min^{-1} in H (Fig. 4). However, when compared the increase ratio of $\dot{V}O_2$max, no significant difference was observed between C (12%) and H (12%). This suggests that training under hypoxic conditions would not elicit necessarily the greater increase in $\dot{V}O_2$max, and dose not support the hypothesis that high altitude training is more beneficial to improve $\dot{V}O_2$max as suggested for a long time.

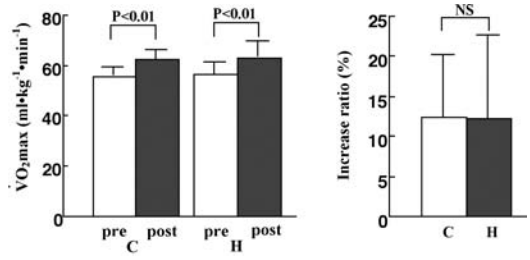

Fig. 4 Comparison of V̇O2 max between pre- and post- training in control group (C) and hypoxic group (H), and comparison of the increase ratio in V̇O2 max between C and H. (Ogita 2003)

Contrary, mean values of MAOD increased significantly 61 to 70 ml •kg^{-1} in C, and 56 to 72 ml •kg^{-1} in H (Fig. 5). When the increase ratio of MAOD between two groups were compared, it was significantly greater in H (29%) than in C (14%). Furthermore, such great increase in MAOD only for the 3 weeks training has been never seen in our knowledge. Therefore, our result suggests that adequate high intensity training under a hypobaric hypoxic environment would improve more effectively anaerobic metabolism such as MAOD.

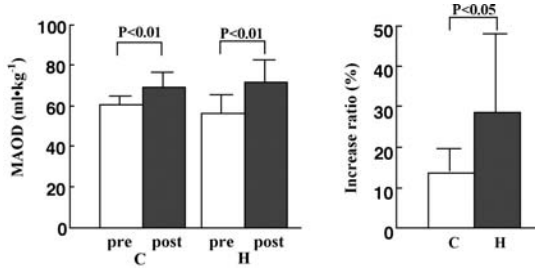

Fig. 5 Comparison of MAOD between pre- and post-training in control group (C) and hypoxic group (H), and comparison of the increase ratio in MAOD between C and H. (Ofita 2003)

Swimming performance

After the training, the swimming performance in 100m and 200m was significantly improved in both groups, and 10 of 12 subjects obtained their personal best records. When the improvement of swimming time was compared between groups, no significant difference was observed (Table 3). However, for the reason that swimming performance in pretest was rather higher in H and the energy demand during swimming increase in relation to the cube of swimming speed (Toussaint 1988, Ogita 1996, 1999, 2003), it is conjectured that the greater energy demand in H should be required to induce the same degree of improvement. Thus, the greater increase in MAOD would contribute successfully for the improvement of the swimming performance in H.

Table 3. Comparison of swimming performance in 100m and 200m event between pre- and post-training

	Contorol Group		Hypoxic Group	
	pre	post	pre	post
100m	56.92±1.81	56.09±1.71	55.86±1.44	55.09±1.71
200m	123.68±2.62	121.26±3.03	121.27±2.27	119.27±2.37

These results suggest that the high-intensity training could induce a large improvement of metabolic capacity and high-intensity exercise performance in both conditions but that high-intensity training in hypoxic condition would be more favorable for the improvement of MAOD rather than $\dot{V}O_2max$.

CONCLUSION

It is concluded that metabolic capacity and swimming performance can be improved more effectively if you understand energetics in competitive swimming of each distance event and you can tax an appropriate training stimulus to the aimed energy system.

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APPLICATION OF THE CRITICAL POWER CONCEPT IN SWIMMING?

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The concept of Critical Power (CP) has been extended to running, cycling, and swimming. However, applying the CP concept to cyclic activities imposes several assumptions (di Prampero, 1999) not always apparent to scientists and coaches. Their understanding would allow a better appreciation of the potential of this concept when applied as a tool for training.

Key Words: critical velocity, assumptions, assessment, training.

INTRODUCTION

The critical power concept originally introduced by Monod and Scherrer (13) attempted to improve the understanding of the local work capacity of one muscle or one synergistic muscle group. The authors highlighted that local work (*W*) and time to exhaustion (*t*) were linearly related (Equation 1). The slope of the relationship, called Critical Power (CP), was defined as a 'threshold of local fatigue' while the y-intercept (a) was corresponding to a reserve of energy.

Equation 1: $W = a + CP.t$

The concept of CP has since been extended to activities involving larger muscle masses such as running (11), cycling (14),

and swimming (24). However, applying the CP concept to cyclic activities requires the consideration of several assumptions (6, 16, 22) not always apparent to scientists and coaches. Understanding the underlying theory of the whole-body CP concept would allow a better appreciation of its potential when applied as a tool for training.

ASSUMPTION 1 – A 2-COMPONENT MODEL

There are only two components to the energy supply system for human exercise. When performing a fatiguing exercise, energy is generated via both the anaerobic and aerobic pathways (Equation 2).

Equation 2: $e = e_{anae} + \dot{V}O_2max.t$

Several authors have evocated the limits of such a simple model based on only two energetic systems to characterise a very complex energy release - time relationship (1, 16). Other models that incorporate a few more physiological variables (15, 18) have been presented and validated in the literature (Billat et al., 1999). However, these models could appear too complex to be used in training. Moreover, no study has yet been conducted to test their effectiveness as a training tool.

ASSUMPTION 2 - ENERGETIC COST OF SWIMMING

It is assumed that the energetic cost of the activity, i.e. the amount of energy required to travel a metre (ml of $O_2.m^{-1}$), is constant in order to allow Equation 2 to be expressed as followed:

Equation 3 : d = ADC + CV.t (d, distance; t, exhaustion time),

Accordingly, distance (d) and time required to cover it (t) are linearly related, with Critical Velocity (CV) and Anaerobic Distance Capacity (ADC) represented by the slope and the y-intercept of the d-t relationship, respectively (Figure 1).

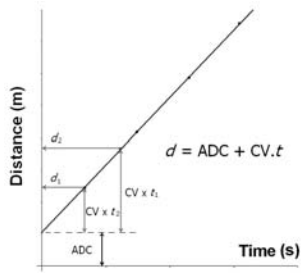

Figure 1: Schematic of the 2-parameter model. The distance covered during two events (d_1 and d_2) is represented. It is equal to the sum of ADC plus the product of CV and t (t_1 and t_2).

In swimming, the observation of a linear relationship linking *d* and *t* has been used to validate the application of the CP concept (Wakayoshi et al., 1992). A low sensitivity of CV (and CP) to large errors in exhaustion times has also been demonstrated (10, 22). However, it is known that the *d-t* relationship is not strictly linear. This has been demonstrated for work involving the whole body or part of the body (5, 23) and is mainly explained by a change in the energetic cost across the range of *t* used to plot the relationships (6, 22). The energy cost of swimming is indeed not constant with increasing swimming speed, due to changes in efficiency, energy contribution and hydrodynamics. Rather, the relationship is exponential resulting in proportionately greater increases in energy cost for changes in swimming speed at the high intensity first part of the *d-t* relationship (3). The lower the values of exhaustion times, the higher the slope, the lower the y-intercept, and vice versa (5, 22). CV and ADC values are therefore dependent on the exhaustion times used to plot the *d-t* relationship. Further studies are needed to determine the effect of this change in the energetic cost on the *d-t* relationship and its parameters.

ASSUMPTION 3 – AEROBIC RELEASE OF ENERGY

The aerobic supply is unlimited in its capacity but is rate limited. It would be solicited at its maximal power ($\dot{V}O_2max$) throughout the duration of the exercise to enable the energy demand to be covered. It is represented in Equation 2 by the second term $\dot{V}O_2max.t$.

This assumption is often forgotten leading to a misapplication of the CP concept and misunderstanding of its parameters. First, the CP concept assumes an attainment of $\dot{V}O_2max$ at the beginning of exercise. This will never be fulfilled and the slope and y-intercept of the *d-t* relationship will always slightly overestimate and underestimate the 'true' CV and ADC (4). The error in the estimation of an 'anaerobic energy reserve' has been shown to be relatively great (around 20%; (4, 21) while those in the estimation of CV has not been yet estimated and can be expected to be lower.

Second, it is known that $\dot{V}O_2max$ cannot be reached from the start of exercise, as assumed. In order to partially fulfil assumption 3, when choosing the range of exhaustion times that will be used to plot the *d-t* relationship, it has to be considered that $\dot{V}O_2max$ should be attained during each trial. In other words, the 2-component model explains the *d-t* relationship for intensities eliciting $\dot{V}O_2max$ (6). Exhaustion times have to range between about 2 minutes (9) and the time to exhaustion at CV (not measured yet in swimming but values of 20-40 min have been recorded in cycling) (2). Therefore, in swimming, the competitive distances ranging the 200m and 1500m can be advised (12, 26). Some authors attempted to simplify the application of the CP concept in swimming by determining which combinations of only two competitive distances should be used to derive CV and ADC (5, 19, 26). The suggestion of using only the 200m and 400m seems to most pertinent (5).

Consequently, CV can be defined as the upper limit of the heavy intensity domain, i.e. the highest intensity that does not allow $\dot{V}O_2max$ to be attained during a constant load exercise (8). Above CV, because of the slow component phenomena, $\dot{V}O_2max$ would be achieved. CV is therefore lower than the end velocity of an incremental test, often identified as the Maximal Aerobic Power. The first belief that CV was sustainable for a very long period of time was a misinterpretation of the mathematical (and not physiological) definition of CV, i.e. the intensity that can be maintained indefinitely (asymptote of the velocity-time relationship).

ASSUMPTION 4 – ANAEROBIC RELEASE OF ENERGY

The anaerobic metabolism is not rate but capacity limited. It generates a finite amount of energy termed e_{anae} in Equation 2.

This energy store (E_{anae} in Equation 2 or ADC in Equation 3) is assumed to be depleted at exhaustion and is independent of

the exhaustion time. This is probably not valid in all cases and especially for short and very long exercises (22) but should be during exercise enabling $\dot{V}O_2$max to be attained. This assumption remains difficult to test since the measurement of anaerobic work capacity is a theoretical construct that is fraught with measurement errors (7). Today, the 'anaerobic' parameter of the CP concept has been the object of several studies whose conclusions are conflicting. In swimming, ADC does not seem to provide a valid estimation of an 'anaerobic reserve of energy' (5) although it is not sure the measurements error inherent to the CP concept is not as great as those of any other methods of estimation of an Anaerobic Work Capacity (4).

ASSUMPTION 5 – END OF EXERCISE

Termination of exercise occurs when all of e_{anae} has been utilised.

The CV/CP concept assumes that performance is determined by metabolic factors relying on the classical and traditional model of fatigue. The explanation for a decrease in velocity during all-out effort or the inability to maintain a velocity during time to exhaustion trials refers to action potential failure, excitation-contraction coupling failure, or impairment of cross-bridge cycling, in the presence of unchanged or increasing neural drive (20), all of these causes being peripheral. However, the origin of fatigue could be quite different. Another model of fatigue (central in its origin) has recently been presented by Noakes and co-workers (17).

CONCLUSION

Despite these several limits, the CV concept has raised lots of interest from the scientific and non scientific communities. The 2-component model is a simple tool enabling to characterise individual *d-t* relationships. CV in swimming is reliable and offers the coach a tool with some precision. Competitive distances ranging from the 200m to the 1500m can be used to plot the *d-t* relationship and would lead to good estimates of CV. CV can be defined as the upper limit of the heavy intensity domain, i.e. the highest intensity that does not allow $\dot{V}O_2$max to be attained during a constant load exercise. ADC corresponds to an anaerobic energy reserve.

The model may provide an interesting way of investigating the energetic contributions to swimming. Coaches and swimmers could also appreciate the ease in using the model to predict performance from the *d-t* relationship, to set training loads, to discriminate effects of training, and to establish energetic potentials of swimmers. The model offers potential to swimming in that it is non-invasive and easy to administer however coaches and scientists should be aware of the assumptions outlined above.

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THE STRUCTURE OF EVALUATION INDICATORS OF VERTICAL SWIMMING WORK ABILITY OF TOP WATER POLO PLAYERS

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The aim of this research is to define a simple method for assessing the level of basic fitness of water polo players (WPP) in the vertical swimming position (VSP). The sample consisted of 35 players, and each subject was tested four times in different training session with four different weights (one weight per session). The task of players was to stay in VSP as long as possible using the standard vertical swimming technique until full exhaustion. On the basis of raw data for each subject the function of dependence Power-Time equation has been calculated for the following nine time intervals (three time intervals per energetic system): 5, 10, 15 seconds for CP , 30, 60, 120 seconds for glycolytic, and 300, 600, 1800 seconds for aerobic energetic system. From the bases of factorial analysis we can conclude that in the context of vertical swimming work ability of top WPP, it is advisable to do tests for VSP in relation to glycolitic and aerobic load realized within 30 seconds (23.95±3.90 kg), and 300 seconds (14.53±1.70 kg), respectively.

Key Words: water polo players, vertical swimming, basic vertical work ability.

INTRODUCTION

Water polo is physically a very demanding sport game, with an "intermittent" nature of playing. Intense bursts of short activity in horizontal and vertical technical and tactical elements are varied with intervening lower intensity intervals (8, 10). On average, a water polo game lasts approximately 55 minutes, whereas actual mean playing time amounted to approximately 48 minutes (8, 10). At the senior top-performance level, a water polo player spends 45-55% up to 66.9% in the vertical swimming position in which he executes different tactical and technical tasks (4, 8). The data indicate the vertical swimming position to be the dominant position in the game. The given data regarding the duration and the structure of the game, the distribution of intensity and the positions during the game implicate that water polo players require fitness for execution of tasks both in the horizontal as well as the vertical direction in all three energetic regimes of exertion and work.
With horizontal swimming as reference, for the control of the fitness level, reliable methods have been defined and then adapted for a simple application (2). However, methods for the control of fitness level in the vertical swimming position have not been adequately developed. The current methods require special lab equipment and conditions of testing that make them practically unusable in the training system and process (11). This brings about the necessity to define a simple, easy-to-apply and reliable method for assessing the level of basic and competitive fitness of water polo players in the vertical swimming position.

METHODS

The sample of water polo players (SCG_{WP}) was made of 35 members of the SCG under-20 and B-national team (Age=19.3±2.6 years; BH=1.914±0.048 m; BM=88.2±7.5 kg). In order to establish fitness level in the vertical swimming position, we have used the following procedure (3, 4). After the usual warm-up procedure (≈ 600 m), the subject was harnessed around the waist with the weights (as a given load, i.e. the intensity of work) hanging on a rope between the legs. The rope was fixed to his lumbar and stomach side. The subject would then get into the water trying to stay in the vertical swimming position between 10-15 seconds in order to check out the gear, and after a one-minute break with assistants in the position of preventing any mishap, the trial would start. The task was to stay in the vertical swimming position as long as possible, i.e. until full exhaustion necessitated trial termination. The subjects were allowed to use egg-beater kick, while their hands performed the semi-circle movements ("the horizontal eight"). Also, the subjects were requested to keep their neck and head constantly in the vertical position and the water level not to go above the lowest part of their chin. The time was measured from the beginning of the subject's vertical swimming with the given weights in position till its end.
Each subject has been tested four times in different training session with different weights (one weight per session - 12, 14, 16 and 18. Each working weight is meant to hypotheticaly represent a strain (work intensity) exerting different energy mechanisms of the body. Thus, for each subject the data we obtained, show the duration in which the vertical swimming position can be maintained with a minor, medium, major and sub-maximal load (4, 5, 12). Applying the described trial method, a set of four specific points for each subject has been established and it defines the fitness level for the vertical swimming position, as a function: the level of load, i.e. the intensity of work (in kilograms of weight's mass) in function of duration, i.e. the capacity of work (7, 12).
On the basis of raw data obtained through testing for each subject the function of dependence Power-Time (P-t) equation has been calculated applying the general equation: $y = a \_ b^x$.
Following which, for each subject, and on the basis of his P-t equation, we synthesised the value of the weight mass (all synthesized data are presented in absolute terms - in kg of weight mass), for the following nine time intervals (three different time intervals per energetic system): 5, 10 and 15 seconds - anaerobic alactic, 30, 60 and 120 s - anaerobic lactic, 300, 600 and 1800 s - aerobic energetic system. The given time intervals have been chosen in accord with the theoretical preposition that they are capable of describing the working capacity of players with three hypothetically possible features of the tested energetic systems – intensity, power and capacity (5, 7, 12). All data have been treated with the descriptive statistical method and multivariant statistics, i.e. factorial analysis – explorative model of extraction with Oblimin rotation method (6).

RESULTS

Table 1 displays the results of the basic descriptive statistic of vertical swimming work abilities (in kg of weight mass) in

function of observed time intervals (in seconds). On the average, the results showed that the players were able to sustain vertical position for the following times and weights: 5, 10, 15 s – 36.43, 30.87 and 28.08 kg; 30, 60, 120 s – 23.95, 20.52 and 17.64 kg; 300, 600, 1800 s - 14.53, 12.59 and 10.11 kg, respectively.

Table 1. The basic descriptive statistics of vertical swimming work abilities in function of observed time intervals.

	Vertical swimming work ability – time intervals (s)								
	5	*10*	*15*	*30*	*60*	*120*	*300*	*600*	*1800*
Mean (kg)	36.43	30.87	28.08	23.95	20.52	17.64	14.53	12.59	10.11
SD (kg)	12.17	8.09	6.27	3.90	2.37	1.65	1.70	1.98	2.32
cV (%)	33.40	26.21	22.32	16.30	11.56	9.35	11.73	15.73	22.95
Min (kg)	23.43	21.59	20.57	18.95	17.46	14.10	10.26	8.06	5.09
Max (kg)	77.96	56.54	46.85	34.37	27.24	21.59	17.42	15.23	12.89

Figure 1 displays the equation function of the model defined in relation to the vertical swimming working capacity of the tested sample. The equation function of the model yielded: Power (kg) = 50.7389 •time$^{-0.2179}$.
Kaiser-Meyer-Olkin measure of sampling adequacy has shown the reliability of the measurement method to be at 0.7481 (74.81%), at a statistically significant level, F_{ratio} = 2431.75, and p = 0.000. Factorial analyses extracted two factors (table 2), the first factor explaining 63.31%, and the second 36.15% of total variance of vertical swimming work ability in players. The former is best represented by the variable which described vertical swimming ability for 30 s (VERT30s), and the latter by the variable for 300 s (VERT300s).

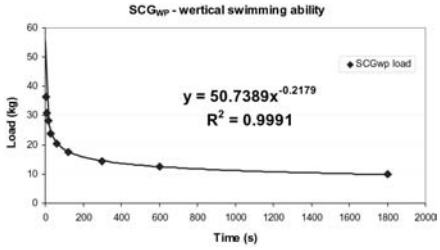

Figure 1. The equation function of the model defined in relation to the vertical swimming working capacity of the tested sample.

Table 2. The results of factorial analysis of structure of evaluation indicators of vertical swimming work abilities in function of observed time intervals.

	Component	
	1	2
VERT30S	.999	-.099
VERT15S	.985	-.275
VERT10S	.970	-.339
VERT5S	.944	-.413
VERT60S	.939	.231
VERT300S	-.070	.999
VERT600S	-.345	.969
VERT1800	-.536	.888
VERT120S	.607	.719

Extraction Method: Principal Component Analysis.
Rotation Method: Oblimin with Kaiser Normalization.

DISCUSSION

In relation to the tested sample and the used method of evaluation, the results of the factorial analysis have shown the existence of two hypotetical/theoretical predominant aspects of the working fitness of water polo players from the vertical swimming position aspect. The first factor is defined by the capacity to withstand work of maximal intensity in the vertical swimming position in the time interval of 30 seconds. The tested sample has shown the hypotetical/theoretical capacity to stay afloat with the load of 23.95±3.90 kg (Min – Max = 18.95 to 34.37 kg).
It is well known that the work of maximal intensity in the time interval of 30 seconds from the physiological aspect, i.e. the energetic criteria, belongs to the space of anaerobic power (5, 7, 12). As water polo players have been noted to perform many intense activities in a vertical or semy-vertical position for a large portion of duration of a match, and if we know that lower limbs play a crucial and predominant role in maintaining the upward propulsion of the body, such as jumps, blocks, in active contact defence situation, grappling for possession, and during the overhead forward throwing - the first defined factor sugest that high or well developed anaerobic power are very important for water polo performance (1, 8, 9).
The second factor is defined by the hypotetical/theoretical capabillity to withstand work of maximal intensity in the vertical swimming position in the time interval of 300 seconds. The tested subjects were able on average to stay afloat with the load of 14.53±1.70 kg (Min – Max = 10.26 to 17.42 kg). It is accepted that the work of maximal intensity in the time interval of 300 seconds from the physiological aspect, i.e. the energetic criteria, belongs to the space of aerobic power (5, 7, 12).
Earlier research has also established that water polo players have a moderately high levels of anaerobic power and possessed a high aerobic fitness capacity (1, 8).
The given capacity is probably the consequence both of the players' selection on the one hand and of the bodily adaptation to the training and competition exertion (10).
Pininton and his collaborators have established that the pulse of water polo players during the fourteen different technical and tactical tasks they realize during a game, goes from 162 to 175 HR/min, or that the game is played at the intensity which is on average at the level of 74.2 to 86.8 % of $\dot{V}O_2$ max (10).

CONCLUSION

These results draw upon the conclusion that in the context of vertical swimming work ability of top water-polo players, it is possible to say that, on the hypotetical/theoretical level, the basic evaluation should be carried out in relation to anaerobic lactic load (anaerobic power) realized within 30 s (23.95±3.90 kg), and aerobic load (aerobic power) realized within 300s (14.53±1.70 kg).

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CHARACTERISTICS FOR SUCCESS IN ELITE JUNIOR AND SENIOR SWIMMERS

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The aim of this study was to describe and compare key anthropometric, physiological and socio-demographic characteristics of junior and senior elite swimmers at two performance levels and to determine the importance of these attributes to successful swimming performance. Sixty-five (34 males and 31 females) senior and 561 (305 males and 256 females) junior elite swimmers undertook a battery of anthropometric and physiological tests, and additional family background assessment. The combination of variables was able to differentiate between the two levels of senior performance in males ($P<0.05$). Significant predictors of swimming performance ($P<0.05$) differed from junior to senior level in both males and females. A longitudinal approach is required to track the importance of certain characteristics during growth and development.

Key Words: Characteristics, performance, elite, junior, senior, talent identification.

INTRODUCTION

Structured talent identification schemes are not new, having been employed widely in Australia and in Eastern Europe, but only in recent years have the UK seriously considered sports science as an aid to identifying and selecting talent for high performance sport development programmes. Past schemes have typically focused on certain physiological and anthropometric attributes, assuming that specific sporting talent and performance are largely based on an innate or genetic predisposition that is responsive to training (2). The alternative view is that genetics or innate ability are not involved in the development of sporting expertise, and that success is determined by the amount of deliberate practice acquired by an individual (4, 7). However, this theory of deliberate practice has been questioned in relation to sport (5) and if a successful talent identification, selection and development (TISD) system is to be formed, these two theoretical positions should not be seen as mutually exclusive, rather that both genetics and sociological/environmental factors contribute to sporting success (6).
A paucity of multidisciplinary research exists in talent identification, with researchers traditionally approaching the problem from a unidimensional perspective. Previous attempts to quantify the importance of certain characteristics to swimming performance have focused on either elite senior (3) or junior swimmers (1) and little is known about the degree to which physiological and anthropometric indices of performance capability prevail through growth and maturation into adulthood (8). Therefore, investigating the construction of a successful talent identification and selection programme should attempt to describe talent from junior to senior level.
The purpose of this study therefore, was to describe and compare key anthropometric, physiological and socio-demographic characteristics of elite and sub-elite junior and senior swimmers across four competitive strokes and to assess the degree to which some of these characteristics might predict elite swimming performance.

METHODS

Subjects included thirty-four swimmers from the 2004 British Olympic team (19 males and 15 females; Olympic group) and a matched sample of 31 swimmers (15 males and 16 females; sub-Olympic group) from the Loughborough University High Performance squads, and 559 junior swimmers (304 males and 255 females) aged eleven to eighteen, from the 2004 British Age and Youth Championships. All procedures were approved by the Amateur Swimming Association's Ethics Department and informed consent was obtained from all subjects or their parents/ guardians.
A battery of anthropometric measurements included: height and sitting height, standing reach, arm span, body mass, torso and waist circumferences, right foot and hand lengths, and right acromiale-radiale (upper arm) and radiale-stylion (lower arm) lengths. Counter movement jump (CMJ) was also measured. Body mass index (BMI; body mass (kg) / standing height (m)^2), sitting height percentage (sitting height (cm) / standing height (cm) x 100), torso to waist ratio (expressed as the number of centimetres of torso circumference to one centimetre of waist circumference) and difference between arm span and height (arm span (cm) – standing height (cm)) were calculated and added to the list of variables to be used in later analyses.
Anthropometric tests were selected based on previous

research into talent identification and selection in swimming (1, 3, 11), the rationale being that a swimmer's morphology influences the horizontal components of lift and drag and thereby affects the swimmer's potential to generate optimum propulsion and to minimise resistance (9). Counter movement jump was selected as a measure of explosive leg power, closely related to maximum power in swimming (11). The family background of the senior subjects was assessed using a questionnaire designed to gather information on the family sporting background and the types and levels of family support received by elite swimmers through their development as age group swimmers. Data were analysed using the Statistical Package for Social Scientists (SPSS, version 11.0) and statistical significance was accepted at the 5 percent level for all analyses. Males and females were analysed separately with the exception of the family background analyses. Senior and junior subject data were analysed using multivariate analysis of variance (MANOVA) with follow up univariate analysis of variance (ANOVA) and discriminant analysis used where appropriate. Age group classifications used for the junior male and female subjects reflect those used at the British Age and Youth Championships. Multiple linear regression was used to determine the predictive power of the anthropometric and physiological variables using personal best swim time as a percentage of the world best swimming time (for 2003) as the criterion of performance for all senior and junior swimmers (reliable for predicting Olympic swimming performance, 10). A descriptive approach employing both quantitative and qualitative techniques was used to analyse the family background questionnaire data.

RESULTS AND DISCUSSION

Table 1 shows the male and female anthropometric measurements and CMJ for Olympic and sub-Olympic swimmers. Both MANOVA and discriminant analysis showed that the combination of anthropometric and CMJ could successfully differentiate between the two levels of performance in senior male swimmers. The individual variables best able to discriminate between groups were standing height, sitting height, torso circumference, torso to waist ratio and CMJ. Multiple regression analysis yielded a significant model ($P<0.01$) accounting for 79% of the variance in swimming performance. The significant positive predictor variables in males were standing reach and CMJ ($P<0.05$) suggesting that greater standing reaches and higher CMJ scores predict faster personal best swimming times. Sprinters usually display higher vertical jump parameters than distance swimmers (11) and therefore, CMJ has been used to predict distance orientation. However, as CMJ focuses on the leg extensor muscles which are important for the start element of the swimming race, it could be seen as a performance predictor for all swimming strokes (the Olympic group scored more highly than the sub-Olympic group on this test). Therefore, CMJ measure might be a simple, useful tool to predict both event orientation and aid talent selection. Although standing reach was unable to differentiate between the two performance levels, the regression analysis showed that standing reach is an important predictor of swimming performance due to its relationship to the streamline position (important for all swimming strokes) and supports its inclusion in the test battery.

Table 1. Anthropometric measures and CMJ (mean ± SD) for senior male and female swimmers.

	Males		Females	
Parameter	Olympic (n = 19)	Sub-Olympic (n = 16)	Olympic (n = 15)	Sub-Olympic (n = 16)
Height (cm)	186.7 ± 4.0*	182.7 ± 5.3*	173.1 ± 4.9*	169.3 ± 5.1*
Sitting Height (cm)	97.3 ± 3.1*	93.7 ± 3.2*	91.2 ± 3.6*	87.4 ± 2.8*
Sitting Height Percentage (%)	52.1 ± 1.1	51.3 ± 1.4	52.6 ± 1.1*	51.6 ± 1.2*
Standing Reach (cm)	245.6 ± 5.6	241.2 ± 8.4	229.0 ± 10.9	224.7 ± 8.0
Arm Span (cm)	193.8 ± 5.6	193.4 ± 6.7	178.4 ± 6.8	176.9 ± 6.0
Arm Span minus Height (cm)	7.2 ± 5.1*	10.7 ± 4.0*	5.3 ± 4.7	7.5 ± 5.0
Mass (kg)	79.2 ± 6.0	76.5 ± 5.9	63.2 ± 6.4	63.4 ± 5.2
BMI	22.7 ± 1.3	23.2 ± 2.3	21.1 ± 1.8	22.1 ± 1.3
Torso Circumference (cm)	102.6 ± 5.4*	96.5 ± 4.1*	93.0 ± 4.2*	90.0 ± 3.7*
Waist Circumference (cm)	79.5 ± 4.0	78.4 ± 4.5	70.9 ± 3.8	70.6 ± 3.4
Torso to Waist Ratio	1.29 ± 0.05*	1.23 ± 0.04*	1.31 ± 0.05*	1.28 ± 0.04*
Foot Length (cm)	27.3 ± 0.9	26.9 ± 1.7	24.9 ± 1.1	25.0 ± 1.0
Hand Length (cm)	19.8 ± 0.8	19.8 ± 0.9	18.3 ± 0.6	18.2 ± 0.7
Acromiale-Radiale Length (cm)	35.4 ± 1.6	35.0 ± 1.6	32.9 ± 1.3	31.8 ± 2.5
Radiale-Stylion Length (cm)	27.0 ± 1.0	26.6 ± 1.3	24.5 ± 1.0	24.7 ± 1.1
CMJ (cm)	43.3 ± 5.2*	39.3 ± 3.7*	33.9 ± 4.5	30.9 ± 4.3

MANOVA shows significant difference between profile of Olympic and Sub-Olympic groups in males ($P<0.01$). Discriminant analysis shows significant difference between profile of Olympic and Sub-Olympic groups in males ($P=0.000$) and females ($P<0.05$). ANOVA shows significant group differences between variables indicated *($P < 0.05$). The relationship between anthropometric measures and CMJ and performance level was less clear in senior females. Only discriminant analysis showed significance, indicating that the set of variables was less able to differentiate between the two performance levels in senior female than in senior male swimmers. A possible reason for this may be the smaller range in performance ability in the group of senior females as a whole. Individual variables that were able to discriminate between groups were standing height, sitting height, sitting height percentage, torso circumference and torso to waist ratio. Individual discriminatory variables for senior female swimmers match closely with the results for senior male swimmers, indicating that the important anthropometric attributes of elite swimmers are similar for both genders. Multiple regression analysis yielded a significant model ($P<0.05$) accounting for 74% of the variance in senior female swimming performance, although no individual predictor variables were significant. The regression analysis produced a performance ability range between 0% and ~10% away from the world best time and therefore, the extreme homogeneity of the female group may have masked regression effects. To more accurately assess the predictive value of the variables, it is necessary to collect data from a larger range of performance abilities.

Key results of the family background analysis showed: 77% of families owned 2 or more cars; 86% of families provided transport to training/competition at least 4 times per week (81% estimated the annual travel cost in excess of €400); family activities frequently had to be adapted to accommodate swimming with meal times (92%) and the family weekend (94%) adapted most often. Results indicate that it is only possible to succeed in elite swimming in Great Britain with significant financial outlay and family support; opportunities to identify and develop talent therefore, may be missed.

The test battery was unable to significantly discriminate between the two performance levels in any junior male or female age group, although multiple regression analysis yielded significant models for junior males (P=0.000) and females (P=0.000) accounting for 74% and 47% of the variance in swimming performance respectively. In junior males, arm span, waist circumference, torso to waist ratio and CMJ were significant predictors of performance (P<0.05) and in junior females, arm span, sitting height, sitting height percentage and CMJ were significant predictors of performance (P<0.05). Several of the characteristics identified as important for junior swimming performance are those that individually differentiate between performance level in senior swimmers (in males, torso to waist ratio and CMJ and in females, sitting height and sitting height percentage). Hence, some characteristics possessed by elite junior swimmers may also be important for elite senior swimming performance.
All regression analyses were unable to explain 100% of the variance in swimming performance indicating that some of this variance must be attributed to other factors such as more detailed physiological measures, swimming technique, psychological and/or environmental characteristics. It seems likely that the inclusion of swimming specific tests in the battery would provide additional predictive power to this analysis, although further multidisciplinary research is required to establish any contribution these factors may have to elite swimming performance.

CONCLUSION

The characteristics that predict swimming performance differ from junior to senior level in both males and females. A longitudinal approach to this type of research would provide valuable information about the importance of certain characteristics to performance during growth and development and at senior level. This type of approach suggests that an appropriate multidisciplinary test battery combined with multivariate analyses could be useful as an important predictive and diagnostic tool for talent identification and development in elite junior swimmers.

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ASSESSMENT OF TIME LIMIT AT LOWEST SPEED CORRESPONDING TO MAXIMAL OXYGEN CONSUMPTION IN THE FOUR COMPETITIVE SWIMMING STROKES

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Time limit at lowest speed of maximal oxygen consumption (TLim-v$\dot{V}O_2$max) was characterized in the 4 swimming strokes, and related with $\dot{V}O_2$max and anaerobic threshold (AnT). 23 elite swimmers performed an incremental protocol for v$\dot{V}O_2$max assessment. 48 hours later, Tlim-v$\dot{V}O_2$max was assessed. $\dot{V}O_2$ was directly measured BxB (K4 b2, Cosmed, Italy) and AnT was assessed individually (YSI 1500L Sport, USA). Tlim-v$\dot{V}O_2$max values were 238.8±39.0, 246.1±51.9, 277.6±85.6 and 331.4±82.7 s in crawl, backstroke, butterfly, and breaststroke (no differences observed). No correlations were found between Tlim-v$\dot{V}O_2$max and $\dot{V}O_2$max, and AnT. However, inverse relationships were observed between Tlim-v$\dot{V}O_2$max and v$\dot{V}O_2$max (r=-0.63, p<0.01) and vAnT (r=-0.52, p=0.01), pointing out that the higher the velocities commonly related to aerobic proficiency, the lower the TLim- v$\dot{V}O_2$max.

Key Words: time to exhaustion, competitive strokes, oxygen consumption, anaerobic threshold.

INTRODUCTION

Time limit at lowest speed of maximal oxygen consumption (TLim-v$\dot{V}O_2$max) was studied both in swimming flume (1, 2, 3) and in normal swimming pool conditions (4, 6, 13). While no studies have been carried out based on other swimming techniques than front crawl, the purpose of this experiment was to characterize, and compare, TLim-v$\dot{V}O_2$max in the four competitive strokes, as well as to observe its relationships with two major performance determinants: $\dot{V}O_2$max and anaerobic threshold (AnT). Complementarily, knowing that top-level swimmers have their specificities (11) and that TLim-v$\dot{V}O_2$max was never assessed in elite swimmers, the pertinence of this study is clearly stated.

METHODS

Subjects

Twenty-three elite swimmers (15 males of 19.4 ± 2.1 yy, 178.1 ± 6.2 cm and 71.8 ± 7.4 kg, and 8 females of 17.2 ± 1.4 yy, 166.0 ± 3.7 cm and 59.7 ± 4.3 kg) from the Portuguese National Swimming Team volunteered to participate in this study and signed an informed consent form.

Test protocol

Each subject performed, in their best technique, an individualized intermittent incremental protocol for $v\dot{V}O_2max$ assessment, with increments of 0.05 $m.s^{-1}$ each 200 m stage and, 30 s intervals, until exhaustion (4). $\dot{V}O_2$ was directly measured using a telemetric portable gas analyzer (K4 b^2, Cosmed, Italy) connected to the swimmers by a respiratory snorkel and valve system (9, 14). Expired gas concentrations were measured breath-by-breath. Swimming velocity was controlled using a visual pacer (TAR. 1.1, GBK-electronics, Aveiro, Portugal) with flashing lights on the bottom of the pool. $\dot{V}O_2max$ was considered to be reached according to primary and secondary traditional physiological criteria (8). $v\dot{V}O_2max$ was considered to be the swiming velocity correspondent to the first stage that elicits $\dot{V}O_2max$. If a plateau less than 2.1 $ml.min^{-1}.kg^{-1}$ could not be observed, the $v\dot{V}O_2max$ was calculated as proposed by Kuipers et al. (9):

$$v\dot{V}O_2max = v + \Delta v \cdot (n.N^{-1}), \quad \text{(Eq. 1)}$$

where v is the velocity corresponding to the last stage accomplished, Dv is the velocity increment, n indicates the number of seconds that the subjects were able to swim during the last stage and N the pre-set protocol time (in seconds) for this step. Capillary blood samples for lactate concentrations ($[La^-]$) analysis were collected from the earlobe at rest, in the 30 s rest interval, at the end of exercise and during the recovery period (YSI1500LSport auto-analyser - Yellow Springs Incorporated, Yellow Springs, Ohio, USA). Those data allowed to assess individual AnT, that was determined by $[La^-]$/velocity curve modelling method (least square method) (5). HR was monitored and registered continuously each 5 s through a heart rate monitor system (Polar Vantage NV, Polar Electro Oy, Kempele, Finland). Forty-eight hours later, subjects swam until exhaustion at their pre-determined velocity, to assess Tlim-$v\dot{V}O_2max$. This protocol consisted in two different phases, all paced: (i) a 10 min warm-up at an intensity correspondent to 60% $v\dot{V}O_2max$, followed by a short rest (20 s) for earlobe blood collection, and (ii) the maintenance of that swimming $v\dot{V}O_2max$ until volitional exhaustion or until the moment that the swimmers were unable to swim at the selected pace. Tlim-$v\dot{V}O_2max$ was considered to be the total swimming duration at the pre-determined velocity. HR was registered continuously using the same procedure previously described.

Statistical analysis

Mean (±SD) computations for descriptive analysis were obtained for all variables (all data were checked for distribution normality with the Shapiro-Wilk test). One-way Anova, with a Bonferroni post-hock test, was also used. A significance level of 5% was accepted.

RESULTS

Data concerning the variables obtained in the incremental test: $\dot{V}O_2max$, $[La^-]max$, HRmax, AnT (velocity and $[La^-]$ values) and $v\dot{V}O_2max$, and the parameters assessed in the Time Limit test: TLim-$v\dot{V}O_2max$, $[La^-]max$ and HRmax, are reported in Table 1 for each competitive stroke.

The values of $\dot{V}O_2max$ obtained in the incremental test are in accordance with those previously published for elite front crawl swimmers for a number of authors (1, 3, 7). Studies that aim to compare $\dot{V}O_2max$ in elite front crawl, backstroke, butterfly and breaststroke swimmers are very scarce, so it is difficult to make valid comparisons. However, the observation of no differences between $\dot{V}O_2max$ values between techniques is in accordance with Troup (15). The obtained values of HRmax are in agreement with the literature since that, for this kind of intensity of exercise (aerobic power zone), values ranging from 180 to 200 $b.min^{-1}$ are consensual (12). Likewise, the $[La^-]max$ mean values are in agreement with the typical requirements for $\dot{V}O_2max$ swimming intensities (8).

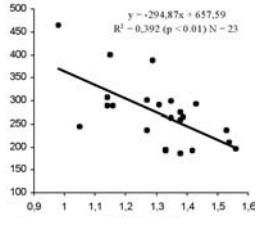
While no significant differences were observed between competitive strokes in TLim-$v\dot{V}O_2max$, pooled data were correlated with $\dot{V}O_2max$ (ml/kg/min) and AnT (mmol/l), being observed no significant interrelationships. However, moderate inverse correlation values were observed between Tlim-$v\dot{V}O_2max$ and $v\dot{V}O_2max$ ($r=-0.63$, $p=0.001$, Figure 1A) and vAnT ($r=-0.52$, $p=0.012$, Figure 1B).

Table 1. Mean (±SD) values for $v\dot{V}O_2max$ (absolute and relative), [La-]max, HRmax, AnT (velocity and [La-] values) and $v\dot{V}O_2max$ (incremental test), and TLim-$v\dot{V}O_2max$, [La-]max and HRmax (Time Limit test), for each competitive stroke. Significant differences are shown through pairs of (1), (2), (3), (4), (5), (6), (7), (8), (9) and (10), $p \leq 0.05$.

Parameters	Front crawl (n = 8)	Backstroke (n = 5)	Butterfly (n = 4)	Breaststroke (n = 6)
$v\dot{V}O_2max$ ($ml.kg^{-1}.min^{-1}$)	64.28 ± 10.27	66.78 ± 11.40	53.95 ± 4.82	63.21 ± 8.14
$v\dot{V}O_2max$ ($l.min^{-1}$)	4.34 ± 1.32	4.69 ± 1.11	3.57 ± 0.54	4.33 ± 0.71
$[La^-]max$ ($mmol.l^{-1}$)	8.34 ± 3.02	11.22 ± 3.63	8.22 ± 1.60	9.13 ± 1.99
HRmax ($b.min^{-1}$)	182.50 ± 5.73	190.00 ± 6.60	179.25 ± 6.50	190.83 ± 7.33
AnT ($mmol.l^{-1}$)	2.59 ± 0.97 (1)	4.56 ± 2.10	5.56 ± 2.30 (1)	3.03 ± 1.50
vAnT ($m.s^{-1}$)	1.33 ± 0.10 (2)	1.25 ± 0.06 (3)	1.21 ± 0.07 (4)	1.01 ± 0.08 (2,3,4)
$v\dot{V}O_2max$ ($m.s^{-1}$)	1.45 ± 0.08 (5,6)	1.35 ± 0.04 (7)	1.29 ± 0.03 (5,8)	1.10 ± 0.07 (6,7,8)
TLim- $v\dot{V}O_2max$ (s)	243.17 ± 30.49	246.08 ± 51.93	277.63 ± 85.64	331.43 ± 82.73
$[La^-]max$ TLim ($mmol.l^{-1}$)	6.92 ± 2.53 (9,10)	10.65 ± 2.40 (9)	9.04 ± 0.91	10.76 ± 1.34 (10)
HRmax TLim ($b.min^{-1}$)	180.00 ± 6.44	176.60 ± 8.56	179.50 ± 4.44	185.67 ± 7.97

$\dot{V}O2max$: maximal oxygen consumption; [La-]max: maximal blood lactic acid concentrations; HRmax: maximal heart rate; AnT: anaerobic threshold; vAnT: velocity corresponding to anaerobic threshold; $v\dot{V}O2max$: lowest speed of maximal oxygen consumption; TLim-$v\dot{V}O2max$: time limit at $v\dot{V}O2max$; n: number of subjects.

The observed inverse relationships between Tlim-$v\dot{V}O_2max$ and $v\dot{V}O_2max$, and/or vAnT, confirms previous findings obtained in national level freestyle swimmers (4, 6), and point out that, whatever the swimming techniques the higher the swimming velocities commonly related to aerobic proficiency, the lower the TLim-$v\dot{V}O_2max$. This observation seems to be justified by the fact that higher swimming velocities indicates more strenuous efforts, with probably more pronounced recruitment of anaerobic energy pathways, leading to earlier fatigue stages and, consequently, to lower TLim-$v\dot{V}O_2max$. However, no relationship was found between Tlim-$v\dot{V}O_2max$ and $[La^-]max$, in opposition with some previous findings (3, 6).



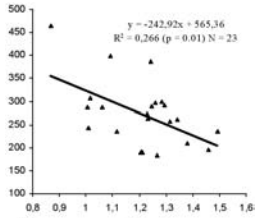


Figure 1. Relationshisp between Tlim-v $\dot{V}O_2$max and v $\dot{V}O_2$max (A panel), and vAnT (B panel).

CONCLUSIONS

TLim-v $\dot{V}O_2$max did not differ between swimming strokes, pointing out that the phenomenon is similar in all four strokes. TLim-v $\dot{V}O_2$max was lower in the swimmers who presented higher v $\dot{V}O_2$max and vAnT, which could be explained by the higher anaerobic rate in that specific exercise effort. $\dot{V}O_2$max and [La^-] values are poor predictors of TLim-v $\dot{V}O_2$max performance.

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OXYGEN UPTAKE AND VENTILATORY THRESHOLD IN SWIMMING

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The purpose of this study was to identify, in terms of percentage of maximal oxygen uptake (%$\dot{V}O_2$max), the intensity of swimming associated with a non linear increase of minute ventilation (Ve), also described as ventilatory threshold (VT). Twenty nine trained swimmers participated in our study: 15 males and 14 females. Each subject performed a intermittent incremental protocol of 200m stages, with increases of 0.05m.s^{-1}, and 30s intervals between each stage. VT was assessed by Ve/$\dot{V}O_2$ curve modelling method (least square method). It was assumed VT to be the intersection point, at the maximal fit situation, of a combined pair of regressions (linear and exponential). The analysed values of $\dot{V}O_2$ and Ve were cropped by direct oximetry. The present study demonstrated that the non linear increase of Ve corresponding to VT in a specific swimming situation seems to happen at 84.3±8.7 %$\dot{V}O_2$max.

Key Words: ventilatory threshold, oxygen uptake, minute ventilation, evaluation.

INTRODUCTION

The concept of whole body maximal oxygen uptake ($\dot{V}O_2$max) has received much attention in the specialized literature, especially on its relevance to endurance performance and adaptation to training, being frequently viewed as one of the most relevant factors of performance [2]. However, di Prampero et al. [9] observed that, besides $\dot{V}O_2$max, other parameters are crucial for the athlete endurance performance, such as motor economy and the capability to sustain a high percentage of $\dot{V}O_2$max (%$\dot{V}O_2$max) along the exercise. On the same perspective, Svedahl et Macintosh [17] support that an athlete with a

lower absolute $\dot{V}O_2$max in comparison with other athletes, can compensate that difference, using a higher %$\dot{V}O_2$max to reach the same oxygen uptake (ml/min/kg) along the exercise. According to this, sub-maximal physiological parameters started to be considered as determinant parameters as $\dot{V}O_2$max for the assessment of athlete's endurance performance potential. Gradually, the Anaerobic Threshold (AT), and its multiple expressions, i.e., lactate threshold (LT), heart rate threshold or ventilatory threshold (VT), became used on training and perceived as determinant parameters on the athlete's performance, once they highly correlate with the %$\dot{V}O_2$max related to aerobic performance [3]. Although the importance given to the capacity to sustain a higher %$\dot{V}O_2$max related to VT [2], due to the difficulties associated with the evaluation of ventilatory parameters in swimming pool conditions, the assessment of the VT in swimming has been less investigated and used than the metabolic parameters, such as LT.
The purpose of this study was to identify the intensity associated with a non linear increase of the minute ventilation (Ve) described as VT [20], expressed as a %$\dot{V}O_2$max, in swimming pool conditions.

METHODS

Subjects

Twenty nine trained swimmers were studied: 15 male (21.4±3.0 yy, 177.3±7.0 cm, 68.3±7.1 kg and a $\dot{V}O_2$max of 70.9±10.2ml/min/kg) and 14 female (18.7±2.4 yy, 164.9±2.3 cm, 55.1±3.9 kg and a $\dot{V}O_2$max of 59.8±8.0ml/min/kg). All subjects were informed about the details of the experimental protocol before beginning the measurements procedures, and volunteered to participate in this study.

Test protocol

The test sessions took place in a 25m indoor poll. Each subject performed an intermittent incremental test for $\dot{V}O_2$max assessment. This test had increments of 0.05m.s^{-1} each 200m stage, with 30s intervals until exhaustion [10]. Initial velocity was established according to the individual level of fitness, and was set at the swimmer's individual performance on the 400m freestyle minus seven increments of velocity (for more details see Cardoso et al [6]). $\dot{V}O_2$ and Ve were directly measured using metabolic cart (Sensormedics 2900 oxymeter, Yorba Linda – Califórnia, USA) mounted on a special chariot running along the pool [19], and connected to the swimmer by a special respiratory valve [18]. Exhaled air was continually measured during the entire test on each 20s. Swimming velocity was controlled using a visual pacer (TAR.1.1, GBK-electronics, Aveiro, Portugal) with flashing lights on the bottom of the pool.
$\dot{V}O_2$max was considered to be reached according to primary and secondary traditional physiological criteria [1, 11]: (i) occurrence of a plateau in oxygen uptake despite an increase in swimming velocity, and (ii) high levels of blood lactic acid concentrations ([La$^-$]≥ 8mmol.l^{-1}), elevated respiratory exchange ratio (R≥ 1.0), high heart rate (HR) (>90% of [220bpm-age]) and exhaustive perceived exertion (controlled visually, and case to case, by the respective coaches and scientific staff).
Capillary blood samples for [La$^-$] analysis were collected from the earlobe at rest, in the 30s rest interval, immediately after the end of each exercise step, and at 3 and 5 min of the recovery period. These blood samples were analysed using an YSI1500LSport auto-analyser (Yellow Springs Incorporated, Yellow Springs – Ohio, USA). HR was monitored and registered continuously each 5s through a HR monitor system (Polar Vantage NV, Polar Electro Oy, Kempele, Finland). Swimmers were instructed to perform an open turn, always performed to the same lateral wall side, without underwater gliding, and were verbally encouraged to swim as long as possible during the test period. The test was carried out in same conditions for each subject, i.e., temperature and humidity.

Statistical analysis

Statistical procedure includes mean and standard deviations for all variables. All data was checked for normality. VT was assessed by Ve/$\dot{V}O_2$ curve modelling method (least square method) and was assumed as the intersection point, at the maximal fit situation, of a combined pair of regressions (linear and exponential) [13]. Intensity related to VT was expressed on %$\dot{V}O_2$max.

RESULTS AND DISCUSSION

The ability to sustain a high %$\dot{V}O_2$max during an endurance exercise appears to be related to %$\dot{V}O_2$max at VT [2]. Although this fact, due to the difficulties associated with the evaluation of the ventilatory parameters in swimming pool conditions, the VT assessment has been scarcely investigated [16].
The results obtained in our study show that the non linear increase of Ve seems to occur at 88.1±31.3 l.min^{-1}. This value corresponds to 84.3±8.7% $\dot{V}O_2$max. These findings seem to be in agreement with other studies conducted in running and cycling ergometers (82.3±3% [14], and 84.6±5.1% [7]), pointing out that, despite the specificity of the aquatic environment, the VT occurs at a similar absolute intensity as in running and cycling. This seem to be so, nonetheless the different haemodinamics (because of the horizontal body position), the decreased effects of gravity, and reflex bradycardia [12], in swimming. It also seems that the variation on training patterns in swimming and other sports, such as running and cycling, does not influence the value of %$\dot{V}O_2$max at that appends the VT. In the study conducted by Roels et al [16], there weren't found differences on the subjects' VT when performing an incremental test on water and on cycle ergometer, or between the two groups observed, swimmers and triathletes.
Although the obtained value of %$\dot{V}O_2$max associated to VT, does not represent the maximal work rate that can be maintained for a long period of time without a continuous rise of blood [La$^-$] (because, like many studies demonstrate [4, 15], the VT appends to an higher intensity than the intensity associated to the non linear increase in blood [La$^-$]), this exercise intensity should not be ignored in the swimming training, once it is associated to a group of physiologic mechanisms (like the bicarbonate buffering of the lactic acidosis) [5, 8, 20], determinant for the impairment of muscle contractility and its capacity to generate energy.

CONCLUSION

To our knowledge, this is one of the first studies in which %$\dot{V}O_2$max and VT are related, in swimming pool conditions. Thus, it is expected to provide additional data to better understanding of VT in swimming. The obtained results seem to indicate that the swimming training should include more intense sets on the aerobic capacity training, than the more "traditional" sets of moderate intensity, normally based or associated to the LT, which only represents one of many parameters associated to the AT. Our results indicate that to fully train the aerobic capacity, sets with intensity close to

85%$\dot{V}O_2$max should also be included, because of the importance of the mechanisms related to VT, on the rapid adjustment of the body's acid-base status during and immediately after exercise.

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LACTATE AND HEART RATE RESPONSES DURING SWIMMING AT 95% AND 100% OF THE CRITICAL VELOCITY IN CHILDREN AND YOUNG SWIMMERS

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The purpose of this study was to compare the lactate and heart rate responses of children (n=8, 11.5±0.6 yrs) and young swimmers (n=7, 16.0±1.7 yrs) when swimming at 95% (V95) and 100% (V100) of their critical velocity (CV). On a series of 4x400m, blood lactate concentration [La] of young swimmers increased at V100 after the 3rd and 4th 400m repetition compared to the 1st (1st:5.55±0.65 vs. 3rd:7.27±1.01 and 4th: 8.02±1.47 mmol/l, $p<0.05$) but remained unchanged at V95 ($p>0.05$). On a series of 4x300m, performed by children, [La] was unchanged after each 300m repetition in both trials (V95 and V100, $p>0.05$). Heart rate was higher in V100 compared to V95 trial ($p<0.05$, between groups $p>0.05$). Swimming at velocity equal to CV increased over time [La] in young swimmers but not in children. This may be attributed to different energetic responses or altered rates of lactate removal in children compared to young swimmers.

Key Words: Endurance training, training intensity, exercise domains.

INTRODUCTION

Metabolic responses during swimming at critical velocity (CV) have been previously reported (8). These early findings suggested that CV and maximum lactate steady state (MLSS) may represent the same exercise intensity. After a more careful examination it was found that CV represents exercise intensity higher than MLSS (2, 3). Energetics of children may differ from those of young swimmers and the metabolic responses have never been examined in children when swimming at this velocity. Even further, it is likely that CV may represent a different exercise domain for children and young swimmers compared to adults (7). The purpose of the present study was to compare the blood lactate and heart rate responses of children and young swimmers when swimming at 95% and 100% of the CV.

METHODS

Seven young swimmers and eight children (male swimmers) (x±SD, age:16.0±1.7 vs. 11.5±0.6years, height:177±6 vs. 149±5cm, body mass:68.9±5.4 vs. 42.9±5.8kg) participated in

the study, after parental agreement. The stage of biological maturation was assessed according to pubic hair development (6). All swimmers covered a distance of 3-3.500m (children) or 4.5-5.500m (young) on a daily basis. Initially, the CV was calculated from performance time on distances of 50-100-200-400m (8). Each swimmer performed a series of 4x400m (young) or 4x300m (children) with a velocity corresponding to 95% (V95) and 100% (V100) of CV in two different days a week apart, randomly assigned with a counterbalanced order. Swimmers had been familiarized with the required velocity two-three days before testing. To avoid any inconsistency with the prescribed velocity, one of the experimenters walked to the side of the pool and gave instructions when necessary.
The time to complete three stroke cycles was recorded during the last 25m of each 100m of the 400 or 300m in each trial for the calculation of the stroke frequency (SF). Stroke length (SL) was calculated from the mean velocity of each repetition divided by the mean SF. The resting interval between repetitions was kept as short as possible (35-45s) to allow for capillary blood sampling. Capillary blood samples were obtained from the finger-tip (10μl) after each 400 or 300m repetition and were enzymatically analyzed for blood lactate concentration ([La]) (Dr Lange M8). Heart rate (HR) was continuously recorded during each trial (Polar xTrainer-plus). Diet and training were controlled two days proceeding each testing session. The front crawl swimming style was used during all testing sessions and controlled warm-up was applied before each trial. All procedures took place in a 50m indoor swimming pool with a water temperature of 26 ºC. Analysis of variance for repeated measures was applied for statistical analysis (group x trial x repetitions). The Tukey post-hoc test was applied to locate the differences between variables. The level of significance was set at $p<0.05$ and the results are presented as mean ± SD.

RESULTS

The CV of young swimmers was higher compared to children (1.34±0.04 vs. 1.17±0.04 m/s, $p<0.05$) and corresponded to 96±0.7% and 97±0.3% respectively of their individual 400m best time. Children were at 2.3±0.5 and young at 4.4±0.8 of Tanner's stage. In young swimmers, blood lactate was higher at V100 compared to V95 (5.95±0.95 vs. 3.91±1.11mmol/l, $p<0.05$) increased at V100 after the third and fourth 400m repetition compared to the first (1^{st}:5.55±0.65 vs. 3^{rd}:7.27±1.01 and 4^{th}: 8.02±1.47 mmol/l, $p<0.05$) but remained unchanged at V95 (1^{st}: 3.80±0.91, 2^{nd}:4.41±1.08, 3^{rd}:4.52±0.94, 4^{th}:4.61±1.03 mmol/l, $p>0.05$, fig. 1).

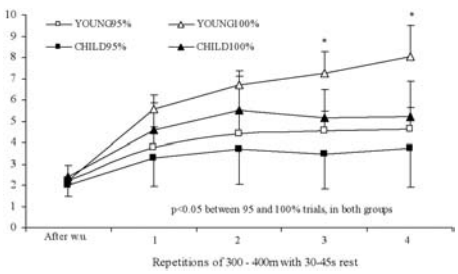

*Figure 1. Blood lactate responses during 4x400 and 4x300m repetitions in young swimmers and children. * $p<0.05$ compared to the first repetition of 400m in young swimmers (mean±SD).*

In children, blood lactate was unchanged after each 300m repetition in both trials (V95; 1^{st}:3.27±1.31, 2^{nd}:3.70±1.67, 3^{rd}:3.48±1.64, 4^{th}:3.74±1.82 mmol/l and V100; 1^{st}:4.56±1.32, 2^{nd}:5.49±1.89, 3^{rd}:5.15±1.35, 4^{th}:5.21±1.68 mmol/l, $p>0.05$, fig. 1). Blood lactate concentration was higher at V100 compared to V95 in both groups ($p<0.05$).

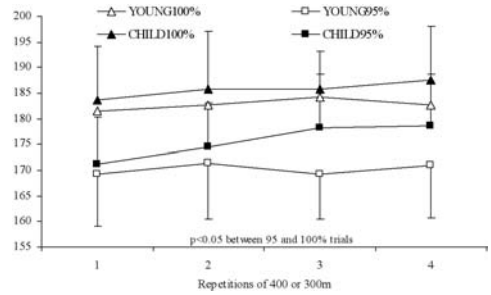

Figure 2. Heart rate responses during each repetition of the 4x400 and 4x300m swimming set (mean±SD).

HR was higher in V100 compared to V95 trial (184±8 vs. 173±8 b/min, $p<0.05$) and no difference was observed between groups ($p>0.05$, fig. 2). SF was increased in children compared to young swimmers (90±13 vs. 77±14 str/min, $p<0.05$). Both groups showed higher SF during the V100 compared to V95 trial ($p<0.05$). However, this increment was statistically significant for children but not for young swimmers (children, V95:79±6 vs. V100:101±6 str/min, $p<0.05$). Conversely SL decreased in children compared to young swimmers as well as during the V100 compared to the V95 trials ($p<0.05$).

DISCUSSION

The findings of the present study indicate that blood lactate responses during swimming at a velocity corresponding to the critical velocity (V100) are not similar between young boys and children. Swimming at V100 caused a rise of blood lactate after the second 400m repetition in young swimmers. In children lactate accumulation did not change after each 300m repetition in the corresponding velocity. Both groups completed the swimming repetitions at a velocity corresponding to 95% of the CV (V95) without blood lactate accumulation (fig. 1).
Blood lactate concentration is a widely used blood marker of metabolic responses during exercise and represents the difference of lactate release and the removal from circulation, but gives us no evidence of the events at the muscle cell.
Therefore, increased blood lactate concentration after each repetition in young swimmers but not in children may be attributed to at least two factors. Firstly, anaerobic contribution which may be expressed by increased lactate concentration is higher in young swimmers compared to children when swimming at the same relative intensity (5). Secondly, the rate of lactate removal may be different between the groups tested in the present study. In fact, recent findings suggest that children and adults do not show the same rate of lactate removal following maximal exercise (1). However, exercise at V100 cannot be considered as maximal since it represents exercise intensity below maximum oxygen uptake (2). Moreover, the rest interval between repetitions may have allowed for some blood lactate removal but this period (30-45s) was similar for both groups.

Even with different rates of removal, therefore, it is unlikely that this short recovery period was responsible for the lower lactate concentration in children compared to adults. On the other side, a different turnover rate of lactate during swimming between young swimmers and children is not improbable if we consider the difference in the training background of both groups (i.e. young 6 years, children 1-2 years of competitive training). Increased blood lactate accumulation at V100 in young swimmers may indicate exercise at a severe intensity domain. On the other side, the stability of blood lactate concentration on the corresponding trial may indicate exercise at a heavy intensity domain in children. The procedures followed in the present study did not allow us to speculate whether the critical velocity represents different exercise domains in these swimmers. However, our results are in agreement with earlier findings which reported that critical velocity represents exercise intensity above the maximal lactate steady state (MLSS) for adult swimmers (2). Research which focused on the location of CV on the exercise intensity domains should take into account that this parameter is estimated with different protocols on the number and duration of the tested distances. In a previous study (2) the trial duration was 1.4 to 7.1 min compared to 27s to 5.6 min in the present study. The shorter duration of our testing trials may have overestimated the CV. It is not surprising then that CV corresponds to 96 and 97% of the 400m velocity in the present study compared to 93% of the velocity at maximum aerobic power (2). Moreover, CV in children may represent exercise intensity similar to lactate threshold (7) while it is far above this level in mature triathletes during swimming (4). The difference in metabolic responses may indicate that CV expresses different exercise intensity domains for young swimmers and children.

HR increased in the V100 compared to V95 trial and was similar between groups. The values are similar to those reported for exercise intensity at 95% of the maximum aerobic speed and this represents exercise intensity above the MLSS (88% of maximum aerobic speed, Dekerle et al. 2005). The HR during the V95 trial (169-179 b/min) is comparable to that observed when swimming at MLSS (i.e. 179 b/min, 2). However, similar HR values between groups corresponded to different metabolic responses.

SF increased and SL decreased during the V100 compared to V95 trials. The SL did not decrease significantly during the 400m or 300m repetitions as it was expected (3) and this may be explained by the intermittent nature of the test which allowed for some recovery and maintenance of performance.

CONCLUSION

The present findings indicate that swimming at CV will induce an increased blood lactate concentration over time in young swimmers. However, this was not observed in children swimmers, and it may be attributed to different energetic responses or altered rates of blood lactate removal between groups. Coaches are advised not to focus on HR responses only but also take into consideration the fact that swimming at a velocity corresponding to CV may lead to different lactate responses and may represent different levels of exercise intensity in children or young swimmers.

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STROKE RATES CORRESPONDING TO CRITICAL SPEED AND THE MAXIMAL SPEED OF 30 MIN IN SWIMMERS OF DIFFERENT TRAINING STATUS

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The objective of this study was to verify the effect of aerobic performance level on the relationship between stroke rates at critical speed (SRCS) and at maximal speed of 30 min (SRS30). Twenty-three male swimmers of 15 to 20 yr were divided by aerobic performance level (S30) into G1 (n = 10) and G2 (n = 13) groups. SRCS was determined by the slope of the regression line between the number of stroke cycles and time. SRS30 was determined trough the mean value of stroke rate obtained during 30 min test. CS was higher than S30 in G1 (1.30 ± 0.04 and 1.23 ± 0.06 $m.s^{-1}$) and G2 (1.17 ± 0.08 and 1.07 ± 0.06 $m.s^{-1}$). CS and S30 were higher in G1 than G2. There was no difference between SRCS and SRS30 in G1 (33.07 ± 4.34 and 31.38 ± 4.15 $cycles.min^{-1}$) and G2 (35.57 ± 6.52 and 33.54 ± 5.89 $cycles.min^{-1}$). In conclusion, SRCS can be used to predict the SRS30 irrespectively of the aerobic performance level.

Key Words: Stroke rate, swimming, aerobic capacity.

INTRODUCTION

In competitive swimming, biomechanical aspects representing the swimming technique and skill may equally contribute to performance when compared to aspects related to the energy production systems. These biomechanical aspects include the level of application of propulsive force and passive and active drag (9, 14).

Studies have shown that these aspects interfere with variables such as energy expenditure and propelling efficiency, with these factors being fundamental for human locomotion in water (3, 18). Among the indices that express the biomechanical skill in swimming is the stroke rate (SR), which corresponds to the number of strokes or stroke cycles performed per unit of time. In addition, the relationship between this variable and stroke length (SL) also seems to express the swimming ability level (3). The mean speed in swimming is equal to the product of SR and SL (16). To maintain a given speed, swimmers generally adopt a combination of SR and SL which they judge to be most efficient. These variables have shown a significant correlation with oxygen uptake at a given submaximal speed and with performance at different swimming distances (100, 200, 368 and 400 m) (2, 3, 10, 18).

With respect to the physiological indices that can estimate aerobic capacity, the critical speed (CS) and the maximal speed of 30 minutes (S30) are among the noninvasive methods most widely used for aerobic assessment during swimming (7, 15). These speeds (CS and S30) have shown high correlations with speed at maximal lactate steady state and with aerobic performance in this modality (5, 8). Recently, Dekerle et al. (4) showed that the SR determined based on the slope of the regression line between the number of stroke cycles and time obtained at different distances (critical stroke rate – SRCS), similar to the method proposed for the determination of CS, is valid to estimate the SR maintained in an S30 test (SRS30) (4). One advantage of this method is that shorter tests (e.g., 200 and 400 m) can be used, since longer tests such as the S30 require more time for assessment and are difficult to perform by less skilled swimmers.

Since the CS depends on the duration of predictive loads (1), a fact that might interfere with the relationship between this variable and the anaerobic threshold (4 mmol.l^{-1} blood lactate) (8), it is possible that the physiological and biomechanical meaning of CS depend on the performance level of the swimmers, since high performance athletes swim the same distances (e.g., 200 and 400 m) in less time. Still regarding the performance level, elite swimmers may adopt combinations of stroke parameters which are very different from those used by their less proficient counterparts (4). Thus, it is possible to hypothesize that the level of aerobic performance may modify the relationship between SRCS and SRS30. On the basis of this hypothesis, the central objective of the present study was to determine the effect of the aerobic performance level on the relationship between SRCS and SRS30.

METHODS

Subjects

Twenty-three male swimmers with similar physical characteristics were divided by aerobic performance level (S30) into G1 (n = 10) (Age = 16.22 ± 2.72 yr., Body mass = 64.74 ± 11.45 kg, Stature = 174.08 ± 7.42 cm, Body fat = 12.80 ± 2.99 %) and G2 (n = 13) (Age = 14.60 ± 1.35 yr., Body mass = 61.56 ± 15.76, Stature = 169.80 ± 10.37, Body fat = 14.80 ± 5.27). They had at least 4 years of experience in the modality and a weekly training volume of 30,000 to 45,000, and were competing in regional and national level. Before participation in the study, the swimmers and their parents or guardians were informed of all test procedures and they provided voluntary written informed consent to participate in the study. The protocol was approved by the university's ethics committee.

Experimental design

The anthropometric characteristics were measured in the first experimental session. Then, the performances of 200 m, 400 m, and 30 min in front crawl were determined in a random order. All tests were performed in a 25 m pool, with at least 48-72 h of rest. Swimmers were divided in groups G1 and G2 based on the maximal speed of 30 min (S30), which was different between groups ($p < 0.05$). For each swimmer, all tests were conducted at the same time of day and after at least 2 h of a meal.

Determination of critical speed (CS)

During training sessions, the participants were instructed to swim distances of 200 and 400 m as quickly as possible. The time taken to swim each distance was recorded using a manual chronometer. Participants swam one event per day in random order. CS was determined using the slope of the linear regression between swimming distances and the time taken to swim them.

Determination of maximal speed of 30 min (S30)

S30 was determined through a maximal 30 min test, recording the distance in m, and calculated dividing the distance by time. At the 10th min and at the completion of the test, 25 μl of arterialized blood were collected from the ear lobe through a heparinized capillary and immediately transferred to microcentrifuge tubes containing 50 μl NaF (1%) for lactate [La] measurement (YSL 1500 STAT, Yellow Springs, OH).

Determination of the stroke rates corresponding to SC (SRCS) and S30 (SRS30)

During the 200 and 400 m tests, the time necessary to complete 5 strokes was measured along the pool, at each passage of 50 m, and the mean value was calculated. SRCS was calculated by the linear slope of the regression line between the number of stroke cycles and time. During the 30 min test, the time necessary to complete 5 strokes was measured along the pool, at each passage of 400 m. To determine SRS30, the mean value was calculated. These measurements were made after 10 m of the turn to avoid its influence in swimming speed.

Statistical Analysis

The values were expressed as mean ± SD. The effect of method (CS and S30) and group (G1 and G2) on the relationship between SRCS and SRS30 was made through ANOVA TWO WAY, with Tukey HSD post-hoc tests where appropriate. The comparison of the physical characteristics between groups was made through Student *t* test for unpaired data. The correlation between CS and S30 was made through Pearson product moment correlation coefficient. Significance was set at $p \leq 0.05$.

RESULTS

Table 1 presents the mean ± SD values of SRCS, SRS30, CS and S30 obtained in G1 and G2. There was no significant difference between SRCS and SRS30 in G1 and G2. The SRCS and SRS30 were similar between groups. CS was higher than S30 in G1 and G2 ($p < 0.05$). CS and S30 were higher in G1 than G2 ($p < 0.05$). There was no significant difference in the blood lactate levels obtained at 10th min and the completion of the 30 min test between G1 (4.37 ± 1.53 and 3.58 ± 1.57 mmol.l^{-1}, respectively) and G2 (4.09 ± 1.57 and 3.66 ± 1.56 mmol.l^{-1}, respectively) ($p > 0.05$). The correlation between CS and S30 (G1 – r = 0.68 and G2 – r = 0.84) and SRCS and SRS30 (G1 – r = 0.84 and G2 – r = 0.88) was statistically significant in both groups.

Table 1. The mean ± SD values of SRCS, SRS30, CS and S30 obtained in G1 and G2.

	G1 (n = 10)	G2 (n = 13)
CS ($m.s^{-1}$)	1.30 ± 0.04	1.17 ± 0.08*
S30 ($m.s^{-1}$)	1.23 ± 0.06	1.07 ± 0.06*
SRCS ($cycles.min^{-1}$)	33.07 ± 4.34	35.57 ± 6.52
SRS30 ($cycles.min^{-1}$)	31.38 ± 4.15	33.54 ± 5.89

** $p < 0.05$ in relation to G1. SRCS – stroke rate at critical speed, SRS30 – stroke rate at maximal speed of 30 min, CS – critical speed, S30 – maximal speed of 30 min.*

DISCUSSION

The central objective of the present study was to determine the effect of aerobic performance on the relationship between SRCS and SRS30 during swimming. The main finding was that the relationship between SRCS and SRS30 was similar in G1 and G2, suggesting that, irrespective of the aerobic performance level, the determination of CS may simultaneously provide information about aerobic capacity and biomechanical skill in this modality.

In a study conducted on trained swimmers, Dekerle et al. (4) found values of SRCS (37.79 $cycle.min^{-1}$), SRS30 (36.41 $cycles.min^{-1}$), CS (1.35 $m.s^{-1}$) and S30 (1.31 $m.s^{-1}$) higher than those observed in the present study for G1 and G2 (Table 1). These authors also observed no significant difference and a high correlation ($r = 0.86$) between SRCS and SRS30, in agreement with our data showing that the relationship between SRCS and SRS30 seems to be independent of aerobic performance. However, in contrast to the above study, in the present investigation CS overestimated S30 in both groups. One aspect that might explain in part this behavior is the small experience of the swimmers, a fact that may have underestimated the S30, since the experience level seems to influence the capacity to perform endurance tests (5). Therefore, modifications in the technical pattern (SRCS x SRS30) seem to occur to an extent differing from the variations in swimming speed (CS x S30), at least at the level of experience and aerobic performance analyzed in the present study.

With respect to the measurement of SR at intensities close to the CS or S30, studies have shown a significant change in the stroke pattern when the individual exercises above the intensity corresponding to the maximal lactate steady state (12), or above the anaerobic threshold (11, 12, 13), suggesting a relationship between metabolic fatigue and a fall in swimming skill (6). In cyclic sports, the fatigue is associated with a reduction in the frequency of the movements (17). Therefore, since biomechanical skill may be compromised as a function of physiological mechanisms associated with fatigue, the measurement of SRCS or SRS30 and of CS or S30 might be an important tool to determine the biomechanical and physiological aspects associated with aerobic capacity.

CONCLUSION

Based on the present data we conclude that the aerobic performance level does not seem to influence the relationship between SR corresponding to CS and S30. Thus, the protocol of determination of CS may simultaneously provide information regarding physiological aspects (aerobic capacity) and an index associated with biomechanical skill, thus representing an important tool for the assessment, control and prescription of aerobic training in swimming, since less skilled athletes might underestimate the distance to be covered for 30 min as a result of lack of experience and high motivation.

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THE FUNCTION OF NASAL PRESSURE FOR BREATHING IN THE BREASTSTROKE

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The purpose of this paper is to discuss the function of the sensation of water touching the face and the effects of nasal pressure on breaststrokers. For examining facial sensation, skin around the nose was covered with film. To study effects of nasal pressure, the nostril was covered with film. Then the pressure data and other data were analyzed using the Student T-test. There was no difference (t=0.40) in depth pressure with swimmers covered with film and not covered. When the nostrils were closed, face depth (average: 30.3cm) was shallower (t=0.006) than in the controlled setting (28.0cm). There were no significant differences (t=0.62) between the experimental and controlled settings with regards to face-sustaining duration above water surface and subjects' breathing.

Key Words: breath control, nasal pressure, water pressure, facial sensation.

INTRODUCTION

Two study discuss in the paper illustrate the importance of facial sensation on swimmer's sense of safety and swimming continuity, which are two important factors in swimming. Using nasal pressure measuring method (3), the result from the experiment revealed that intranasal pressure was a little higher than the pressure in water at the depth where subjects were swimming while exhaling and holding their breath. Novice swimmers often have problems controlling breathing while swimming. As a result, the water is swallowed or swimming is cut short due to breathing problems. This is directly linked to how the swimmer times exhalation or inhalation appropriately.
The purpose of this paper is to discuss the results of two experiments. The first experiment was to determine the sensation of water touching the face, especially the cheek area. The second examines how nasal pressure sensation affects the timing of exhalation and inhalation.

METHODS

The purpose, methods and risks were explained to the subjects in verbal and written form and consent was given prior to carrying out the experiments. The methods used were approved by the Department of General Planning Research Cooperation Section of Kokugakuin University. The characteristics of subjects are shown in Table 1.

Table 1. Characteristics of Subjects (average).

Experiment	N	Age (yrs)	Body Fat(%)	Sex	Swim Experience
#1) Cheek covered	6	23.0	17.3	male	recreational
#2) Nostril closed	6	23.2	18.0	male	recreational

Nasal pressure was measured during ten strokes with two sensors. One sensor was inserted in the nasal passage and the other was placed outside the nostril wall with surgical tape. The outside pressure was measured at face depth (fig. 1). All pressure measurements were performed in a swim-mill. To cover the facial area and close the nostril, see-through protector film was used. The film was 0.03 mm thick, made of polyurethane, which is primarily used for covering lesions. Differences in water pressure and nasal pressure were analyzed by the Student T-test (probability = 0.05).

Figure 1. Lowest stroke position; the arrow (from the surface to the sensor) shows the depth where measurements were taken.

Figure 2. Cheeks were covered with film around the nose and below the nose (The area inside the black line).

Experiment #1 attempted to determine the function of the sensation of water touching the face. To do this we compared facial depth of breaststroke swimming in normal conditions (controlled condition) to film-covered trials, which included subjects' cheeks, nose, and the part below the nose being covered with protector film (fig. 2). In both the conditions, the nostrils were not closed with film. To measure intranasal pressure and water depth pressure, two interface tubes were attached by surgical tape.
Experiment #2 compared facial depth when influenced by the closing of the nostrils with film. Facial depth was measured while subjects swam the breaststroke under normal conditions (controlled condition) and when nostrils were closed (experimental condition).

Pressure was measured with a pressure transducer (SPC-464:Millar) connected to a control unit (TCB-500:Millar). This was also used to measure arterial blood pressure and to obtain reliability (1, 4). Data was recorded on LogWorx (Distributed Design Concepts) and measured pressure was analogically curved (fig. 3).

RESULTS

This section discusses the statistical data of two experiments. In experiment #1 (facial depth pressure study) there was no significant difference between the control condition and the film-covered condition (Fig. 4-left). The Student T-test result was t=0.40. In the second experiment, a difference in the depth pressure was found (Fig.4-right). In the control condition, the average pressure was 28.0 cmH2O, and in nostrils-closed condition, it was 30.3 cmH2O, and the result of Student T-test was t=0.62. On the pressure curves, the face-sustained duration was also measured (Fig.3), which was detected between depth pressure curves (fig. 2). Then it rose once again when the sensor went below the water. The duration of the curve was measured while at the bottom. No significant difference was found between experiments pertaining to face-sustained duration.

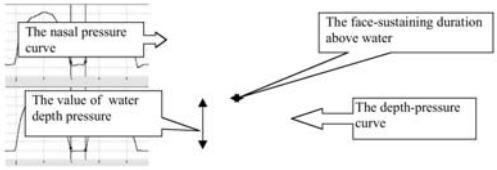

Figure 3. The pressure curves obtained from the experiment and an explanation of sections analyzed.

DISCUSSION

In an earlier study, it was reported that nasal pressure is higher, albeit minutely, than water depth pressure when the face is immersed in water (2). This pressure is required to protect the nose from incoming water. Another consideration, while swimming, aside from pressure, is the timing of breath inhalation and the intake of water. Intake of unwanted water occurs due to a lack of sensation when water touches the skin, and/or due to a lack of sensing nasal pressure. When exhaling while swimming, there is a tendency to inhale from the nose and mouth as soon as possible, at the moment the face is above water. This is done in an effort to avoid holding one's breath longer than is deemed necessary. For the purpose of quick breathing, the cutaneous sensor and pressure sensor in the nasal area must perform their roles effectively.

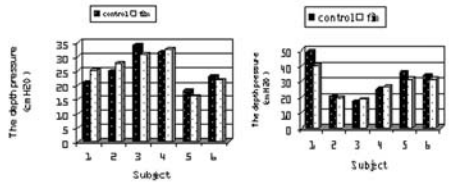

Figure 4. Comparison of average depth pressures in the first experiment (LEFT: film covered the cheek area) and the second experiment (RIGHT: the film closed the nostrils).

Based on the results of the two experiments, safe breathing exhalation from nose appears to be more important than the sensation on the cheeks. Previous research supports this hypothesis. Tsubone (5) reports that negative pressure receptors are found in the nasal passage of rats. Similar receptors may exist in humans. Wheatley (6) describes breathing routes; one through the mouth and the other via the nose. Therefore, nasal exhalation while swimming is very important for breath control. The pressure receptor might have an important role in pushing the switch on to start inhalation at the moment of when a positive amount of pressure changes to state of near zero pressure in the air.

In the case of swimming instruction, knowledge about timing sensory mechanisms can enhance successful swimming, especially for beginners. While swimming, novice swimmers usually have two kinds of difficulties in regards to breathing. One is difficulty in timing inhalation, for fear of swallowing water at the moment of inhalation. Negative pressure in the nose reassures the swimmer that inhalation can be carried out without fear of swallowing water because their face is in the air. To alleviate such a fear, exhaling while the nose is still in the water is effective. To keep the face in the air, the face must be held in a high position for a longer period of time. To avoid having the face out of the water for too lengthy a duration, early inhalation is very important.

The other difficulty surrounding exhalation for a novice swimmer is the fear of not being able to be inhale on the next breathing motion opportunity. To combat this fear while swimming, it is important to be conscious of one's facial position, both in and out of water. When cutting the surface with a quick vertical head motion, the cutaneous sensation on the face is confusing for breath control. With slow head rises, one can easily recognize whether one's mouth and nose are still in or out of water.

ACKNOWLEDGEMENT

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CONCLUSION

When instructing beginners, breathing is the most important factor to assure safety and to make them psychologically comfortable. Therefore, investigating the breathing mechanism of the breaststroke is meaningful in developing physiological grounds for instruction of novice swimmers.

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MIXED-MODEL ANALYSIS OF THE RELATIONSHIPS BETWEEN TRAINING LOADS AND HEART RATE VARIABILITY IN ELITE SWIMMERS

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INTRODUCTION

Heart rate variability (HRV) analysis is a well-recognized method to assess autonomic nervous system perturbations, and was shown to be influenced by the fitness and the fatigue in endurance athletes (6). The relationships between HRV and training loads were shown to be highly individualized (6), and dependent of several factors, including gender (G), training level (L) and specialty (S) (1). Indeed, the HRV responses could probably be influenced by long-term effects (LTE) (6). When only few repeated measurements are available for several subjects characterized by a large inter-individual variability, mixed models provide an attractive solution (2). Instead of constructing a personalized model for each subject, a model of common behavior is constructed, allowing parameters to vary from one individual to another, to take into account the heterogeneity between subjects. The aim of this study was to investigate the immediate and differed effects of training loads on HRV taking into account: (a) the mean structure of the covariates G, L, S; (b) individual profiles, and (c) subpopulation profiles.

METHODS

Twenty one (11 females, 10 males) national and international level French swimmers were studied, (20±3 yr, 179±6 cm, and 65±11 kg). HRV was monitored during 1 to 3 years, twice a month, during each period of the training cycle. The mean number of recordings per subject was 23±12. Each test lasted 12 min, in supine position. The RR interval (time between two R waves of the recorded cardiac electric activity) was measured with a Polar S810 HR monitor (Polar®, Kempele, Finland). Fast Fourier Transform (FFT) was then applied to calculate the spectral power using Nevrokard HRV software (Nevrokard® Medistar, Ljubljana, Slovenia). Peaks were extracted from the spectrum and determined on low frequency (LF between 0.04 Hz and 0.15 Hz) and high frequency (HF between 0.15 Hz and 0.5 Hz). This allows us the determination of LF and HF powers, total power (TP) and computing the LF/HF ratio. Quantification of the training stimulus was performed as proposed by Hellard et al. (5). Three training loads were determined according to 3 training zones. Low intensity training (LI), represented swimming speeds below the onset of blood lactate accumulation (OBLA), and high intensity training (HI), represented swimming speeds above OBLA. Strength training (ST) was quantified in minutes of active exercise, excluding resting periods. Then, 3 training phases were identified during each training cycle: the short term phase (STP) was defined as the last week before each HRV measure; the intermediate (ITP) and long term phase (LTP) were defined as week 1 and week 2 prior each HRV measure. Finally, 9 distinct independent variables were defined STP_{LI}, ITP_{LI}, LTP_{LI}, STP_{HI}, ITP_{HI}, LTP_{HI}, STP_{ST}, ITP_{ST}, LTP_{ST} and linked to HRV measures using mixed models.

RESULTS

TP and LF were higher in male than in female (18687±2888 vs. 8227±1857 ms^2; 3885±2888 vs. 1857±2269 ms^2, respectively $p \leq 0.01$). TP and LF were higher for international swimmers than for national (14475±12407 vs. 10655±14712 ms^2; 8392±9483 vs. 5752±9445 ms^2, respectively $P < 0.01$). TP and LF increased significantly from the first to the second part of the season (16512±14166 vs. 10109±12115 ms^2; 10246±10657 vs. 5005 vs. 7772 ms^2). The mixed model described a significant relationship between training and HRV $HF = 0.18L\ [0.09\text{-}0.26] + 0.16SU\ [0.06\text{-}0.23] + 0.16\ STP_{LI}\ [0.06\text{-}0.23] + 0.11G\ [0.03\text{-}0.21] - 0.10\ STP_{ST}\ [0.02\text{-}0.18]$, $R\_ = 0.1$, $F = 7.71$, $p \leq 0.0001$. In the model the inter-subject differences were statically significant. The fit between real and modelled HRV values was significant for all swimmers ($0.10 \leq R^2 \leq 0.47$, $p \leq 0.05$). For instance, for subject 4, $LF/HF = -0.32\ STP_{LI}\ [-0.58;-0.06] - 0.48\ STP_{HI}\ [-0.73;-0.23] + 0.59\ STP_{ST}\ [0.33;0.85] + 0.60\ ITP_{HI}\ [0.39;0.81]$, $R\_ = 0.40$, $F = 3.11$, $p \leq 0.05$. The number of measured LF/HF data included into the 95% CI was 15 in 21 measured (Figure 1).

DISCUSSION

The four main observations emerging from these analyses were: 1) HRV was higher for international level swimmers. 2) The impacts of training on HRV increase significantly from the first to the second part of the season. 3) Considering the overall sample, the training variables explained only a weak part of HRV variance. 4) Finally the variations of HRV were specific to the interactions of the various types of training loads during the course of time.

HRV was higher for international level swimmers. Several researches pointed that basic characteristics of the autonomous nervous system would largely induce the nature of the responses to training. Hautalla et al. (3) highlighted in 39 sedentary subjects (ages 36 ± 6 years) a relationship between the improvement of the aerobic power after a 8 weeks training course and the night power parasympathetic HF at the beginning of the study. Hedelin et al. (4) showed in seventeen cross-country skiers and canoeists that those having improved their $\dot{V}O_2max$ were characterized by higher initial power HF values. These results let suppose that initial high levels of variability prelude to the increase in the VO_2max (3, 4).

The impacts of training on HRV increase significantly from the first to the second part of the season. These higher values of variability could be one consequence of the more intense and prolonged training as well as of the delayed effects of the first part of the year. Indeed, the HF rhythmic component responses could probably be influenced by long-term effects. For instance, (Furlan et al. 1993) showed that high level swimmers examined after a six weeks detrained period were characterized by slight bradycardia accompanied by a spectral profile suggestive of a prevailing vagal tone. In the same trend Pichot et al. (6) observed a persistence of the parasympathetic prevalence after a 7 weeks period of detraining following a two months training period.

For the group as a whole the training variables explained only a weak part of the measurements HRV variance. Indeed, large inter individual variations were observed in the autonomic cardiac regulation (7). Several researches showed that the genetic factors determined a broad proportion (~ 20%) of the HRV inter individual variations (7, 8). Moreover, several factors (quality of the sleep, psychological states) are likely to influence diurnal measurements of HRV (1).
Figure 1 shows for subject 4 the real and modelled LF/HF ratio evolution compared to the swimming training load (n=21, r=0.28, p=0.2). This figure highlights the difficulty to interpret the HRV measures evolution from only one training parameter. Indeed the solution of the regression for this subject points that the training swimming load during the week of the test decreases ratio LF/HF, whereas two weeks weight and water severe training loads tends to increase this ratio.
Finally the HRV variations were specific to the various types of training loads, to their interactions and distribution in the course of time. Moreover the cardiovascular responses during training were specific to the nature and intensity of exercise (1).

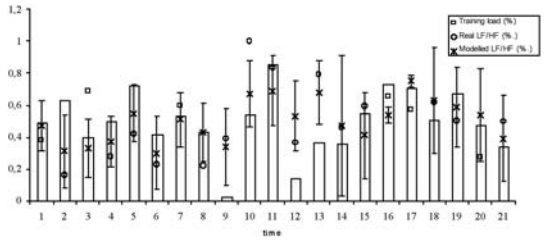

Figure 1. Real and modelled LF:HF ratio associated with the weekly training swimming load for subject 4. Values in vertical axis are expressed in normalised values. In horizontal axis are expressed the number of HRV measures. Real LF:HH measures is indicated with circles and modelled LF:HF measures with crosses. Weekly swimming training loads are represented with yellow rectangles.

CONCLUSION

In conclusion, the HRV was higher in high-level swimmers and increased throughout the sporting season. It could be interesting to model the individuals training loads/HRV relationships in order to control the training impact on autonomic nervous system.

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THE VALIDITY OF A NON-PACED LACTATE PROFILE TEST FOR SWIMMERS

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The aim of this study was to examine whether swimming without pace-lights affects lactate test results compared to swimming with pace-lights. Each of the 11 competitive swimmers performed, in a randomized order, on one day with paced workloads and one day without. The test protocol consisted of five 400m front crawl workloads with increasing velocity. Predetermined velocities for each swimmer were either paced using a set of 14 pace-lights moving below the swimmer or self paced. Mean velocities of paced or unpaced workloads at lactate values of 2, 3, 4 and 5 mM showed no statistical differences (p>0.05), and mean standard deviation of lap times was 0.60±018 and 0.57±0.17s for the paced and unpaced trials respectively (p>0.05). This study shows that during lactate testing, competitive swimmers are able to hold an even pace and meet predetermined workloads without the use of external pacing.

Key Words: lactate testing, validity, pace lights, testing methodology, pacing.

INTRODUCTION

On the contrary to maximal oxygen uptake testing, blood lactate profile testing has several suggestions for test protocols. The whole concept rests on different theoretical backgrounds, like ventilatory threshold (8), onset of blood lactate accumulation (OBLA) (3) or a fixed 4 mM lactate threshold (4). These different concepts make it difficult to establish a gold standard for lactate profile testing. However, the concept of maximal lactate steady state (MaxLass) (e.g. 2) seems to establish a standard, and lactate testing often aims at finding the MaxLass in an indirect way. However, research has shown differences in test results due to only small differences in testing protocol, for instance by different lengths of workloads, different rest intervals and different intensity increases between the workloads (2).
The important features of indirect lactate testing protocols to find MaxLass are the ability to 1) keep a even pace during the workload, and 2) keep the increase in intensity from workload to workload at reasonable steps and 3) to have a short but standardised rest interval (2). In a dry-land laboratory the use

of workload control by a motorised treadmill or an electrically controlled ergometer cycle is a certainty. In the pool laboratory this control is not often an option and the use of pacing lights has been suggested to control workload when testing swimmers (5). Whether the pacing by moving underwater lights really is necessary has not yet been investigated. The question is whether competitive swimmers, who often use pace-clocks in their training and have been doing so for many years, are able to keep an even pace without the use of pace lights. The aim of this study was to examine whether swimming without pace-lights affects lactate test results compared to swimming with pace-lights.

METHODS

A randomized crossover design was conducted, where each of the 11 swimmers (mean age 20 years (range 16-24)) was their own control. All subjects were competitive swimmers, and consisted of 3 females and 8 males. Their performance level ranged from one Olympic swimmer, through Norwegian Championship medallists and club level swimmers. Average weekly training volume for the last 6 months before the study was 36 000m.

The test protocol was performed once with and once without paced workloads on two different days, at the same time of day, and with one resting day between the two tests. The order of the two test days was randomized. A stepwise test protocol consisted of five 400m front crawl workloads with increasing velocity and a 60s rest interval. Working times ranged from slowest swimmer and slowest workload with 362s (6:02 min) to 250s (4:10 min) for the fastest workload on the fastest swimmer. Predetermined velocities for each swimmer were either controlled by the swimmer himself or paced using a set of 14 pace-lights (Optimal Controlbox Corp., USA) moving below the swimmer (fig. 1). During the paced trials the subjects were excluded from using the pace clock. A standardised warm-up procedure was used, and before the paced test subjects were familiarized with using the pace lights.

Lactate data was collected using an YSI 23L lactate analyser (Yellow Springs Instruments, Yellow Springs, USA). The analyzer was calibrated according to standard procedures (using 5 and 15mM standard lactate solutions). True velocity was calculated in $m \cdot s^{-1}$ using a stopwatch and the pool length. A paired t-test was used for statistical comparisons.

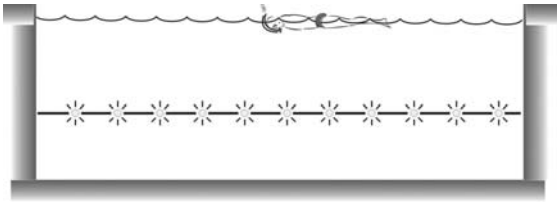

Fig 1: Pace- lights controlling the velocity of the swimmer.

RESULTS

The mean velocities of paced or unpaced workloads at lactate values of 2, 3, 4 and 5mM showed no statistical difference and are shown in fig. 2. The mean absolute difference between paced and un-paced velocities at lactate values of 2, 3, 4 and 5 mM are all 0.02 (± 0.01) $m \cdot s^{-1}$.

Standard deviation of the mean times for each pool lap in each workload (16 laps) was chosen as the measurement of how evenly paced each workload was conducted. The mean standard deviation for each workload number is shown in fig. 3. For all trials and all subjects the mean standard deviation was 0.60±018s using pace lights and 0.57±0.17s swimming freely (p=0.32). A two-way ANOVA test for the effects of pacing and workload number showed no statistical effect of pacing, a significant effect of workload number (p=0.03) and no interaction effect. A Bonferroni corrected post hoc test revealed a significant smaller mean standard deviation of lap times for unpaced workload nr 4 compared to workload nr 1.

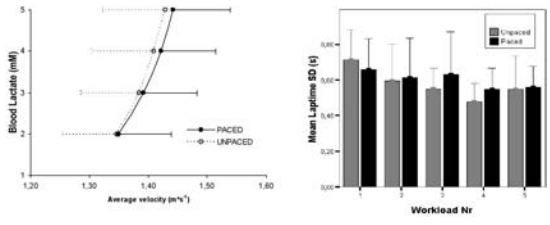

Figure 2. Average velocities (±SD) for Fig. 3: Mean (error bars show SD) lap paced and non-paced workloads time standard deviation (s) for paced (n=11) at lactate levels of 2, 3, 4 an and unpaced workloads. 5mM

Furthermore, no statistical difference was found between the average decrease in swimming time from workload to workload in paced compared to unpaced swimming (mean± SD of 14.4±1.66 and 13.0±1.14s respectively p>0.05).

DISCUSSION

The use of lactate testing in swimming without any form of pacing control is a widespread custom. This custom is justified by the present results, showing that competitive swimmers are able to keep an even pace and that they are able to work at the prescribed workload (velocity) without pacing help. The results show that mean difference of velocities at 2, 3, 4 and 5 mM lactate values is 0.02 $m \cdot s^{-1}$. This must be considered a low difference and was found to be statistically not significant. For comparison, a common velocity step when testing swimmers for sub maximal VO_2 is 0.05 $m \cdot s^{-1}$, and the mean decrease in velocity from lap 3 to lap 4 during international short course 100 m races may be in the area of 0.04 $m \cdot s^{-1}$ (unpublished results from race analysis). The relatively large standard deviations shown in fig. 2 are due to a relatively vide range in performance of the subjects.

Looking at the variations in lap times for each workload it seems that a pacing device for swimmers is not necessary. In laboratory testing on dry land, keeping an even pace to attain a representative steady state workload is important (2). For the unpaced swimming lactate test the mean standard deviation of the lap times was no different from the paced test. This means that swimmers are able to keep an even pace without external pacing help. As the lactate measured at the end of the workload depends on a reached steady state, the evenly performed unpaced workload strengthens the validity of this testing protocol.

There are few scientific studies on external pacing for swimmers. One study investigated the physiological effects of even, positively or negatively paced 200m breaststroke swims, and

found that the evenly paced swim produced lower physiological stress (lower post exercise blood lactate concentration) (6). The accuracy of pacing using paced and unpaced swims has also been investigated by this group of researchers. However they used an acoustic pacing device. This form of pacing gave a pacing signal for each 12.5m of the pool and is quite different from the moving pace lights where the pacing is continuous and the swimmer instantly gets visual feedback on the pacing position. The results from the study on the acoustic pacing situation show that swimmers are able to pace a 200m sub maximal breaststroke swim accurately without external pacing within 2.2-2.7s (95% level of agreement) of their target time (7) (no significant bias was found). Moreover, in the same study these authors also concluded that external acoustic pacing produced a more accurate final time, from -1.8 to +1.3s of target time, in a group of less well trained and less homogenous swimmers. However in this study no measurements were done to assess the within-trial pacing for sub maximal swimming, so it is not known whether the subjects were able to hold an even pace for the whole 200m.

Our findings are further supported by results obtained on runners. Billat et al. (1) found that long distance runners produced only small variations in velocity during free paced runs, and there were no significant difference in pacing compared to paced runs. Possibly, swimmers are accustomed to swimming at prescribed paces due to the use of pace clocks in daily training routines. We assume that after many years of swimming training this ability have been developed to a high degree in swimmers. It would be logical to assume that this effect would be strongest at the training paces most often used by the swimmers.

Looking more closely on the lap time variations, it may seem that a pacing device is more needed when the velocities are low (fig.3). The mean standard deviation of lap times for the first workload on both the unpaced and the paced trials showed the highest variation. The results of the ANOVA test revealed that lap time variations decrease as workload number increase for paced and unpaced trials together. However post hoc testing (Bonferroni corrected) revealed only a statistically difference between workload number 1 and 4 for the paced trials, and this means that the lap time variations of the unpaced trials can be considered to be independent of workload number. However measurements of oxygen uptake and other physiological parameters may still require the use of pace-lights.

Wearing breathing masks and other types of apparatuses may alter the relationship between the physiological intensity and the velocity, thereby reducing the swimmers feel for the right speed. Furthermore, at maximal VO_2 test protocols the workload is not at steady state or at an even intensity, thereby justifying the necessity for external pacing. Additionally, and as indicated by the results, but not confirmed statistically, when the velocity of swimming differs widely from the normal training paces a pacing device may have its function.

CONCLUSION

The use of lactate testing in swimming without some form of pacing control has become a widespread custom. The results of this study support the common practice of lactate testing in the pool for swimmers, without the use of paced workloads. The validity of this form of lactate testing is supported. Competitive swimmers are able to hold an even pace and meet predetermined workloads without this form of assistance.

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ASSESSING THE INDIVIDUAL ANAEROBIC THRESHOLD: THE MATHEMATICAL MODEL

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This work presents a mathematical method based on a fit to the observed velocity/[La^-] data points for swimmers that allows the determination of the anaerobic threshold individually. In the present method a straight line is fitted to the lower velocity data points, while an exponential line is fitted to the higher velocity data points. The point of interception of both lines is considered as the point of beginning of the anaerobic threshold. Some practical examples are shown.

Key Words: mathematical model, anaerobic threshold, swimming.

INTRODUCTION

Several methods have been developed to assess the exercise intensity after which the lactate production exceeds its removal, i.e., the anaerobic threshold (AnT) (1). One of the most used methods for AnT assessment is based on the averaged value of 4 mmol/L of blood lactate concentration [La^-], proposed by Mader et al. (4). However, the [La^-] corresponding to AnT has been reported to have great variability between swimmers. Other methodologies for AnT determination have been proposed to find more specific and individualized values for this parameter. These methods also contain some limitations, namely: (i) the subjectivity of the observation of the [La^-]/velocity curves' inflection point; (ii) the use of long test distances with significant velocity differences between steps (MaxLass) and (iii) the necessity of very high values of [La^-]

(15 mmol/L), which implies strenuous exercise intensities (cf. Bunc et al. (2)).
This work presents in detail a mathematical model to obtain a particular value for the anaerobic threshold for each swimmer. This model has been used by Fernandes et al. (5) to assess the individual AnT (IndAnT) for 32 swimmers.

METHODS

Consider a set of N distinct data points (x_i,y_i). These points may be fitted by a straight line with equation:

$$y = m \cdot x + c, \quad (1)$$

where *m* and *c* are constants to be determined, based on the observed data points. They may also be fitted by other functions, for example the exponential function, with equation:

$$y = a \cdot \exp(b \cdot x), \quad (2)$$

where a and b are constants to be determined, also based on the observed data points. One method to find the unknown coefficients of the fitting curve is the Method of Least Squares, where the vertical distance between the observed data points and the fitted ones is minimized. Symbolically, the quantity

$$\sum_{i=1}^{N} \left(y_i - f(x_i)\right)^2 \quad (3)$$

is minimized. For the case of a straight line, this corresponds to finding

$$\min\left(\sum_{i=1}^{N} \left(y_i - m \cdot x_i - c\right)^2\right);$$

while for an exponential, it corresponds to finding

$$\min\left(\sum_{i=1}^{N} \left(y_i - a \cdot \exp(b \cdot x_i)\right)^2\right).$$

It is a well known result that to adjust a function with p different parameters to N data points we must have: $N \geq p$. When N = p, the fitting reduces to an interpolation, and there is no difference between the observed points and the adjusted function, that is, the result of the sum in equation 3 is zero.
Due to the nature of the observed data points for the lactate concentration as function of the swimming velocity, the lactate concentration has two different regimes: at low values of the velocity the lactate concentration increases linearly with the velocity; after the velocity corresponding to the anaerobic threshold[1] the increment is exponential. Therefore a given observed set of N velocity-[La$^-$] data points were split in two groups: points 1 to k for the first group and points k+1 to N for the second group, where k ranged from 2 to N-2. Two separate least squares fits were made: a straight line fit to the first group; and an exponential fit to the second group. These two separate fits were computed for all N-2 possible values of k. From the values of k it is found that in some cases the fit was indeed an interpolation since the number of data points and the number of coefficients of the fitting function are the same. This occurs for the straight line when k=2, while for the exponential line it occurs when k=N-2, in both situations the numbers of points to be fitted by one of the lines is 2.
The computer program implementing these lines of action was written in the language MatLab[2].

The output of the program are N-2 plots (loosely called samples) of the two distinct fits superposed on the observed velocity-[La$^-$] data points. To these plots is added another plot with all data points being fitted by a straight line or by an exponential. Examples of the graphical output can be seen in figures 1 and 2. The program also creates a text file with the fitting parameters for both curves, the point of interception of the curves and the value of the residue[3] for each of the samples. Both the partial and the total residues are printed, as well as the corresponding residues normalized to the mean value of the [La$^-$], as these allow a more direct comparison of the values from different samples.

RESULTS

The figures 1 and 2 show examples of the graphical output from the program for two different swimmers chosen such one (swimmer 1) has the anaerobic threshold below 4mmol/L, while the other (swimmer 2) exceeds this value.
These swimmers have participated in a study where each subject performed, in a 25 m indoor swimming pool, an intermittent incremental test for freestyle $\dot{V}O_2$max assessment, with increments of 0.05 m/s each 200 m stage and 30 s intervals, until exhaustion (Fernandes et al., (3)). The velocity was controlled using a visual pacer with flashing lights on the bottom of the pool. In-water starts and open turns were used. The blood lactate concentrations were assessed at rest, during the 30 s intervals, immediately after each step, and at minutes 3 and 5 of the recovery period (using the YSI1500LSport auto-analyser).

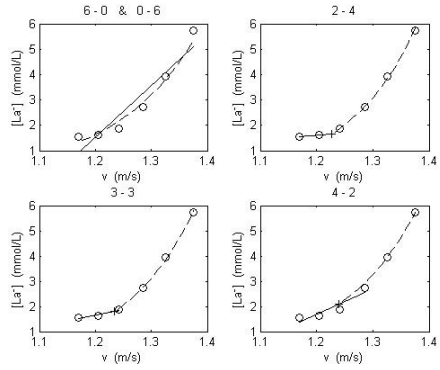

Figure 1. Example of the output plots from the program, for swimmer 1. The circles are the observed velocity-[La$^-$] data points, the solid line is the fitted straight line, the dashed line is the fitted exponential line, and the cross marks the position of the interception of both lines, when applicable.

Analysis of figures 1 and 2 shows that the best fitting situations occur for the adjustment of a straight line for the low velocity points and by an exponential for the high velocity ones. This visual inspection also reveals that the value of 4mmol/L of [La$^-$] to access the velocity at the anaerobic threshold is not valid in these two examples: for swimmer 1 the exponential increase of the [La$^-$] starts around 2mmol/L, well below the 4mmol/L value, while swimmer 2 has blood concentrations of La$^-$ always above 4mmol/L, effectively preventing the use of this value to access the anaerobic threshold.

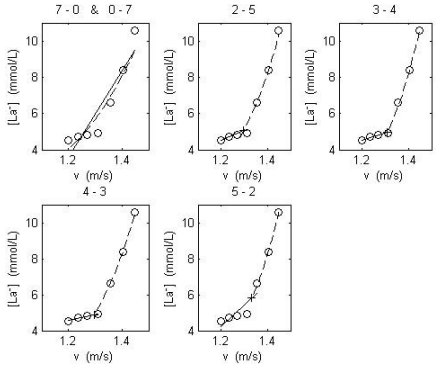

Figure 2. Same as figure 1, but for swimmer 2.

A pair of numbers above each plot represents the number of points used for the straight line fit (first number, which equals the value of k, see above) and for the exponential line fit (second number). This is important to help choosing the best fitting sample since the interception point must be between the last data point used for the straight line and the first one used for the exponential line, otherwise one of the fitting lines must be prolonged out of its region of validity. This can be seen in figure 1, for example, where the 3-3 and the 4-2 samples are ruled out since the interception point is found in the straight line after having prolonged the exponential line away from its region of validity, in order to intercept the straight line. This effect is most evident in the 4-2 sample.
After a visual inspection of the plots for each sample and taking into account the value of the respective residue, the user chooses the most suitable sample for the swimmer under study. The value of the residue shall not be the only parameter to be considered in this choice, as sometimes the interception point is in the wrong place, as was discussed in the previous paragraph. Furthermore, due to the fact that for two of the samples (k=2 or k=N-2) the residue from one of the lines being zero, since it is an interpolation as referred in the Methods section, which may result in a mistaking small value for the residue.
With all these considerations in mind, the user chooses the most suitable sample, and from the point of interception of both lines can determine the velocity at the anaerobic threshold.
Fernandes et al. (5) found that the velocity obtained using the 4 mmol/L of [La^-] was significantly different from that obtained using the present method, in a test involving 32 swimmers.

DISCUSSION
The main conclusion of this work is that this method seems to model in an adequate and individual way the anaerobic threshold of swimmers. The use of the value of 4mmol/L of [La^-] to identify the anaerobic threshold and the corresponding velocity is a valid method on average terms, but is unable to respond to the individual values of an athlete. The method of the present work is flexible enough to adjust and determine the anaerobic threshold, even in situations where the measured value of [La^-] is always above 4mmol/L (cf. figure 2).

NOTES
[1] For high intensity exercises the anaerobic mechanisms for providing energy to the muscle cells account for a significant fraction of the total. As the anaerobic mechanisms produce lactate, its concentration starts increasing, the lactate being produced faster than it can be removed. The minimum exercise intensity for this to occur corresponds to the anaerobic threshold.
[2] www.mathworks.com
[3] The residue is the square root of the sum in equation 3.

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MATHEMATICAL MODELLING OF THE SLOW COMPONENT OF OXYGEN UPTAKE KINETICS IN FRONT CRAWL

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This work presents a mathematical method to model the $\dot{V}O_2$ kinetics during heavy exercise. This methods is able to discriminate between the different components of the oxygen uptake, including the basal, cardiodynamic, fast and slow components. Each of these components is fully characterized, not only in amplitude, but also in time of start of that component. The method is applied to two swimmers, and the results are presented, resulting in both cases in a good description of the slow component for oxygen uptake.

Key Words: mathematical model, $\dot{V}O_2$max, slow component, swimming.

INTRODUCTION
The $\dot{V}O_2$ kinetics has been the subject of several studies since the early 40's. In 1961 Astrand and Saltin (1) observed the so called 'slow component' of oxygen uptake arising in heavy exercises, which has been since then the subject of several works. Most of these works are for exercises performed in cycle ergometers, and yet the first work dealing with swim only appeared in 2001 (4). The present work follows this line of study, and tries to model the $\dot{V}O_2$ kinetics for front crawl

swimming, paying particular attention to the slow component. The data points for maximal $\dot{V}O_2$ used in this work were determined through direct ventilatory oxymetry, using a portable breath-by-breath gas analyser (K4b², Cosmed, Italy) connected to the swimmers by a respiratory snorkel with low hydrodynamic resistance, in a test where the swimmers swam until exhaustion, at the previously determined velocity corresponding to $\dot{V}O_2max$ (cf. (5)).
The typical aspect of the recorded breath-by-breath values of the oxygen uptake during heavy exercise is shown in fig. 1.

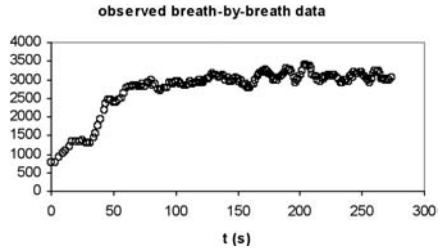

Figure 1. Observed breath-by-breath oxygen consumption by a swimmer during an exercise at maximal intensity. The origin of the time is set at the beginning of the exercise.

From the comparative analysis of the data collected through the years by different authors, it eventually turned out that the behaviour of the $\dot{V}O_2$ kinetics may be described by several components, as is schematically presented in figure 2 (for example, (3)). In the $\dot{V}O_2$ kinetics we may identify three distinct regions/components, apart from the constant basal value. The first component starts at the onset of the exercise, and is called the cardiodynamic component. A few seconds later starts the so called 'fast component', while the 'slow component' starts 2 to 3 minutes afterwards.

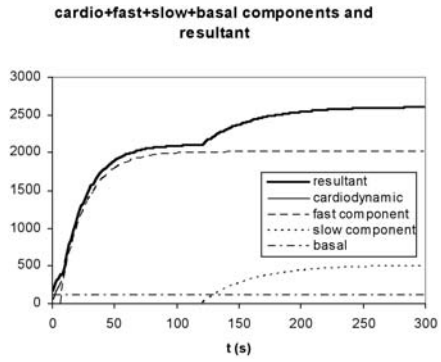

Figure 2. Plot representing schematically the different components of the $\dot{V}O2$ kinetics.

The cardiodynamic component is caused by the increase of the heart rate, as demanded by the exercise, while the fast component is caused by the need of oxygen by the body, mainly the muscle fibres, as the exercise proceeds (for example (2)). The cause of the slow component is still a matter of debate, the activation of the type II fibres being frequently referred as its cause (see for example (8) for a review of several different hypothetical causes for its origin).

METHODS

The $\dot{V}O_2$ kinetics is usually fitted by the following model:

$$\dot{V}O_2(t) = \dot{V}_b \quad \text{(basal } \dot{V}O_2\text{)}$$
$$+A_0 \times (1 - e^{-(t/\tau 0)}) \quad \text{(phase 1: cardiodynamic component)}$$
$$+ A_1 \times (1 - e^{-(t-TD1)/\tau 1}) \quad \text{(phase 2: fast component)}$$
$$+ A_2 \times (1 - e^{-(t-TD2)/\tau 2}) \quad \text{(phase 3: slow component)}$$

Where t is the time; A_i represents the various components amplitudes; TD_i are the times for the onset of the different components; and τ_i stands for the transition period needed for the component to attain the steady state, during which physiological adaptations adjust to meet the increased metabolic demand (6).
Analysis of the above mathematical expression shows that the $\dot{V}O_2$ kinetics is characterized by a constant value, the basal $\dot{V}O_2$, by an exponential function modelling the cardiodynamic component, and by two exponentials modelling the fast and slow components. These later components start after the time delays TD1 and TD2, respectively. The model cardiodynamic component acted from the beginning of the exercise until TD1, moment at which it was replaced by the fast component, which acted from this instant until the end of the exercise. The slow component started at TD2, being added to the fast component, and remained active until the end of the exercise. In figure 2, above, we can see a scheme with the four different components – cardiodynamic, fast, slow and basal –, as well as their sum, the resultant, that ultimately adjusts/models the observed data for the oxygen uptake.
The characteristics of the fitting function above, in particular the fact of being the sum of several exponentials, confers a nonlinear nature to it, which in this case is not removable, preventing its linearization. Consequently, for the adjustment of this function to the data points we used a nonlinear least squares method implemented in the MatLab[1] program, using the routine LSQCURVEFIT.
Prior to start the curve fitting we must perform some mathematical operations on the $\dot{V}O_2$ data. First of all, the oxygen consumption must be normalized to the body mass, such that it is presented as oxygen consumption per unit mass (ml/min/kg). In this way we can compare directly the amplitudes of the various components found for different persons. Dividing the oxygen consumption by the body mass is an operation performed simultaneously at all data points that does not alter the shape of the plot, it merely changes its scale.
Since this curve fitting uses a non-linear least squares method we must provide an initial guess for all the parameters (nine in this model), based on a visual inspection of the colleted data values. To further constrain the amplitude of variation the computational model parameters can have, we should impose the minimum (LB) and maximum (UB) ranges of variation for all parameters. Since all the parameters are positive, we must set the lower bound for all parameters to zero, with the exception of TD2 which clearly begins at a later time. Considering the upper bounds, they depend on the individual parameters, being conditioned by the collected data values for the oxygen uptake.

RESULTS

We present two real situations for the adjusting of this model to data collected in front crawl swimming. These two swimmers were chosen such that one has a large amplitude slow

component while the other has a small amplitude slow component, as is shown by the values of A2 in the following table. This table also displays the values of the remaining model parameters.

Table 1. Values for the remaining model parameters.

Swimmer	$\dot{V}_b$ (ml/kg/min)	A0 (ml/kg/min)	τc (s)	A1 (ml/kg/min)	TD1 (s)	τ1 (s)	A2 (ml/kg/min)	TD2 (s)	τ2 (s)
1	8.6	20.3	57.2	42.6	21.9	20.5	3.0	105.0	59.7
2	22.9	23.2	25.5	37.9	6.7	21.2	12.0	95.0	14.1

Figures 3 and 4 display the graphics for swimmers 1 and 2, respectively. Both graphics show the collected data points normalized to the body mass, as well as the adjusted function, whose model parameters were already displayed in the table above.

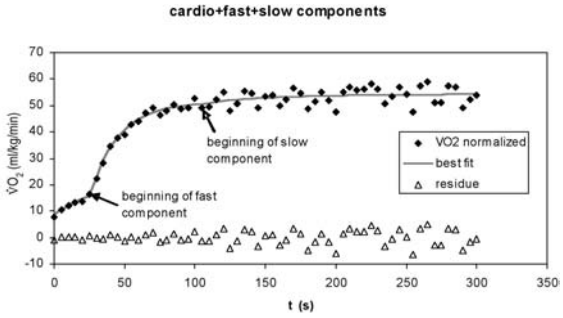

Figure 3. Curve fitting for swimmer 1, displaying a low amplitude slow component.

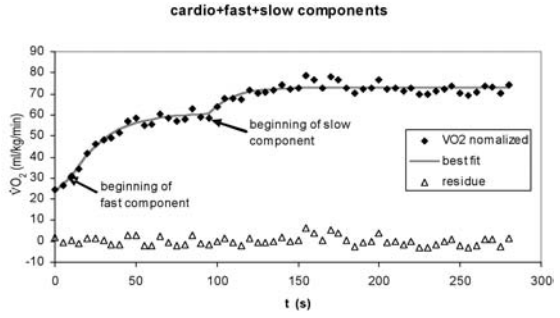

Figure 4. Curve fitting for swimmer 2, displaying a high amplitude slow component.

Analysis of these graphics shows that the implemented mathematical model is able to conveniently adjust the collected values for the oxygen uptake, regardless of the amplitude of the slow component.

DISCUSSION

The main conclusion of this work is that this method seems to model in an adequate way the collected data for $\dot{V}O_2$ in swimming, being possible to characterize the different components of the oxygen consumption, namely, the basal, the cardiodynamic, the fast and the slow components. This method describes the slow component in terms of amplitude, time of beginning and duration of the transition phase.

There are other methods to estimate the oxygen uptake components, particularly the slow component amplitude, some of them being described in (7). Nevertheless, comparison of those methods with the present mathematical model shows that the later gives the possibility to discriminate the different components of the $\dot{V}O_2$ kinetics, including the amplitude of the slow component, while the others usually fail in this respect.

NOTES

[1] http://www.mathworks.com/

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RELATIONSHIP BETWEEN LEFT VENTRICULAR DIMENSIONS AND FUNCTION AND MAXIMAL OXYGEN UPTAKE IN YOUNG SWIMMERS

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The purpose of this study was to analyse the relationship between left ventricular (LV) dimensions/function and maximal oxygen uptake ($\dot{V}O_2$max) in young swimmers. Twelve well trained swimmers (15.9±0.2years; 64.2±6.8kg; 1.75±0.06m) underwent anthropometric measurements, resting M–mode/Doppler echocardiography and a treadmill running

protocol. Allometric scaling of heart morphological characteristics by body dimensions was performed. Heart size was highly correlated with $\dot{V}O_2$max and end–diastolic LV internal chamber dimension was the main determinant factor. Ejection fraction and $\dot{V}O_2$max were uncorrelated suggesting that the systolic function at rest does not reflect cardiac function at maximal exercise. Conclusion is that $\dot{V}O_2$max determined by a non-specific maximal protocol can be an indicator of cardiac adaptations to aerobic exercise.

Key Words: LV hypertrophy, athlete's heart, cardiac function, echocardiography, $\dot{V}O_2$max.

INTRODUCTION

In well-trained endurance athletes, the heart has to adapt to both volume and pressure loads, by increasing, respectively, left ventricular (LV) internal diameter and wall thickness. The increase in stroke volume is a prerequisite for the increase in maximal oxygen uptake ($\dot{V}O_2$max) resulting from training. Notwithstanding being a poor predictor of race performance in elite swimmers, $\dot{V}O_2$max is considered as a useful indicator of aerobic adaptations to exercise in broader populations, including age-group swimmers.

Little attention has been given to young athletes with respect to factors controlling $\dot{V}O_2$max and their influence on the adaptation of cardiac morphology and function in swimming training. Few data are available about the possible impact of left ventricular structure on cardiac performance during physical effort (1, 4, 5, 8, 10).

The purpose of this study was to analyse the relationship between left ventricular (LV) dimensions and function at rest and $\dot{V}O_2$max in young swimmers.

METHODS

Twelve young swimmers (table 1) took part in this study. They performed 7 – 8 training sessions a week in water (about 110 min each), 5000 m per session, 85/90% of total volume in the aerobic zones together and with out of water endurance weight training.

Table 1. Age, physical characteristics, body composition and maximal oxygen uptake of the young swimmers.

	M	SD	Max	Min
Age (years)	15.9	0.2	16.2	15.5
Height (m)	1.75	0.06	185	167
Body mass (kg)	64.2	6.8	75	52.9
Body surface area (m^2)	1.77	0.12	1.94	1.57
Body mass index ($kg.m^{-1}$)	20.9	1.4	22. 9	19.0
Body fat percentage (%)	9.4	1.3	11.8	7.7
Body fat mass (kg)	6.0	1.2	8.9	4.7
Fat free mass (kg)	58.2	6.0	66.1	48.1
$\dot{V}O_2$max ($l.min^{-1}$) 4. 10	0.66	4.74		3.42
$\dot{V}O_2$max ($ml.kg^{-1}.min^{-1}$)	63.8	9.2	72.2	57.4

Body mass (BM), height (H), body surface area (BSA), body fat percentage (BFP) and fat free mass (FFM) were measured according to standard procedures.

Two dimensionally guided M mode recordings were obtained parasternally in accordance with the recommendations of the American Society of Echocardiography (16). All the measurements were performed by the same investigator. Left ventricular (LV) wall thickness and internal diameter were obtained by positioning the trackball cursor on the screen. The echocardiographic parameters measured included: end–diastolic LV internal chamber dimension (LVIDd), end–systolic LV internal chamber dimension (LVIDs), posterior wall thickness (PWT), septal wall thickness (ST), LV end-diastolic volume (LVedV), LV end-systolic volume (LVesV), resting heart rate (HRr), and cardiac output (Qc). Derived parameters were calculated as follows: relative end–diastolic wall thickness (RWTd) by the quotient (PWT+ST)/LVIDd, LV mass by 0.8 x (1.04 $(ST+PWT+LVIDd)^3$–$LVIDd^3$)+0.6 (7), LV volumes were obtained according to Teicholz formula (7/(2.4+LVIDd) x $LVIDd^3$), LV shortening fraction (FS %) by the quotient (LVIDd–LVIDs)/LVIDd) x 100 and the ejection fraction (EF %) by (TDV–TSV)/TDV) x 100 stroke volume (SV). Early (E) and late (A) diastolic peak filling velocities, disacceleration E time (DT) and E/A ratio were estimated by pulse wave Doppler measurements in the four chamber apical view. Echocardiographic data was expressed in absolute units and then scaled allometrically for anthropometrical data.

$\dot{V}O_2$max was determined using the modified Balke treadmill protocol. The initial work was set at 5.25 km/h (0% of inclination) and the exercise intensity was increased by 2.5 % each two min. (6). The athletes were encouraged to reach maximal effort. $\dot{V}O_2$max was defined as peak VO_2. $\dot{V}O_2$max was expressed in absolute units and then scaled allometrically for individual differences in anthropometrical data. A body mass exponent of 0.67 for scaling $\dot{V}O_2$max was also used, as a standard value supported by literature (2).

Pearson product–moment correlation coefficients were calculated to evaluate the relationships between LV dimensions and function and $\dot{V}O_2$max. Results of all statistical testes were considered significant at $p \leq 0.05$.

RESULTS AND DISCUSSION

The results suggest that young swimmers with large LVIDd have a higher $\dot{V}O_2$max and a greater development of the LV morphology have a better cardiorespiratory performance.

Absolute $\dot{V}O_2$max and $\dot{V}O_2$max/BFP correlated significantly with LVIDd, LVM, LVIDs, LV volume at end–diastole, LV volume at end–systole, SV and Q. $\dot{V}O_2$max/BM correlated significantly with LV volume at end-diastole and SV, $\dot{V}O_2$max/$BM^{0.821}$ correlated significantly with LVIDd, LV volume at end-diastole and SV, $\dot{V}O_2$max/$BM^{0.67}$ correlated significantly with LVIDd, LV volume at end–diastole, LV volume at end–systole, SV and Q, $\dot{V}O_2$max/FFM correlated significantly with LV volume at end–diastole and SV.

No significant correlation was observed between absolute and relative $\dot{V}O_2$max and fractional shortening (FS), ejection fraction (EF) and ratio of early passive (E) to late atrial contraction (A) filling of LV (E:A ratio) (table 2).

SV and LVedV correlated significantly with absolute and relative $\dot{V}O_2$max. LVedV and SV should be the critical determinants of the high $\dot{V}O_2$max in young swimmers and factors that influence resting SV are important in defining $\dot{V}O_2$max. SV response to exercise depends on changes in cardiac filling, intrinsic myocardial contractility and LV afterload (7). Thus, higher SV obtained in young swimmers depends on factors influencing resting SV, such as cardiac hypertrophy, augmented myocardium relaxation properties or expanded blood volume (3).

*Table 2. Correlation between $\dot{V}O_2$max and echocardiographic measurements. LVIDd - end–diastolic LV internal chamber dimension; LVIDs - end–systolic LV internal chamber dimension; ST - septal wall thickness; PWT - posterior wall thickness; LVM - LV mass; BM - body mass; BSA - body surface area; FFM - fat free mass; BFP - body fat percentage; HRr - rest heart rate; Qc - cardiac output; SV - stroke volume; E/A - filling of LV; EF - ejection fraction; LVesV - LV end - systolic volume; LVedV - LV end - diastolic volume; Peak E - early (E) diastolic peak filling velocitie; Peak A - late (A) diastolic peak filling velocitie; FS - LV shortening fraction. * p< 0.05; ** p< 0.01; n.s.: non significant.*

	$\dot{V}O_2$max (l/min)	$\dot{V}O_2$max /BM	$\dot{V}O_2$max /BFP	$\dot{V}O_2$max /FFM	$\dot{V}O_2$max /BFM	$\dot{V}O_2$max /BM$^{0.821}$	$\dot{V}O_2$max	$\dot{V}O_2$max /BM$^{0.67}$
LVIDd (mm)	0.65**	n.s	0.73**	n.s	0.56**	0.46*	0.51*	
LVIDs (mm)	0.45*	n.s	0,60**	n.s	0,48*	n.s	n.s	
ST (mm)	n.s	n.s	n.s	n.s	n.s	n.s	n.s	
PWT (mm)	n.s	n.s	n.s	n.s	n.s	n.s	n.s	
LVM (gr)	0.47*	n.s	0.517**	n.s	n.s	n.s	n.s	
EF (%)		n.s	n.s	n.s	n.s	n.s	n.s	
LVesV (ml)	0.57**	n.s	0.67**	n.s	0.53**	n.s	0.45*	
LVedV (ml)	0.71**	0.41*	0.76**	0.41*	0.58**	0.52**	0.57**	
PeakE (ms)	n.s	n.s	n.s	n.s	n.s	n.s	n.s	
PeakA (ms)	n.s	n.s	n.s	n.s	n.s	n.s	n.s	
E/A	n.s	n.s	n.s	n.s	n.s	n.s	n.s	
FS (%)	n.s	n.s	n.s	n.s	n.s	n.s	n.s	
SV (ml)	0.73**	0.42*	0.74**	0.43*	0.56**	0.54**	0.59**	
HRr (bpm)	-0.43*	n.s	n.s	n.s	n.s	n.s	n.s	
Qc (l/min)	0.56**	n.s	0.58**	n.s	0.42*	n.s	0.43*	

CONCLUSION

The results of this study indicate that heart size is highly correlated with $\dot{V}O_2$max in young swimmer athletes and LVIDd is the main determinant factor. The relationship between estimated diastolic function and $\dot{V}O_2$max suggests that the maximal heart pumping capacity during exercise is associated by LV volume at end–diastole at rest. On the contrary, EF and $\dot{V}O_2$max are unrelated, possibly because the systolic function at rest does not have a relevant connection with cardiac function during maximal exercise and LV volume at end–systole is related to LV size and not to ejection performance.

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EFFECTS OF ACUTE MODERATE ALTITUDE EXPOSURE ON PHYSIOLOGICAL AND TECHNICAL PERFORMANCE IN FRONT CRAWL SWIMMING.

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The aim of this study was to analyse how acute moderate altitude exposure affects technique during a sub-maximal swimming protocol. Eleven subjects swam two steady-state test of 400 m front crawl, under normoxia (N, 690 m) and acute hypoxia (H, 2320 m). Stroke rate (SR) and stroke length (SL) was recorded during each lap. Blood lactate concentration (BLa), heart rate (HR) and rating of perceived exertion (RPE) were also measured after each trial. Results showed a reduction in SL with an increase in SR by altitude effect ($p<0.05$). HR, BLa and RPE were increased during altitude test respect normoxia ($p<0.05$). The obtained results did not show relation between physiological and technical variables in N and H. Technical parameters, like physiological ones, should be considered in altitude training camps.

Key Words: Stroke length, stroke rate, lactate, heart rate, RPE.

INTRODUCTION

In swimming, velocity is defined as the product of the stroke rate (SR) and distance travelled in each cycle (SL). Various factors have been observed to influence this relationship as training, intensity or swimming distance (1). Therefore we could consider fatigue as one of the major factors that modify swimming technique (2).
During ascent in altitude, the barometric pressure falls together with the density of the surrounding air, so that the inspired partial pressure of oxygen is also reduced, diminishing the O_2 content of arterial blood. An increase in heart rate, stroke volume, tissue vasodilatation and bronchodilatation can be observed immediately, contributing to improve O_2 delivery especially during exercise (3).
Exposure to acute hypoxia produces a significant increase in lactate production (4, 5, 6, 7), an important reduction in

$\dot{V}O_2max$ (8), and slower VO_2 kinetics during isolated work loads (3) with respect to normoxia. Performance during short-intensity exercises, majority sustained by anaerobic metabolism, seems not to be affected by altitude ascent (3, 9). However when the duration of effort lasts more than approximately 30 s, aerobic and anaerobic metabolism pathways are implicated (10). Several studies have shown an increased anaerobic contribution to exercise to compensate the lost of aerobic ATP production (4, 10). These changes could explain the expectation of limited performance during high-intensity exercise for more than 30 s executed at altitude respect normoxia due to a faster accumulation of anaerobic metabolites, such as lactate, which also could develop differences in technical parameters as has been observed in normoxia (11).
In the literature revised, very few studies have been developed to analyze the effect of altitude on technique. For this reason, the aim of this study was to investigate changes on technical parameters in swimming due to acute moderate altitude exposure.

METHODS

Eleven swimmers, six males and five females (22.7±1.8 and 19.8±2.2 years of age, 181.8±4.7 and 172.8±5.1 cm tall, 76.9±3.6 and 63.3±7.5 Kg of weight, respectively), physical education students and members of water-polo and swimming team clubs, participated in this study. They all lived in the city of Granada at 690 m altitude.
Before participation, all swimmers were fully informed about the demands and procedures of the study and provided their written consent to take part. The experiment was approved by the University Ethic Committee and was in compliance with Spanish Laws. To avoid compromising the results of this study all participants were instructed about food intake rules and not to participate in any exhaustive workouts on the days of testing. All swims were completed in randomized order and at the same time of the day (12 p.m. ± 60 min) to minimize biological variation.
Each subject was randomly assigned to two different groups (Groups 1 and 2), forty-eight hours after a preliminary test. The first experimental protocol was carried out by group 1 in hypoxia, in the swimming pool of the Altitude Training Centre of Sierra Nevada (Granada, Spain), located at 2320 m above sea level and 560 mmHg of barometric pressure (H). Tests were conducted during the first 3 or 4 hours after arrival (9). The experimental protocol was then repeated forty-eight hours later, in a 50 m pool of the Sport Complex of the University of Granada (Granada, Spain) at 690 m altitude and 717 mmHg barometric pressure (N). Group 2 performed both trials in reverse order.
The preliminary test consisted in a maximal 400 m front crawl trial from a water start after a standard 800 m warm-up in normoxia. To ensure the capability of all swimmers to attain the 400 m test in hypoxia, the time to complete a 400 m repetition during experimental protocols was reduced to 92.5% of the maximal speed (of 344±20 and 335±31 s time for males and females, respectively). Previous essays showed us to be the appropriate percentage to ensure the capability of all swimmers to conclude experimental test in H.
Light sequencing was used to control the right pace in all swimmers, maintaining swimming velocity constant in all laps. This system consisted in a lane of underwater successive lights (n=50) connected to a speed controller box (Swim Master). This lighting system was placed on the pool floor, as described in previous reports (12). The lighting time was individually adjusted in all turns. All participants were familiarized to the underwater lighting system with previous training sessions. During all testing trials, a sagital camera (mini DV) recorded each trial. SR was measured lap by lap (cycle·min^{-1}). It was calculated over five cycles. Its value was obtained as a quotient of number of cycles and time employed to finish five completed cycles, multiplied by sixty. SL was calculated dividing swimming speed by SR in Hz and expressed as the result of the distance swum during a complete cycle (m·cycle^{-1}).
HR was measured just at the end of the test with a Polar 610 heart rate monitor. Immediately after the end of each trial, an integrated perceived exertion value (15 grades Borg's rating - RPE) was registered (13). Blood lactate concentration (BLa) was analyzed three and five minutes after finishing the test from the fingertip, using a portable blood lactate analyser Lactate Pro. The highest BLa obtained was considered as the peak or maximum value.
SPSS 12.1 was used for statistics analyses. Descriptive data was obtained and expressed as mean and standard deviation (SD). Homogeneity and normality of data was analyzed before studying the variance. The difference between altitude conditions was tested by repeated measures (ANOVA). When a significant difference was detected this was further examined by Sidak post-hoc test. Pearson test was employed to analyze the correlation relationships between physiological and technical parameters. The interval of confidence accepted for all comparisons was less than 0.05.

RESULTS AND DISCUSSION

The results of physiological and technical parameters obtained in this study under normoxia and acute hypoxia are displayed in Table 1.
It was observed significant differences between SR and SL by altitude effect ($p<0.05$). After ascent, SR (cycle·min^{-1}) increased a 2.45% while SL decreased but with similar percentage as SR (2.62%). Certain studies have related changes in swimming technique due to physiological stress generated during swimming (14) and the implication of anaerobic metabolism on it (2). Thus, swimmers can keep a high level of SL values throughout exercises performed at slow and aerobic speed corresponding to moderate and heavy sub maximal intensities. However, when the intensity increases above the maximal lactate steady state, the reduction in SL becomes progressively greater (2, 11, 14), overcoming this lost in SL with an increase in SR to maintain the swimming speed during constant load tests. In this sense, our data reveal that there were significant differences between both experimental conditions in the physiological variables.
It was observed an increase in BLa, RPE and HR in altitude respect normoxia conditions of a 36.67, 8.48 and 4.57% respectively for the same work-load, which are consistent with previous studies (5, 6, 7) under similar conditions. The increase in lactate production is associated with a fall of blood and muscle pH (15, 16). These results are consistent with the RPE response obtained. As it has been described in others works (14, 16), a decrease in pH produces fatigue, which could be defined as a reduction of the capacity to deliver a high amount of work per stroke as well as the capacity to swim at a high propelling efficiency (14) in the presence of an increased perception of effort (17).

Although, previous studies have suggested that changes in technique variables could be connected to simultaneous changes in metabolic variables, such as BLa (2, 11); the results of this study have not showed any correlation between physiological and technical parameters in both conditions (Table 2). The found results can be interpreted as acute moderate altitude exposure affects directly both variables, technical and physiological, without necessarily a relation among them exists. Later studies will have to be focused in analyzing how affects environmental modifications due to altitude in the technical parameters.

Table 1. Mean and SD obtained in a 400-m test at 690 m (N) and 2320 m (H) above sea level. Where: BLa=Peak of maximum blood lactate concentration; RPE=Rating of Perceived Exertion; HR=Heart Rate; SR=Stroke Rate; SL=Stroke Length.

	BLa (mmol·l^{-1})	RPE (6-20)	HR (bpm)	SR (cycle·min^{-1})	SL (m·cycle^{-1})
690 m	6.44 (2.44)	15.00 (2.63)	161.27 (15.66)	31.75 (5.49)	2.29 (0.38)
2320 m	8.81* (2.63)	16.27** (1.10)	168.64** (13.66)	32.53** (5.74)	2.23* (0.39)
	Δ 36.8 %	Δ 8.5%	Δ 4.5%	Δ 2,4%	-Δ 2.6%

* Indicates p<0.01 ** Indicates p<0.05.

Table 2. "P" values obtain in correlation analysis between physiological and technical variables in Normoxia (N, 690 m) and acute Hypoxia (H, 2320 m). Where: BLa=Peak of maximum blood lactate concentration; RPE=Rating of Perceived Exertion; HR=Heart Rate; SR=Stroke Rate; SL=Stroke Length.

	BLa 690m	BLa 2320m	HR 690m	HR 2320m	RPE 690m	RPE 2320m
SR 690m	0,412 n.s.	0,213 n.s.	0,111 n.s.	0,135 n.s.	0,055 n.s.	0,164 n.s.
SR 2320m	0,533 n.s.	0,263 n.s.	0,213 n.s.	0,184 n.s.	0,347 n.s.	0,141 n.s.
SL 690m	0,577 n.s.	0,317 n.s.	0,345 n.s.	0,504 n.s.	0,310 n.s.	0,279 n.s.
SL 2320m	0,673 n.s.	0,379 n.s.	0,481 n.s.	0,570 n.s.	0,426 n.s.	0,262 n.s.

*n.s. = not significant * p<0.05*

CONCLUSIONS

We concluded on the base of the results analyzed, that stroking parameters are affected during front crawl swimming by acute moderate altitude exposure. The results also have shown an important effect of the altitude in the physiological respond to effort, especially in the level of registered acidosis, although it cannot explain directly the changes undergone in the technical parameters. However, we suggest the necessity of a period of stroke technique adaptations during the first days of altitude training camps, before acclimatization occurs.

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RED BLOOD CELLS SUSCEPTIBILITY TO PEROXIDATION IN SWIMMERS

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The purpose of this study was to evaluate the influence of training on red blood cells' (RBC) susceptibility to peroxidation induced *in vitro* by H_2O_2 and on RBC' antioxidant enzymes activities. Fiveteen high competition male swimmers and 16 active men not involved in any regular sport activity participated in the study. Nutritional information was collected and body composition and physical condition were assessed. Blood was collected at rest. RBC peroxidation and superoxide dismutase, catalase, glutathione peroxidase and reductase and methahaemoglobin reductase activities were evaluated by photometry. Swimmers showed higher RBC' resistance to oxidation even though antioxidant enzymes were not higher. This beneficial adaptation may result from an accelerated RBC' renewal, leading to more efficient O_2 delivery to tissues and to lower RBC' intracellular oxidant stress.

Key Words: oxidant stress, red blood cells oxidation, antioxidant enzymes, training.

INTRODUCTION

Moderate physical exercise is believed to have many health benefits (3). However, for intense and sustained exercise, such as that performed by high competition athletes, controversy about the protective effects still exists (2, 11, 12, 18). As physical exercise is associated with accelerated reactive oxygen species (ROS) generation (7) it may establish conditions where ROS production may overwhelm the antioxidant defences and consequently induce damage to macromolecules resulting in adverse effects on health.

The susceptibility of red blood cells (RBC) to oxidation is a result of the high polyunsaturated free fatty acid content of their membrane and the high cellular concentrations of oxygen and haemoglobin, a potentially powerful promoter of oxidative processes. ROS constantly generated from both internal and external sources, even under normal conditions, may target RBC to oxidative damage during exercise.

However, these cells, as well as the whole body, contain very efficient protective antioxidant systems that include antioxidant enzymes such as superoxide dismutase, catalase, glutathione peroxidase, glutathione reductase and methahaemoglobin reductase and non-enzymatic antioxidants such as α-tocopherol, β-carotene, ascorbate, urate and reduced glutathione (8).

Nutritional habits may condition antioxidants availability as antioxidant enzymes are metalo-enzymes, and some of the non-enzymatic antioxidants are of exogenous sources (e.g. α-tocopherol, β-carotene and ascorbate) (14).

The purpose of this work was to evaluate the influence of training on RBC' susceptibility to peroxidation induced *in vitro* by H_2O_2 (RBC Px) and on RBC' antioxidant enzymes activities.

METHODS

Fiveteen high competition male swimmers (S) training between 17 and 23 $h.wk^{-1}$ for at least 5 years, and 16 active men (AM) not involved in any regular sport activity agreed to participate in the study. They were between 18 and 25 years old (S: 20.0±1.65 years and AM: 21.1± 1.47 years). Their mean weight and height were respectively 70.6±5.3 kg and 176±6.0 cm for the S group and 71.1±10.1 kg and 176±7 cm for the AM group. The mean body mass index (BMI), derived from weight and height, was 22.7±1.6 $kg.m^{-2}$ for the S group and 23.0±2.9 $kg.m^{-2}$ for the AM group. Medical and running histories obtained by questionnaire indicated no smoking habits or known coronary heart diseases. Informed written consent was obtained from all the subjects.

Nutritional information was collected using a 3 days food record. Subjects were previously informed of the most correct and complete form of fulfilment of the record and interviewed afterwards to compare the items recorded with real size photos in a Portuguese manual for analysing food records (Modelos Fotográficos para Inquéritos Alimentares do Instituto Nacional de Saúde Dr Ricardo Jorge). Macro and micronutrients intake were quantified with Food Processor (Nutrition Analysis Software version 7.4, made by ESHA, Research, Salem, Oregon, 1999).

An all body analysis by Dual-energy x-ray absorptiometry (DXA) was used to assess body fat mass percentage (FM%), free fat mass (FFM) and bone mineral content (BMC) (QDR-1500, Hologic, Waltman, USA, pencil beam mode, software version 5.67 enhanced whole body analysis). Appendicular muscle mass (AMM) was calculated according to Heymsfield and co-workers (9).

Subjects performed a continuous graded maximal run on treadmill (Quinton TM 55) until oxygen uptake stabilization or exhaustion with expired gas analysis (Cardiorespiratory Diagnosis System, Medical Graphics Corporation, St. Paul, MN) and heart rate monitorization (Polar® - Pacer ECG/Telemetry Finland).

Blood was collected by venopucture at rest, at fast. After separation from plasma, RBC were washed 3 times with NaCl 0.9 % (w/v). RBC' susceptibility to peroxidation induced *in vitro* by H_2O_2 (RBC Px) was evaluated by photometry with a method modified from the group of Rayssiguier (personal communication). The antioxidant enzymes activities were evaluated by photometry after hemolysis of RBC. Superoxide dismutase activity was determined according with Winterbourn et al. (19); catalase activity according with Aebi (1), glutathione peroxidase activity according with Paglia & Valentine (15); glutathione reductase activity according with Beutler (4) and methahaemoglobin reductase activity according with Board (5).

Results are presented as mean±standard deviation. Normal distribution of the samples was tested with Shapiro-Wilk's test ($n<50$). Results were compared between groups with unpaired t test or with Man Whitney's U. Micronutrients intakes for each group were compared with the respective RDAs with one sample t test. All statistical analysis was performed with SPSS for Windows, version 11.5, released in 2002 by SPSS Inc., Chicago, USA.

RESULTS

As expected, swimmers showed higher $\dot{V}O_2max$ (51.3±7.1 $ml.min^{-1}.kg^{-1}$ versus 43.2±5.7 $ml.min^{-1}.kg^{-1}$; $p < 0.01$), VO_{2AnaT} (38.0±4.4 $ml.min^{-1}.kg^{-1}$ versus 29.2±5.1 $ml.min^{-1}.kg^{-1}$; $p < 0.01$), FFM (62.6±4.4 kg versus 58.2±5.7 kg; $p < 0.02$) and AMM (24.8±2.3 kg versus 23.0±2.4 kg; $p < 0.05$) and lower FM% (10.4±3.3 % versus 17.5±6.9 %; $p < 0.01$) than active men. Food intake was similar between the two groups (table 1), with low percentage of carbohydrate intake and high percentage of fat intake. Iron, zinc, copper and selenium intakes were over the RDAs. Retinol and α-tocoferol intakes were under the RDAs in both groups and folate was under the RDA in the AM group.

Table 1. Discriptive analysis of nutritional parameters for the two groups (S: swimmers, AM: active men). Results of the comparison between groups (p) and with the respective RDAs.

Energy/Nutrients	S	AM	p
Calories (kcal.day^{-1})	2976±744	2845±450	0.57
Calories per kg of weight (kcal.day^{-1}.kg^{-1})	42.8±10.2	40.6±7.34	0.51
Calories from fat (%)	34.2±5.23	33.6±5.32	0.76
Calories from saturated fat (%)	13.1±3.38	12.7±2.15	0.95
Calories from proteins (%)	18.4±3.74	18.2±1.86	0.90
Calories from carbohydrates (%)	48.3±6.19	48.8±4.79	0.82
Calories from sugar (%)	15.8±5.69	17.6±5.26	0.40
Iron (mg.day^{-1})	24.3±9.69**	20.7±6.93**	0.39
Zinc (mg.day^{-1})	14.5±4.69*	13.5±3.93*	0.55
Copper (µ.day^{-1})	1336±499**	1255±339**	0.62
Selenium (µ.day^{-1})	101±48.0**	102±39.1**	0.94
α-tocoferol - Vit E (mg.day^{-1})	5.75±3.00**	6.02±2.21**	0.79
Retinol - Vit A (µ.day^{-1})	433±289**	412±199**	0.63
Ascorbate - Vit C (mg.day^{-1})	136±120	108±70.4	0.77
Folate - Vit B9 (µ.day^{-1})	283±208	132±163**	0.06

*Comparison with the respective RDAs: * p≤ 0.05 : ** p≤ 0.01.*

Swimmers showed lower RBC susceptibility to peroxidation induced *in vitro* by H_2O_2 and methahaemoglobin reductase activity (Table 2).

Table 2. Discriptive analysis of biochemical parameters for the two groups (S: swimmers, AM : active men). Results of the comparison between groups (p).

Variable	S	AM	p
RBC susceptibility to peroxidation induced *in vitro* by H_2O_2 (%)	39.2±4.83	46.3±9.54	0.03
Superoxide dismutase activity (U.g Hb^{-1})	2222±411	2198±410	0.88
Catalase activity (s^{-1}.g Hb^{-1})	192±46.5	207±31.8	0.34
Glutathione peroxidase activity (mol.min^{-1}.g Hb^{-1})	103±24.2	115±25.2	0.21
Glutathione redutase activity (mol.min^{-1}.g Hb^{-1})	89.7±14.1	86.6±13.9	0.41
Methahaemoglobin reductase activity (µ.min^{-1}.g Hb^{-1})	7.45±2.07	9.14±2.29	0.03

DISCUSSION

The nutritional habits of the subjects don't seem to limit the activity of antioxidant enzymes, as the intakes of their co-factor metals are above the recommended dietary allowances. However, they may benefit from some changes in their foods as high intakes of fat associated with low intakes of fat-soluble vitamins increase susceptibility to oxidation.

Lower methahaemoglobin reductase activity in the group of swimmers may suggest lower production of methahaemoglobin in their RBC. Methahaemoglobin formation occurs along with the formation of superoxide radical. Such radical can originate other more reactive ROS and so induce damage to the RBC. The accumulation of methahaemoglobin in the RBC gives rise to the formation of Heinz bodies which render the RBC less flexible and deformable. As a consequence, RBC' half life tends to decrease, with premature reticulo-endotelial entrapment, especially by the spleen (6), and the probability of intravascular haemolysis increases, by osmotic pressure induced by the binging of these substances to the RBC' membrane (10, 13, 17). So, less methaemoglobin formation can be associated to more resistant RBC.

According to Smith (17), in athletes, the frequent oxidant pressure, in association with the osmotic and acid-base unbalances, can induce the decrease of RBC half life and the increase of eritropoiesis. A higher percentage of young RBC can make them less susceptible to oxidation. As long as anaemia doesn't occur, athletes can so be favoured as these are more efficient in the transport of oxygen to tissues (16).

CONCLUSION

Swimmers showed higher RBC' resistance to oxidation even though antioxidant enzymes were not higher. This beneficial adaptation may result from an accelerated RBC' renewal, leading to more efficient oxygen delivery to tissues and to lower RBC' intracellular oxidant stress.

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OXYGEN UPTAKE AT THE LACTATE THRESHOLD IN SWIMMING

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The purpose of this study is to identify, in terms of $\%\dot{V}O_2max$, the intensity of swimming associated with a non linear increase of blood [La^-]. Twenty nine swimmers participated in the study: 15 males and 14 females. Each subject performed a intermittent incremental protocol of 200m stages. The individual kinetics of the [La^-]/ velocity and VO_2 / velocity curves were taken in account for the assessment of lactate threshold (LT). The value of the [La^-] corresponding to LT was $2.99\pm0.80 mmol.l^{-1}$. In $\%\dot{V}O_2max$, LA was $73.54\pm0.8\%$. This result seems to confirm that the best single [La^-] value to predict LT, when testing trained swimmers, should be lower than the usual value of 4 $mmol.l^{-1}$.

Key Words: anaerobic threshold, lactate threshold, oxygen uptake, evaluation.

INTRODUCTION

Lactate Threshold (LT), the intensity above which it is observed an exponential increase in blood lactate concentrations ([La^-]), has been considered as a topic of great interest in swimming literature. This parameter is used on performance prediction, in assessment of aerobic capacity, in swimming training intensities prescription, and in exercise intensity control [6, 19]. The results from the most recent studies [10, 15] also stress out the importance of the aerobic metabolism on total energetic required for almost all the competitive exercise duration in swimming events. According to these previous findings, training at the intensity correspondent to LT consists on an important physiological goal in swimming training [14], in order to develop the swimmer's aerobic capacity [15]. The conventional approach of LT determination consists on the relationship between [La^-] and swimming velocity (v), based on the interpolation of the swimming velocity to a fixed value of [La^-] [13], or by an individualized method, finding a non linear increase on [La^-] [9]. In swimming, due to the difficulties usually imposed to the evaluation of $\dot{V}O_2max$ in normal swimming conditions, the definition of LT intensity expressed in $\%\dot{V}O_2max$ as not yet been accomplished, despite, in others sports, the determination of $\%\dot{V}O_2max$ correspondent to the LT received relevant attention [2, 3, 4, 7].
Wakayoshy et al. [19, 20] gave some attention to AT and LT related to VO_2, in their studies on critical swimming velocity, although they didn't define the percent value of $\dot{V}O_2max$ associated to the LT, they also didn't relate the intensity of LT to $\%\dot{V}O_2max$, or suggested a value of $\%\dot{V}O_2max$ representative of LT.
The purpose of this study was to identify, in terms of $\%\dot{V}O_2max$, the intensity associated with a non linear increase of [La^-] in normal swimming conditions.

METHODS

Subjects

Twenty nine trained swimmers were studied: 15 males (21.4 ± 3.0 yy, 177.3 ± 7.0 cm, 68.3 ± 7.1 kg and a $\dot{V}O_2max$ of $70.9\pm10.2 ml/min/kg$), and 14 females (18.7 ± 2.4 yy, 164.9 ± 2.3 cm, 55.1 ± 3.9 kg and a $\dot{V}O_2max$ of $59.8\pm8.0 ml/min/kg$). All subjects were informed about the details of the experimental protocol before beginning the measurements procedures and volunteered to participate in this study.

Test protocol

The test sessions took place in a 25m indoor poll. Each subject performed an intermittent incremental test for $\dot{V}O_2max$ assessment. This test had increments of $0.05 m.s^{-1}$ each 200m stage, with 30s intervals until exhaustion [8]. Initial velocity was established according to the individual level of fitness and was set at the swimmer's individual performance on the 400m freestyle minus seven increments of velocity (for more details see Cardoso et al. [5]). VO_2 was directly measured using a metabolic cart (Sensormedics 2900 oxymeter, Yorba Linda – Califórnia, USA) mounted on a special chariot running along the pool [18], and connected to the swimmer by a special respiratory valve [17]. Exhaled air was continually measured during the entire test each 20s. Swimming velocity was controlled using a visual pacer (TAR.1.1, GBK-electronics, Aveiro, Portugal) with flashing lights on the bottom of the pool.
$\dot{V}O_2max$ was considered to be reached according to primary and secondary traditional physiological criteria [1, 11]: (i) occurrence of a plateau in the oxygen uptake kinetics, despite an increase in swimming velocity, and (ii) high levels of blood lactic acid concentrations ([La^-]$\geq 8 mmol.l^{-1}$), elevated respiratory exchange ratio ($R\geq 1.0$), high heart rate (HR) values (>90% of [220bpm-age]) and exhaustive perceived exertion (controlled visually, and case to case, by the respective coaches and scientific staff).
Capillary blood samples for [La^-] analysis were collected from the earlobe at rest, in the 30s rest interval, immediately after the end of each exercise step, and 3min and 5 min of the recovery period. These blood samples were analysed using an YSI1500LSport auto-analyser (Yellow Springs Incorporated, Yellow Springs – Ohio, USA). HR was monitored and registered continuously each 5s through a HR monitor system (Polar Vantage NV, Polar Electro Oy, Kempele, Finland).
Swimmers were instructed to perform an open turn, always performed in the same lateral wall side, without underwater glid-

ing, and were verbally encouraged to swim as long as possible during the test period. The test was carried out in the same conditions for each subject, i.e., temperature and humidity.

Statistical analysis
The statistical procedure includes mean and standard deviations for all variables. All data was checked for normality. LT was assessed by $[La^-]/VO_2$ curve modelling method (least square method) and was assumed to be the intersection point, at the maximal fit situation, of a combined pair of regressions (linear and exponential) [12]. Intensity related to LT was expressed on $\%\dot{V}O_2max$.

RESULTS AND DISCUSSION

The use of an average value that represents the $[La^-]$ related to LT as been an area of great discussion among scientists. Our results showed that the non linear increase in $[La^-]$ occurred at a mean value of 2.99±0.8 $mmol.l^{-1}$.This value seems to be in accordance with the results obtained by Beneke [3] who observed a mean $[La^-]$ correspondent to the maximal lactate steady state (MLSS) of 3.0 ± 0.6$mmol.l^{-1}$. Our results also seem to be in agreement with the results obtained by Wakayoshi et al. [19] (3.2$mmol.l^{-1}$) in a study conducted in swimming flume, relating the swimming critical velocity with $[La^-]$. Results also seem to confirm that the $[La^-]$ of 4$mmol.l^{-1}$, suggested by Mader et al. [13], does not satisfactory represent the LT of trained subjects, once it tends to be lower than that reference value. This observation seems to be in agreement with Stegmann et al. [16]. Our study also reveals that the non linear increase in $[La^-]$ occurred at 73.54±8.0%$\dot{V}O_2max$. To our knowledge, this is one of the first studies, conducted in swimming pool conditions were LT was related to oxygen uptake. However, similar approaches were already attempted in different ergometers. Our results seem to be in agreement with the finings of these studies, namely with the study conducted by Dekerle et al. [7], who tested swimmers in cycle ergometer (74.3±84.0%), Baron et al. [2] (73.0±4.1%) and Beneke et al. [4] (71±7.0%).

CONCLUSION

The present study shows that the non linear increase of $[La^-]$ corresponding to LT in a specific swimming situation occurs at 73.54±8.0%$\dot{V}O_2max$. This value should be interpreted as the value upon what the aerobic capacity should be trained.
Our results also seem to confirm that, on the unavailability of an individual value correspondent to the LT, the best single $[La^-]$ value to predict this parameter, when testing trained swimmers, should be lower than the usual value of 4 $mmol.l^{-1}$.

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OXYGEN UPTAKE AND VENTILATORY THRESHOLD IN SWIMMING

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The purpose of this study was to identify, in terms of percentage of maximal oxygen uptake (%$\dot{V}O_2$max), the intensity of swimming associated with a non linear increase of minute ventilation (Ve), also described as ventilatory threshold (VT). Twenty nine trained swimmers participated in our study: 15 males and 14 females. Each subject performed a intermittent incremental protocol of 200m stages, with increases of 0.05m.s^{-1}, and 30s intervals between each stage. VT was assessed by Ve/VO_2 curve modelling method (least square method). It was assumed VT to be the intersection point, at the maximal fit situation, of a combined pair of regressions (linear and exponential). The analysed values of VO_2 and Ve were cropped by direct oximetry. The present study demonstrated that the non linear increase of Ve corresponding to VT in a specific swimming situation seems to happen at 84.3±8.7 %$\dot{V}O_2$max.

Key Words: ventilatory threshold, oxygen uptake, minute ventilation, evaluation.

INTRODUCTION

The concept of whole body maximal oxygen uptake ($\dot{V}O_2$max) has received much attention in the specialized literature, especially on its relevance to endurance performance and adaptation to training, being frequently viewed as one of the most relevant factors of performance [2]. However, di Prampero et al. [9] observed that, besides $\dot{V}O_2$max, other parameters are crucial for the athlete endurance performance, such as motor economy and the capability to sustain a high percentage of $\dot{V}O_2$max (%$\dot{V}O_2$max) along the exercise. On the same perspective, Svedahl et Macintosh [17] support that an athlete with a lower absolute $\dot{V}O_2$max in comparison with other athletes, can compensate that difference, using a higher %$\dot{V}O_2$max to reach the same oxygen uptake (ml/min/kg) along the exercise. According to this, sub-maximal physiological parameters started to be considered as determinant parameters as $\dot{V}O_2$max for the assessment of athlete's endurance performance potential. Gradually, the Anaerobic Threshold (AT), and its multiple expressions, i.e., lactate threshold (LT), heart rate threshold or ventilatory threshold (VT), became used on training and perceived as determinant parameters on the athlete's performance, once they highly correlate with the %$\dot{V}O_2$max related to aerobic performance [3]. Although the importance given to the capacity to sustain a higher %$\dot{V}O_2$max related to VT [2], due to the difficulties associated with the evaluation of ventilatory parameters in swimming pool conditions, the assessment of the VT in swimming has been less investigated and used than the metabolic parameters, such as LT. The purpose of this study was to identify the intensity associated with a non linear increase of the minute ventilation (Ve) described as VT [20], expressed as a %VO_2max, in swimming pool conditions.

METHODS

Subjects

Twenty nine trained swimmers were studied: 15 male (21.4±3.0 yy, 177.3±7.0 cm, 68.3±7.1 kg and a $\dot{V}O_2$max of 70.9±10.2ml/min/kg) and 14 female (18.7±2.4 yy, 164.9±2.3 cm, 55.1±3.9 kg and a $\dot{V}O_2$max of 59.8±8.0ml/min/kg). All subjects were informed about the details of the experimental protocol before beginning the measurements procedures, and volunteered to participate in this study.

Test protocol

The test sessions took place in a 25m indoor poll. Each subject performed an intermittent incremental test for $\dot{V}O_2$max assessment. This test had increments of 0.05m.s^{-1} each 200m stage, with 30s intervals until exhaustion [10]. Initial velocity was established according to the individual level of fitness, and was set at the swimmer's individual performance on the 400m freestyle minus seven increments of velocity (for more details see Cardoso et al [6]). VO_2 and Ve were directly measured using metabolic cart (Sensormedics 2900 oxymeter, Yorba Linda – Califórnia, USA) mounted on a special chariot running along the pool [19], and connected to the swimmer by a special respiratory valve [18]. Exhaled air was continually measured during the entire test on each 20s. Swimming velocity was controlled using a visual pacer (TAR.1.1, GBK-electronics, Aveiro, Portugal) with flashing lights on the bottom of the pool. $\dot{V}O_2$max was considered to be reached according to primary and secondary traditional physiological criteria [1,11]: (i) occurrence of a plateau in oxygen uptake despite an increase in swimming velocity, and (ii) high levels of blood lactic acid concentrations ([La^-]≥ 8mmol.l^{-1}), elevated respiratory exchange ratio (R≥ 1.0), high heart rate (HR) (>90% of [220bpm-age]) and exhaustive perceived exertion (controlled visually, and case to case, by the respective coaches and scientific staff). Capillary blood samples for [La^-] analysis were collected from the earlobe at rest, in the 30s rest interval, immediately after the end of each exercise step, and at 3 and 5 min of the recovery period. These blood samples were analysed using an YSI1500LSport auto-analyser (Yellow Springs Incorporated, Yellow Springs – Ohio, USA). HR was monitored and registered continuously each 5s through a HR monitor system (Polar Vantage NV, Polar Electro Oy, Kempele, Finland). Swimmers were instructed to perform an open turn, always performed to the same lateral wall side, without underwater gliding, and were verbally encouraged to swim as long as possible during the test period. The test was carried out in same conditions for each subject, i.e., temperature and humidity.

Statistical analysis

Statistical procedure includes mean and standard deviations for all variables. All data was checked for normality. VT was assessed by Ve/VO_2 curve modelling method (least square method) and was assumed as the intersection point, at the maximal fit situation, of a combined pair of regressions (linear and exponential) [13]. Intensity related to VT was expressed on %$\dot{V}O_2$max.

RESULTS AND DISCUSSION

The ability to sustain a high %$\dot{V}O_2$max during an endurance exercise appears to be related to %$\dot{V}O_2$max at VT [2]. Although this fact, due to the difficulties associated with the evaluation of the ventilatory parameters in swimming pool conditions, the VT assessment has been scarcely investigated [16].

The results obtained in our study show that the non linear increase of Ve seems to occur at 88.1±31.3 l.min^{-1}. This value

corresponds to 84.3±8.7% $\dot{V}O_2$max. These findings seem to be in agreement with other studies conducted in running and cycling ergometers (82.3±3% [14], and 84.6±5.1% [7]), pointing out that, despite the specificity of the aquatic environment, the VT occurs at a similar absolute intensity as in running and cycling. This seem to be so, nonetheless the different haemodinamics (because of the horizontal body position), the decreased effects of gravity, and reflex bradycardia [12], in swimming. It also seems that the variation on training patterns in swimming and other sports, such as running and cycling, does not influence the value of %$\dot{V}O_2$max at that appends the VT. In the study conducted by Roels et al [16], there weren't found differences on the subjects' VT when performing an incremental test on water and on cycle ergometer, or between the two groups observed, swimmers and triathletes.
Although the obtained value of %$\dot{V}O_2$max associated to VT, does not represent the maximal work rate that can be maintained for a long period of time without a continuous rise of blood [La^-] (because, like many studies demonstrate [4, 15], the VT appends to an higher intensity than the intensity associated to the non linear increase in blood [La^-]), this exercise intensity should not be ignored in the swimming training, once it is associated to a group of physiologic mechanisms (like the bicarbonate buffering of the lactic acidosis) [5, 8, 20], determinant for the impairment of muscle contractility and its capacity to generate energy.

CONCLUSION

To our knowledge, this is one of the first studies in which %$\dot{V}O_2$max and VT are related, in swimming pool conditions. Thus, it is expected to provide additional data to better understanding of VT in swimming. The obtained results seem to indicate that the swimming training should include more intense sets on the aerobic capacity training, than the more "traditional" sets of moderate intensity, normally based or associated to the LT, which only represents one of many parameters associated to the AT. Our results indicate that to fully train the aerobic capacity, sets with intensity close to 85%$\dot{V}O_2$max should also be included, because of the importance of the mechanisms related to VT, on the rapid adjustment of the body's acid-base status during and immediately after exercise.

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EFFECTS OF SUPINE FLOATING ON CARDIAC AUTONOMIC NERVOUS SYSTEM ACTIVITY AFTER TREADMILL EXERCISE IN WATER

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The purpose of this study was to determine the effects of supine floating on rectal temperature and cardiac autonomic nervous system activity after treadmill exercise in the water. Six healthy males volunteered for this study. Subjects were placed in a supine position for 30 minutes in both a water condition (W-condition) and control condition (C-condition) after treadmill exercise in the water. And subjects were measured for recovery while sitting for 15 minutes. During supine floating after treadmill exercise in the water, log HF was significantly increased ($p< 0.05$) under the W-condition, as compared to the C-condition, during the recovery process. These data suggest that supine floating after treadmill exercise in the water could increase cardiac parasympathetic nervous system activity. Also, the increase in cardiac parasympathetic nervous system activity continues for recovery while sitting after supine floating.

Key Words: supine floating, recovery, cardiac autonomic nervous system, rectal temperature.

INTRODUCTION

In the water, humans have different physical responses compared to land due to influences of physical characteristics of water, such as water temperature, water pressure, buoyancy and viscosity. Nishimura and Onodera (1) reported on the relaxation effects of supine floating on heart rate, blood pressure and cardiac autonomic nervous system activity, and suggested that cardiac parasympathetic nervous system activity was significantly increased by supine floating. Supine floating was useful to get into a relaxation state. Matsui et al. (2) reported on the effects of water immersion on systemic cardiovascular responses during recovery periods following steady state land exercise. After exercise, stroke volume and cardiac output were significantly increased in water, when compared to land. Increased left ventricular preload with immersion, would be an important factor in cardiovascular regulation not only at rest, but also during recovery after exercise. We (3) suggested that supine floating after high and moderate intensity exercise with a cycle ergometer on land could promote the recovery of rectal temperature and an increase in cardiac parasympathetic nervous system activity. However, it doesn't make clear the effects of supine floating after water exercise. Therefore, the purpose of this study was to determine the effects of supine floating on rectal temperature and cardiac parasympathetic nervous system activity after treadmill exercise in the water.

METHODS

Six healthy males volunteered for this study. Their mean age, height, body weight, % body fat, and maximal oxygen uptake were, respectively: 21.8±0.7years (mean±SD), 172.8±8.9cm, 63.8±6.1kg, 17.5±3.0% and 49.2±4.8ml/kg/min., respectively. All subjects signed an informed consent form prior to participation in this study. Subjects were placed in a supine position for 30 minutes in both a water condition (W-condition) and control condition (C-condition) after treadmill exercise in the water. And subjects were measured for recovery while sitting for 15 minutes. Walking velocity was 4 km/h. Water level was umbilicus. During W-condition, subjects could float using an air pillow, aqua blocks and a floating belt (fig. 1.). Heart rate, blood pressure, rectal temperature, oxygen uptake and cardiac autonomic nervous system activity were measured under these conditions. Expired gases were collected in a Douglas bag. Then O_2 and CO_2 gas concentrations were measured by mass spectrometry (Westron. WSMR-1400. Japan), and gas volume was determined using a dry gas meter (Shinagawa Dev. DC-5. Japan). Cardiac autonomic nervous system activity was calculated using Maximum Entropy Calculation (MemCalc) Methodology. The frequency domain was divided into two parts: high frequency (HF; 0.15-0.40Hz) and low frequency (LF; 0.04-0.15Hz). Cardiac autonomic nervous system activity was transformed into logarithmic values to obtain a statistically normal distribution. Log HF was an index of cardiac parasympathetic nervous system activity. Water temperature was 30 degrees Celsius. Room temperature and humidity were 27.0±1.3 degrees Celsius and 81.3±5.5%, respectively. All experiments were performed at the same hour each morning. All subjects went without food after 10 p.m. prior to the experiment day. Also, caffeine components weren't allowed for three hours before experiments. All data were expressed as mean ±SD. Two-way analysis of variance for repeated measurements was used for comparison of each measured value between the W-condition and the C-condition trials. In cases where the data showed a significant difference in the two-way analysis of variance, post hoc assessment with individual time point comparisons between two trials were carried out by Students-Newman-Keuls test. The level of significance was set up as $p< 0.05$.

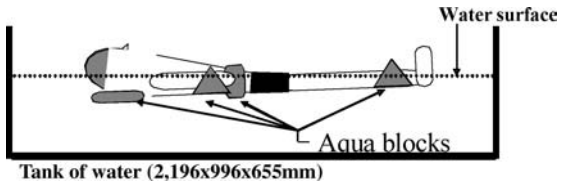

Figure 1. View showing a frame format of supine floating.

RESULTS

During treadmill exercise in the water, heart rate remained about 85 bpm and oxygen uptake remained about 1.2l/min. in both the W-condition and the C-condition. All measurement items of post exercise showed no significant differences under the W-condition, as compared to the C-condition. During supine floating after treadmill exercise in the water, delta rectal temperature (point 0-0 is end of exercise) was significantly reduced ($p< 0.05$) under the W-condition, as compared to the C-condition (fig. 2). And log HF was significantly increased ($p< 0.05$) under the W-condition, as compared to the C-condition, during the recovery process (fig. 3).

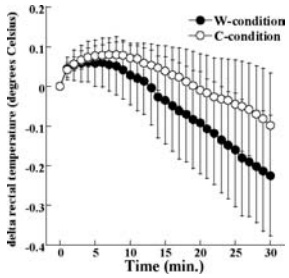

Figure 2. Changes in delta rectal temperature between the W-condition and the C-condition during recovery in supine position. Point 0-0 was end of exercise. ANOVA; $p<0.05$ W-condition VS C-condition.

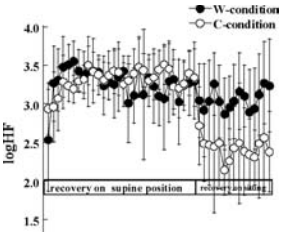

Figure 3. Changes in log HF between the W-condition and the C-condition during recovery in the supine and sitting position. ANOVA; p<0.05 W-condition VS C-condition.

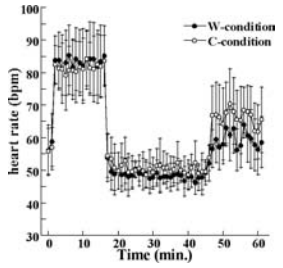

Figure 4. Changes in heart rate between the W-condition and the C-condition.

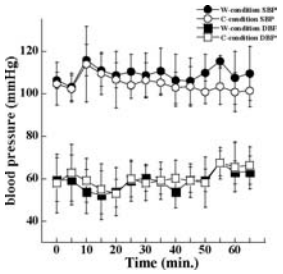

Figure 5. Changes in blood pressure between the W-condition and the C-condition.

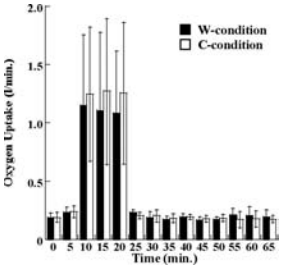

Figure 6. Changes in oxygen uptake between the W-condition and the C-condition.

Heart rate (fig. 4), blood pressure (fig. 5) and oxygen uptake (fig. 6) showed no significant differences under the W-condition, as compared to the C-condition, during recovery process.

DISCUSSION

The conductive heat transfer coefficient of water is 25 times higher than that of land. This means that venous return was cooled during water immersion. Therefore, rectal temperature was reduced by the increase of heat loss under the W-condition, as compared to the C-condition during the recovery in the supine position. The increase in log HF was caused by the bradycardia reflex, which increased central venous pressure, and the arterial baroreceptor, which increased the stroke volume. Blix et al. (4) suggested that the bradycardia reflex was caused by face immersion. In this study, the increase in log HF is the tendency that is similar to the face immersion. The increase in log HF continues for recovery while sitting after supine floating. We suggested (1) that heart rate, blood pressure and oxygen uptake showed no significant differences under the W-condition, as compared to the C-condition, during supine floating after high and moderate intensity exercise with a cycle ergometer on land. This study showed similar tendency. These data suggest that supine floating after treadmill exercise in the water could increase cardiac parasympathetic nervous system activity. Also, the increase in cardiac parasympathetic nervous system activity continues for recovery while sitting after supine floating.

CONCLUSION

Supine floating after exercise is useful for increasing cardiac parasympathetic nervous system activity not only with exercise on land, but also exercise in water.

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HOW CARDIOVASCULAR RESPONSES AFFECT TISSUE OXYGENATION AT REST AND DURING EXERCISE IN WATER?

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This study investigated how cardiovascular responses affect tissue oxygenation at rest and during exercises in water. Nine healthy men performed cycling exercises on land (LE) and in water (WE) at xiphoid levels of 40 and 60% $\dot{V}O_2$,peak. The $\dot{V}O_2$, heart rate (HR), cardiac output (CO), total peripheral resistance (TPR) and mean blood pressure (MBP) were measured. The oxy-haemogbloin (HbO_2) and total-haemoglobin (T-

Hb) were also measured using near infrared spectroscopy (NIRS). At rest, the CO and stroke volume (SV) increased ($p<0.05$) with immersion. A correlative increase in the HbO_2 level was noted. These results indicate that the oxygen supply to the muscles increased on immersion. Contrarily, the MBP during WE was higher ($p<0.05$) than that of LE at both intensities. The HbO2 level during WE was lower than that of LE at both intensities The water pressure seems to restrict the blood flow, thereby increasing MBP through activation of a muscle metaboreceptor or mechanoreceptor.

Key words: water exercise, cardiovacular response, muscle oxygenation, near infrared spectroscopy.

INTRODUCTION

The central shift in blood volume from lower limbs to the thoracic region during water immersion is caused by hydrostatic pressure, which subsequently increases the cardiac output (CO) (1, 3, 5, 8). The CO increase has been attributed to elevated stroke volume (SV), which is related to enhanced diastolic filling (1, 3, 5, 8). Although cardiovascular responses are well studied, it remains unclear how they affect skeltal muscle metaborics in water.

During the last 15 years, the physiological knowledge of human skeletal muscles substantially increase because of the utilisation of muscle biopsy complemented by non-invasive techniques such as near infrared spectroscopy (NIRS) (4, 7, 10, 11). Muscle oxygenation indicates the relationship between O_2 delivered and consumed within the tissues. Although several studies in the field of sports medicine have utilised NIRS (4, 7, 10, 11, 15), there is a lack of information on skeletal muscle oxygenation at rest and during exercise in water. It is also important to investigate how water characteristics (e.g., hydrostatic pressure) affect muscle oxygenation and associated physiological responses such as the venous return. This study was undertaken to investigate how cardiovascular responses affect tissue oxygenation at rest and during exercise in water.

METHODS

Nine healthy males participated as subjects. Their mean age, height, weight and body fat were, respectively, 24 ± 2.2 years, 175.2 ± 3.8 cm, 70.1 ± 4.7 kg and 17.0 ± 2.5%. The mean adipose tissue thickness of the vastus lateralis (VL) was 5.8 ± 1.5 mm. The subjects were informed of the experiments and their associated risks, after which they gave their consent to participate. They were then asked to perform two sets of exercises. In the first, they underwent a recumbent cycle-graded exercise on land (LE) and in water (WE). In this part of the protocol, the workload was increased every 2 min until the maximal effort was attained. The heart rate (HR) and oxygen consumption ($\dot{V}O_2$,) were continuosly mesured during the tests. The water temperature was set thermoneutrally at 32°C (5). In the second part of the protocol, the subjects performed cycle-submaximal steady-state exercises at 40% and 60% $\dot{V}O_2$,peak both in land and in water. Each protocol was separated at least 5 days. After the subjects rested on land in sitting position, they immersed up to the set xiphoid levels in water, then rested on the ergometer for 5 min and finally pedalled for 12 min at both intensities. The $\dot{V}O_2$,, HR, CO and systolic (SBP) and diastolic (DBP) blood pressures were measured during all the experiments. The CO was measured with C_2H_2 rebreathing method (2). The mean blood pressure (MBP) was calculated as follows: DBP + (SBP-DBP)/3. The total peripheral resistance (TPR) was calculated as follows: (MBP-CVP)/CO, where CVP represents an estimate of central venous pressure (5). The CVP was assumed to be 0.4 mmHg for subjects resting in air, 3.9 mmHg for subjects exercising in air and 11.1 mmHg for subjects either resting or exercising in water (5). The oxy-haemoglobin (HbO_2) and total-haemoglobin (T-Hb) values were measured simultaneously using a NIRS system (Model HEO-200, Omron Ltd., Japan). This system has a flexible probe that consists of two light-emitting diodes set at 760 nm and 840 nm (16). Their emitted lights can penetrate soft tissues to a maximum depth of 1.5-2.0 cm. Approximately 10 min before immersion, a pneumatic cuff was inflated to over 300 mmHg to occlude arterial blood flow for 7-9 minutes until the HbO_2 bottomed out. The lowest value attained during cuff ischaemia was defined as 0%; the maximal value reached after recovery from cuff ischaemia was referred to as 100% (6) (fig. 1).

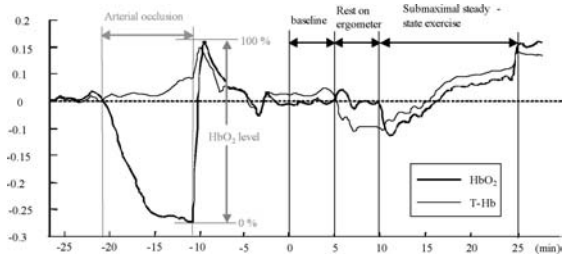

Figure 1. Submaximal steady-state exercises protocol and estimation of HbO_2 level from NIRS (6). The HbO_2 signals were measured continuously during all experiments.

RESULTS

Figures 2A and 2E show that HR and TPR, respectively, decreased significantly ($p<0.05$) upon immersion. The CO and SV, however, increased significantly ($p<0.05$). During WE and LE at both intensities, no cardiovascular responses differed, except MBP (fig. 2). The MBP was considerably higher ($p<0.05$) during WE than LE ($p<0.05$). The HbO_2 level increased during immersion (Fig. 3). The HbO_2 level for WE at 60% $\dot{V}O_2$,peak was lower than that of LE ($p<0.05$).

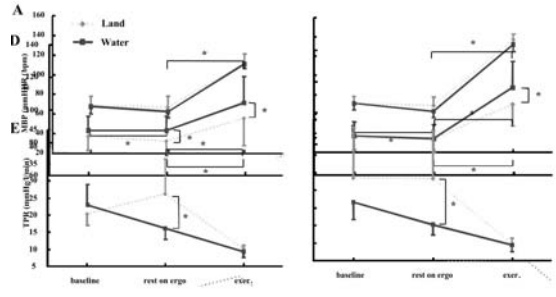

*Figure 2. Changes in HR (A), CO (B), SV (C), MBP (D) and TPR (E) ar rest and during exercise at 40% (figures on left) and 60% $\dot{V}O_2$peak (figures on right) on land and in water. Values are given as mean ± SD. egro; ergometer; exer.; exercise. * = p<0.05.*

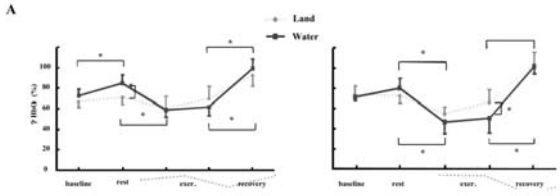

*Figure 3. Changes in HbO2 levels (A) and T-Hb (B) at 40% (left panels) and 60% $\dot{V}O_2$peak (right panels). Values of the HbO_2 levels and T-Hb are given respectively as mean ± SD and mean. * = p<0.05*

DISCUSSION

It has been suggested that both CO and SV increase with immersion or during water exercise (1, 3, 5, 7). The results of the present study reaffirmed these observation: the increase was probably caused by enhanced venous return as noted in several studies (1, 3). We could ascertain the enhanced venous return from the result of decreased T-Hb during immersion. Regarding muscle oxygenation, our data indicate that the HbO_2 level increased with immersion at both 40% $\dot{V}O_2$peak and 60% $\dot{V}O_2$peak trials. This increase might be due to the increment of CO and decrement of TPR, and suggests the increment of oxygen supply.

Some studies reported inconclusive data regarding the behaviour of BP at rest in water. In fact, the blood pressure (SBP, DBP and/or MBP) at rest in water might display slight increase (13), slight decrease (14) or no change at all (3). Our data show no changes or increase in MBP upon immersion, which is inadequately explained at present. Because some of factors stated above might be inlvoved, further research might reveal the reaons for that lack of change.

Previous studies (5, 14) reported an increase in CO and SV during ergometer exercise in an upright position in water. No signficant differences in cardiovascular responses between land and water exercise, except for that of MBP, were found in the present study. These phenomena, including the reduced venous return, might be caused by the inclined positions of the subjects in our study.

Suzuki (17) reported that hydrostatic pressures as slight as 20 mmHg can compress arterial vessels, subsequently distorting their walls; the reactivated periareterial sympathetic nerve can thereby raise blood pressure. During ergometer exercise with lower body positive pressure (LBPP), which is similar to water immersion, Nishiyasu et al. (12) reported increased MBP. They interpreted that the reduced blood flow promoted the accumulation of metabolic by-products, which activated the muscle metaboreceptor, consequently inducing reflex-rise (i.e., muscle metaboreflex). The water environment used during this study is considered to create similar conditions to that of LBPP. Therefore, we suggest that, in such an environment, the hydrostatic pressure probably raised the MBP. However, Gallagher et al. (9) argued that the MBP increase is not attributable to muscle metaboreflex, but rather to muscle mechanoreflex, a condition that is sensitive to reflex associated with increased intramuscular pressure. Thus, based on our data, it remains unclear whether the hydrostatic pressure activated the metaboreceptor or mechanoreceptor during water exercise. Hence, the MBP increase could be caused by one of these receptors.

Svedenhag and Seger (18) recognised a higher anaerobic metabolism caused by lowered perfusion pressure in the legs during running in water, resulting in maldistribution or decrease of muscle blood flow. During dynamic leg exercise with LBPP, Nishiyasu et al. (11) reported a drastic decrease of HbO_2 (and blood flow) in the thigh muscle and proposed that the decrease indicated a shift of the metabolic state to glycolysis. The water environment of this study is similar to the LBPP. Therefore, it is argued that the hydrostatic pressure restricted the blood flow and reduced the quantity of oxygen supplied to the muscles.

CONCLUSION

In conclusion, the results of this study suggest that the increments of CO and SV might increase the oxygen supply to the muscles at rest and during exercise in water at 40% $\dot{V}O_2$peak and 60% $\dot{V}O_2$peak. The hydrostatic pressure can induce the restriction of the blood flow and the oxygen supply to the muscles. That restriction probably activated the muscle metaboreceptor or mechanoreceptor, which consequently increased the MBP.

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CHANGES IN CROSS SECTIONAL AREA OF INFERIOR VENA CAVA DURING ARM CRANKING EXERCISES IN WATER

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The purpose of the present study was to investigate the cross sectional area of inferior vena cava changes during exercises in water. Six subjects voluntarily participated in this study and performed an arm cranking exercise program under the four experimental conditions (20% $\dot{V}O_2$max, 40% $\dot{V}O_2$max, 60% $\dot{V}O_2$max and control). Water temperature was 30 degrees C. Water depth was axilla. Heart rate and cross sectional area of inferior vena cava were measured by radiotelemetric electrocardiography and B-mode echocardiography, respectively. The cross sectional area of inferior vena cava decreased during the exercise program, and there was a significant relationship between the cross sectional area and intensity of the exercise program ($p < 0.05$). The findings of the study indicated that venous return had been keeping the volume during the low intensity exercise program and that had been changing the treatment from volume to velocity during the high intensity exercise program.

Key Words: venous return, the cross sectional area of inferior vena cava, exercise intensity, in water exercise, arm cranking exercise.

INTRODUCTION
It is well known that bradycadia and increases in stroke volume occur induced by hydrostatic pressure during water immersion. Onodera et al (1) clarified that the venous return increased in dependence on hydrostatic pressure. The cross sectional area of inferior vena cava significantly increased in accordance with increasing water depth. We expected that the venous return would have two factors of volume and velocity. Onodera et al (2) clarified that the response of venous return was about twenty seconds using the change of size in the cross sectional area of the inferior vena cava. However, there is still no common agreement on changes of volume in venous return during exercises in water. Therefore, the present study investigated the volume of venous return using the cross sectional area of inferior vena cava changes during exercises in water.

METHODS
Six subjects voluntarily participated in this study. All were healthy adult males with no history of cardiopulmonary disease. Descriptive data (mean + SD) are as follows: age of 23±1 years, height of 173±15 cm, body weight of 173±5, %Fat of 19±2%, maximal oxygen uptake ($\dot{V}O_2$max, STPD) of 2.44+0.55 liter/min. We used informed consent for subjects according to the HELSINKI Ethical Principle.
The exercise was performed by an arm cranking ergo meter (881, MONARK). The study was set into four experimental conditions of 20% $\dot{V}O_2$max, 40% $\dot{V}O_2$max, 60% $\dot{V}O_2$max and control. The data were compared in air and water, respectively. $\dot{V}O_2$max was measured by the steady-state conditions. Expired air for the determination of $\dot{V}O_2$ was collected in two successive bags though the respiratory valve. Collection started 2 min before the end of work. Expired O_2 and CO_2 gas concentrations were measured by mass spectrometry (Westron MGA 1200, Japan), and gas volume was determined using a dry gas meter (Shinagawa Dev.NDS-2A-T, Japan).
Subjects participated in an arm cranking exercise program for 10-min. The rest after exercise program was 10 min. To determine $\dot{V}O_2$ expired air was collected six (in water) or five (in air) times (rest in air, rest in water, 3-5 and 8-10 min during exercise, 3-5 and 8-10 min after exercise).
Heart rate was measured by radiotelemetric electrocardiography (DS-2202, FUKUDADENSHI Japan), and was monitored minute by minute. The cross sectional area of the inferior vena cava was measured using B-mode echocardiography (SSD-870 ALOKA Japan) while standing in air and water. Water and room temperature were 30.5±0.6 and 25.4±0.4 degrees C, respectively. Water depth was set on axilla height. Data were analyzed by specify ANOVA for repeated measures and the level was set at $p < 0.05$.

RESULTS
The heart rate was significantly increased according with increasing intensity of the exercise program ($p < 0.05$). At the same intensity of exercise program, heart rate in the water condition was significantly lower than in the air condition (fig. 1a, b). $\dot{V}O_2$ was significantly increased in accordance with the increasing intensity of the exercise program ($p < 0.05$), and was the same in air and water (fig. 2a, b). These results suggest that the load is the same in air and in water conditions.

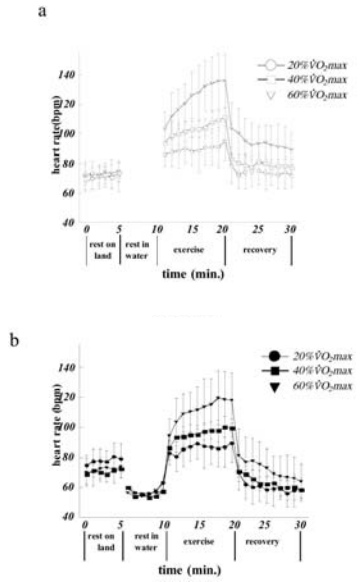

Fig.1. Comparision of heart rate during different intensity arm cranking exercise.
a: out of the water condition b: in the water condition.

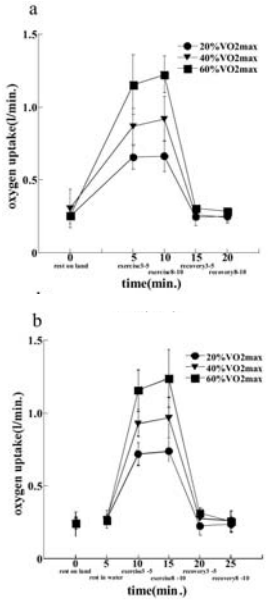

Fig. 2. Comparison of oxygen uptake during different intensity arm cranking exercise.
a: out of water condition, b: in water condition.

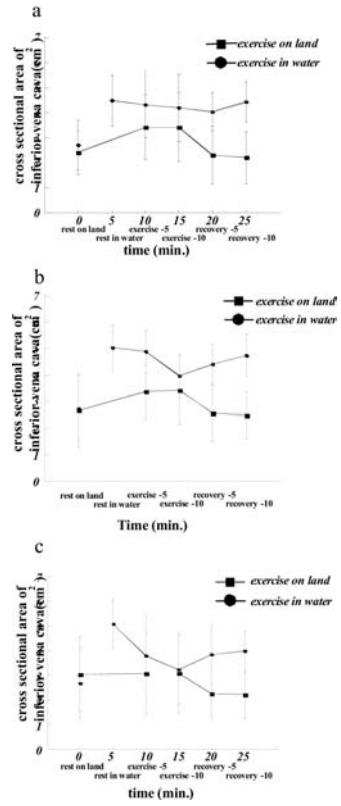

Figure 3. Comparison of cross sectional area of inferior vena cava between the exercise on land and the exercise in water. a: 60% V̇O2max. b: 40% V̇O2max. c: 20% V̇O2max.

The cross sectional area of inferior vena cava of 20% $\dot{V}O_2$max in water was significantly higher than in air at the point of all expired air (fig. 3a, $p < 0.05$). The cross sectional area of inferior vena cava of 40% $\dot{V}O_2$max in water was significantly higher than in air at the point of 3-5 min during exercise and of 3-5 min and 8-10 min after exercise (fig. 3b, $p < 0.05$). The cross sectional area of inferior vena cava of 60% $\dot{V}O_2$max in water showed no significant difference during exercise, and was significantly higher than in air at the point of 3-5 min and 8-10 min after exercise (fig. 3c, $p < 0.05$). The cross sectional area of inferior vena cava after exercise was significantly lower in accordance with increasing intensity of the exercise program (fig. 3a, b, c, $p < 0.05$).

DISCUSSION

These results indicate that the cross sectional area of inferior vena cava decreased during the exercise program and that there is a significant relationship between the cross sectional area and the intensity of the exercise program ($p<0.05$). The results of recovery after the exercise program also indicate that there is a significant difference between the cross sectional area and the intensity of the exercise program ($p < 0.05$).

We suspect that the venous return has two factors controlling the velocity and volume. The findings of the study indicated

that venous return had been keeping the volume during the low intensity exercise program and that had been changing the treatment from volume to velocity during the high intensity exercise program. The increase in venous return with water immersion may be associated with bradycardia during low intensity exercise in water.

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THE INFLUENCE OF COMPETITIVENESS ON MATCH EXERCISE INTENSITY IN ELITE WATER POLO PLAYERS

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This study was designed to investigate the physiological responses that elicited in different competitive level players during water polo games. Specifically, the hypothesis that the players of International calibre (IA; Greek National Team) perform with higher intensity than the National level players (NA; 1st Greek National League) was tested. Thirty players, who had equally split to IA and NA, participated in this study. No differences were found with respect to the percentage of time spent with exercise intensity above and below the threshold between IA and NA. However, regardless of relative terms (%), IA swam with significantly higher velocity than NA throughout the game. Both groups preferred to compete with an intensity fluctuating around their lactate anaerobic threshold. It is concluded that the International level players performed at higher absolute exercise intensity than National level players.

Key Words: national team, males, physiological demands.

INTRODUCTION
Successful water polo players display moderately high aerobic power (58-61 ml·kg^{-1}·min^{-1}) and high concentrations of blood lactate (13 – 16 mmol·l^{-1}) after performing an exhaustive anaerobic test (9). A comprehensive study, examining field play physiological demands in water polo, found that athletes maintained a heart rate in excess of 150 beats·min^{-1} for 91.8 % of the actual water polo game playing time. In addition, 50.8 % of the actual playing time was allotted to higher exercise intensity than the one corresponding to the subjects' ventilatory anaerobic threshold (4).
However, exercise intensity in a water polo match is known to be affected by game duration (5) and closeness of final score mach (6). It is also known that field-playing positions do not attain specific exercise intensity traits in water polo (2, 5) contrary to what happens in other ball game events (i.e. 7). The level of competitiveness has also been found to affect the metabolic demands of playing in other ball game sports (i.e. 1). In water polo, studies investigating the influence of the level of competitiveness on match play exercise intensity have not been conducted yet.
This study was designed in order to investigate the physiological responses exhibited by different competitive level players while they were playing water polo. Specifically, the hypothesis that international calibre players perform with higher absolute intensity than the national players was tested.

METHODS
Thirty water polo male players signed a informed consent sheet to participate in the study, it was previously approved by the respective ethics committee. Subjects were members of 10 different water polo clubs, out of 12 in total, participating in the First Greek National Division Championship. They were selected in such way as they could be equally split to different levels of competitiveness. The first was a group of international players (IA; n=15) who were belonging to the Greek national team continuously for the last three years and had been selected by the national coach using his own criteria without having any access to objective performance tests. The second was group of national caliber athletes (NA; n=15) who were participating regularly in the First Division Championship without affiliation with any national team. Subjects' characteristics are presented in Table 1. One week prior to the experimental games, performance testing was conducted in order to determine the physical abilities of the subjects. Then field measurements were performed during ten simulated competition games. Each one lasted 28 min of net playing time equally split into four periods.
The following measurements were performed:
1) monitoring of blood lactate during the break between each playing quarter,
2) continuous recording of the heart rate responses during competition.
Competitive exhibition games took place right after two months of regular training for securing homogeneous expression of physical abilities by all participants. During each game, the variables were recorded from 3 subjects. These subjects were arranged to play throughout the entire game without being substituted at all. All games were played following the zone defense system.

Testing Performance
Each subject completed a 400 m front crawl stroke swimming test with a constant maximum speed, in an indoor 25-m pool to determine his highest oxygen consumption (VO_{2peak}) and performance (3). Recovery metabolic rate was recorded, in a breath-by-breath mode, for 30 sec aiming to obtain the peak oxygen value. Otherwise, VO_{2peak} was calculated as it has been previously reported (8). Lactate threshold (LT) of each subject was determined by asking the participant to swim in a 50 m long pool four times the distance of 200 m at progressively incremented velocity. Heart rate (HR) was monitored (Polar Vantage NV, FI) throughout the whole test whereas blood samples from the fingertip of the subject were taken during recovery of each effort, and analysed using the reflectance photometry - enzymatic reaction method (Accusport, Boehringer, Germany).

Physiological responses during competition
The heart rate of each subject was recorded at 5 sec intervals

during the game using a radio telemetry system (Polar Vantage NV, FI). The emitter was placed and secured with a network of straps on the chest of the athletes without limiting their movement freedom. The receiver was set in each subject's swimming suit. In each game, the receivers were arranged on three athletes in remote playing positions in order to avoid telemetric signal interference. Fingertip blood samples were obtained from all three subjects within 90s of the completion of each quarter of play and analyzed. Testing details were described by Platanou et al. (5).

Table 1. Anthropometric characteristics of subjects participating in the study. Values are means ± SD.

		Age (years)	Height (m)	Body mass (kg)
National athletes	(n=15)	22.4±3.3	1.83±0.05	88.3±10.64
International athletes	(n=15)	22.6±3.6	1.82±0.05	82.1±08.14
Total	**(n=30)**	**22.5±3.4**	**1.83±0.05**	**85.2±09.82**

Statistical treatment of data

Two Way Analysis of Variance with repeated measures over time was applied to explore differences, on various dependent variables, among levels of competitiveness. Student's t-test was performed in order to detect any existing difference in all physiological characteristics between International and National athletes.

RESULTS

Table 2 summarises the physiological and performance characteristics of all subjects in total (n=30), as well as divided equally (n=15) in two subgroups according to their level of competitiveness. In addition, Table 2 shows HR and La values obtained during the water polo games. Figure 1A illustrates the mean HR response pattern per quarter of play for National and International level players. Heart rate response during the games was converted to swimming velocity (Figure 1B) based on the respective relation recorded in the preliminary performance testing. Regardless the competitiveness level, approximately 40% of total time (36.5 for NA, 46.3 for IA), excluding the breaks among quarters, was spent with a HR less or equal to 85% $HR_{peak.}$ The rest of the time was almost equally distributed among heart rate intensities within the spectrum of 85-90, 90-95, and 95-100% of its highest value. No differences were found with respect to the percentage of time spent with exercise intensity above and below the threshold between IA and NA.

Table 2. Mean values of physiological and performance characteristics as well as mach exercise intensity of elite water polo players (n=30) subdivided equally to International and National caliber athletes (n=15 in each group).

	National		International		P	Total	
	Mean	± SD	Mean	± SD		Mean	±SD
400m swim							
400 m swim (min:sec)	5:07:56	0:22.42	4:48:35	0:10:94	008	4:57:80	0:22.36
VO_{2peak} (ml·kg^{-1}·min^{-1})	57.14	9.26	70.23	6.97	.001	63.69	10.44
VO_{2peak} (l/min)	4.9	0.8	5.5	0.6	.02	5.2	0.8
HR_{peak} (beats·min^{-1})	186.80	7.20	179.90	6.31	.01	183.00	7.78
95% of HR_{peak}	177.50	6.80	170.20	6.20	.002	173.60	6.40
90% of HR_{peak}	168.40	6.70	161.30	5.90	.002	164.30	6.20
85% of HR_{peak}	158.80	6.12	152.30	5.50	.002	155.60	5.80
4X200m swim							
LT (mmol·l^{-1})	4.60	0.80	3.47	0.76	.002	4.03	0.96
V_{LT} (m/sec)	1.25	0.07	1.31	0.06	.02	1.28	0.07
HR_{LT} (beats·min^{-1})	163.07	9.59	147.53	9.63	.0003	155.30	12.32
HR_{LT} as % HR_{peak}	87.33	4.01	83.79	4.36	.002	85.56	4.49
Water-polo match							
HR (beats/min)	162.90	9.90	149.80	8.20	.001	156.4	8.90
La (mmol/l)	4.67	2.17	3.04	1.09	.002	3.9	1.89

HR_{peak}: The highest of heart rate; VO_{2peak}: Peak oxygen uptake; LT: Lactate Threshold; V_{LT} : Swimming velocity at lactate threshold, HR_{LT}: Heart Rate at lactate threshold.

HRpeak: The highest of heart rate; VO_{2peak}: Peak oxygen uptake; LT: Lactate Threshold; V_{LT}: : Swimming velocity at lactate threshold, HR_{LT}: Heart Rate at lactate threshold.

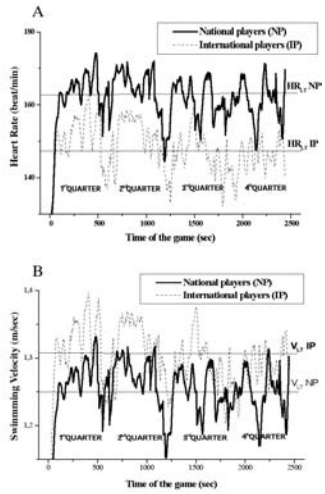

Figure 1. Mean Heart Rate response (A) and swimming velocity (B) per quarter of game for national and international players during 10 water polo games HR_{LT}: Heart Rate at lactate threshold V_{LT}: : Swimming velocity at lactate threshold.

DISCUSSION

The present study investigated the physiological responses imposed by the demands of the water polo game on two distinct groups of players, namely members of the national Olympic Greek team and players participating in the First National Division.

It was shown that the IA compared with NA possessed higher aerobic capacity and swam faster the 400 m crawl distance. Furthermore, LT in former group exhibited at higher swimming velocity than in the latter group of athletes. The lower HR_{peak} in IA compared with NA players, at the 400 m free style, is worth mentioning. Despite the high variability of the HR_{peak} values, our findings are in agreement with those recorded in other studies performed in the water, (e.g. 184±4 beats/min) (4). Due to higher values of HR_{peak} relative values of HR_{LT}, expressed as percentage of HR_{peak}, were also higher (87.3±4.01%; 163±9.6 beats/min in NA vs. 83.4±4.4; 147±9.6 beats/min in IA). As Figure 1A shows, the absolute HR recorded during the games was significantly higher (162.9±9.9 beats/min) in NA group than that measured in the members of IA (149.8±8.2 beats/min). Surprisingly, the average playing intensity in the two groups corresponded to 87 and 83% of the group's HR_{peak}, percentages that seem to be similar with respective ones at the lactate threshold. Similarly, the higher blood lactate concentration observed during the games in NA subjects compared to IA members simply reflect the different LA threshold values between the two groups. The finding that the IA exhibited significantly greater swimming velocity at lactate threshold than the NA (Table 2; Fig 1B) indicates a physiological advantage during competition for the former group of water polo players. In conclusion, these results appear to strengthen the previously expressed notion (4, 5), that water polo players

select to work overall with intensity around their anaerobic lactate threshold regardless of their skills and capabilities, and any differences observed in absolute values between the experimental groups are probably attributed to the specific physiological characteristics of the players being involved in each group.

CONCLUSIONS

The hypothesis that during water polo games International caliber players perform with higher absolute intensity than the National players was confirmed. It appears that this is mainly due to a superior aerobic capacity and an advantageous lactate threshold. Water polo games are primarily played with an intensity fluctuating around to the players' lactate thresholds.

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COMPARISON BETWEEN DIFFERENT METHODS FOR THE ASSESSMENT OF THE $\dot{V}O2$ SLOW COMPONENT OF FREESTYLE ELITE SWIMMERS

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The purpose of this study is to compare different methods for the assessment of the Oxygen uptake Slow Component (SC) in elite swimmers in a time limit test at the minimum velocity that elicits maximal oxygen consumption. Five females and two males participated in this study. $\dot{V}O_2$ was measured by a portable gas analyser connected to the swimmers by a respiratory snorkel. To describe the SC kinetics was used a mathematical model with three exponential functions. This model was compared with different methods of rigid time intervals defined as the difference between the final $\dot{V}O_2$ and that at the 2nd min ($\Delta\dot{V}O_{2[end-2]}$) or at the 3rd min of exercise ($\Delta\dot{V}O_{2[end-3]}$). This study showed that the use of the $\dot{V}O_{2[end-3]}$ underestimates the results since the SC usually begins earlier than the 3rd minute and that the use of the $\dot{V}O_{2[end-2]}$ seems to be a good solution, being less accurate but more simple to use in a day-to-day basis.

Key Words: $\dot{V}O_2$ slow component, modelling, rigid time intervals, freestyle swimmers.

INTRODUCTION

During exercise at heavy intensities, which engenders a sustained elevation in blood lactate, the $\dot{V}O_2$ kinetics becomes considerably more complex than for moderate exercise. We can observe a secondary slower component to the rise in $\dot{V}O_2$, such that attainment of a new steady-state, if attained, is delayed (1). This Slow Component (SC) usually begins 80s to 180s after the onset of the heavy exercise (1).
In the literature we can find several methods for the assessment of the $\dot{V}O_2$ SC. Many investigators have used a rigid interval to estimate the SC (2), most frequently the difference in oxygen consumption between the 3rd min and some later moment in the bout, (for example: 4, 5, 6, 7, 9, 10, 12, 18). Some authors have defined the 2nd min as the onset of the SC (8, 11, 16). Furthermore the use of a rigid interval as index of a physiologic parameter, which varies among subjects, is clearly prone to error, in addition the magnitude and significance of this error has not been investigated (2).
The purposes of this study are: (i) verify the existence of a $\dot{V}O_2$SC in Portuguese elite freestyle swimmers; (ii) compare the results of the values of the SC determined through the utilization of the mathematical model and the rigid time intervals, in a $\dot{V}O_2$ TLim test.

METHODS

Subjects

Five females (16.9±1.5 yy, 59.0±3.1 kg and 165.8±3.2 cm) and two males (18.5±0.6 yy, 74.6±8.5 kg and 176.0±11.3 cm) elite freestyle swimmers volunteered to participate in this study. All subjects were informed about the details of the experimental protocol before beginning the measurement procedures.

Test protocol

The test sessions took place in a 25m indoor pool. First, each subject performed an intermittent incremental protocol for freestyle v$\dot{V}O_{2max}$ assessment (8). $\dot{V}O_2$ was directly measured by a portable gas analyser (K4 b² Breath by breath Pulmonary Gas Exchange System – COSMED, Italy) connected to the swimmers by a specific respiratory snorkel for swimming (17). Expired air was continuously measured during the entire test and averaged every 5s. Swimming velocity was controlled using a visual pacer (TAR.1.1, GBK-electronics, Aveiro, Portugal) with flashing lights in the bottom of the pool.

$\dot{V}O_{2max}$ was considered to be reached according to primary and secondary traditional physiological criteria (for more information see 8). The velocity for maximal oxygen consumption, $v\dot{V}O_{2max}$, was considered to be the swimming velocity corresponding to the first stage that elicits $\dot{V}O_{2max}$. Capillary blood samples for ([La$^-$] analysis were collected from the earlobe at rest, in the 30s rest intervals, immediately after the end of each exercise step, and at 3min (and 5 min) during the recovery period. These blood samples were analysed using an YSI1500LSport auto analyser (Yellow Springs Incorporated, Yellow Springs – Ohio, USA). Heart rate (HR) was monitored and registered continuously each 5s through a heart rate monitor system (Polar Vantage NV, Polar Electro Oy, Kempele, Finland).

The second test session took place forty-eight hours later. All subjects swam until exhaustion at their previously determined $v\dot{V}O_{2max}$, to assess TLim. This protocol consisted in two different phases, all paced with the referred visual lightpacer: 1) a 10min warm-up at an intensity corresponding to 60% $v\dot{V}O_{2max}$, followed by a rest period of 20s for blood collection; 2) the maintenance of the swimming $v\dot{V}O_{2max}$ until exhaustion. TLim was considered to be the total swimming duration at $v\dot{V}O_{2max}$.

[La$^-$] were assessed at rest, during the 20s intervals, immediately after the exercise, and at 3min (and 5min) of the recovery period. HR was registered continuously using the same procedure previously described.

Swimmers were instructed to perform an open turn, always done to the same lateral wall without underwater gliding, and were verbally encouraged to swim as long as possible during the test period. Both tests were carried out in the same conditions for each subject, i. e., temperature, humidity and time of day.

Slow Component assessment

Mathematical model

The mathematical model consisted in three exponential terms, representing each, one phase of the response. The first exponential term started at the onset of the exercise and the other terms started after independent time delays (TDi in the equation). The following equation describes the mathematical model for the $\dot{V}O_2$ kinetics (13):

$$\dot{V}O_2(t) = \dot{V}_b \quad \text{(basal } \dot{V}O_2\text{)}$$
$$+A_0 \times (1 - e^{-(t/\tau 0)}) \quad \text{(phase 1: cardiodynamic component)}$$
$$+ A_1 \times (1 - e^{-(t-TD1)/\tau 1}) \quad \text{(phase 2: fast component)}$$
$$+ A_2 \times (1 - e^{-(t-TD2)/\tau 2}) \quad \text{(phase 3: slow component),}$$

where t is the time, A_i represents the various components amplitudes, TD_i are the times for the onset of the different components, and τ_i stands for the transition period needed for the component to attain the steady state, during which physiological adaptations adjust to meet the increased metabolic demand (14). For the adjustment of this function to the data points it was used a nonlinear least squares method implemented in the MatLab program, using the routine LSQCURVEFIT. For each test we averaged the data values every 5s.

Methods of rigid time intervals

To assess the $\dot{V}O_2$ SC with the rigid time intervals methods we calculated: (i) the value for $\dot{V}O_2$ averaged over the 20s before the 2nd min (120s), the 3rd min (180s) and at the end of the exercise - $\Delta\dot{V}O_{2[end-2]}$20s before 2min and final; $\Delta\dot{V}O_{2[end-3]}$20s before 3min and final (3); (ii) $\dot{V}O_2$ averaged over the 30s before the 2nd min, the 3rd min and at the end of the exercise - $\Delta\dot{V}O_{2[end-2]}$30s before 2min and final; $\Delta\dot{V}O_{2[end-3]}$30s before 3min and final (iii) $\dot{V}O_2$ averaged over the 40s before the 2nd min, the 3rd min and at the end of the exercise - $\Delta\dot{V}O_{2[end-2]}$40s before 2min and final; $\Delta\dot{V}O_{2[end-3]}$40s before 3min and final (iv) $\dot{V}O_2$ averaged over the 20s before and 20s after the 2nd min, 3rd min (centred) and 20s before the end exercise – $\Delta\dot{V}O_{2[end-2]}$20s+20s around 2min and 20s before final; $\Delta\dot{V}O_{2[end-2]}$20s+20s around 3min and 20s before final; (v) $\dot{V}O_2$ averaged over the 20s before and 20s after the 2nd min, 3rd min (centred) and 30s before the end exercise $\Delta\dot{V}O_2$end - $\Delta\dot{V}O_{2[end-2]}$20s+20s around 2min and 30s before final; $\Delta\dot{V}O_{2[end-2]}$20s+20s around 3min and 30s before final; (vi) $\dot{V}O_2$ average of the 20s before and 20s after the 2nd min, 3rd min (centred) and 40s before the end exercise - $\Delta\dot{V}O_{2[end-2]}$20s+20s around 2min and 40s before final; $\Delta\dot{V}O_{2[end-2]}$20s+20s around 3min and 40" before final (8, 11).

Statistical analysis

Statistical procedures included means, standards deviations and paired Student's t-test. All data were checked for normality. The statistical procedures were conducted with SPSS 13.0. The significance level was set at 5%.

RESULTS AND DISCUSSION

In the table 1 we can see the different values of the parameters we used to describe the $\dot{V}O_2$ kinetics. The Amplitude 1 (A1), Time Delay 1 (TD1) and Time Constant (Tau1) refer to the $\dot{V}O_2$ fast component and the Amplitude 2 (A2), Time Delay 2 (TD2) and Time Constant 2 (Tau2) refer to the $\dot{V}O_2$ SC.

Table 1. Parameters of the $\dot{V}O2$ kinetics.

Swimmer	A1 (ml/ /kg/min)	TD1 (s)	Tau1 (s)	A2 (ml/ kg/min)	TD2 (s)	Tau2 (s)
1	33,11	32,39	10,88	4,21	103,87	30,00
2	42,61	21,94	20,50	3,04	105,00	59,71
3	34,24	17,70	11,09	5,05	115,00	21,32
4	34,36	24,76	14,93	8,87	108,82	46,58
5	37,87	6,67	21,20	12,00	95,00	14,13
6	39,14	5,94	20,54	2,97	105,00	59,76
7	54,63	19,34	11,98	4,78	98,92	11,57
Mean±SD	39,42±7,5	18,39±9,51	15,87±4,7	5,85±3,4	104,52±6,5	34,72±20,6

Our results indicate that all subjects present a $\dot{V}O_2$ SC. Even considering the small number of studies about this theme in swimming, there where already some indications that this activity also presented a SC in heavy exercise (7, 8, 15). Although Billat et al. (5) referred that some studies presented the drawback of studying untrained subjects or poor trained subjects and considered the SC magnitude as being almost negligible in resistance athletes (4, 5), Carter et al. (6) observed a significant SC in running and cycling athletes. The authors referred that the SC first becomes evident at about 2 min into exercise. Therefore, defining the SC as an increase in $\dot{V}O_2$ above the value at 3 min of exercise will significantly underestimate the magnitude of the SC (6).

Table 2. Mean (± SD) values for the SC amplitude (in ml.kg-1.min-1) calculated from the different methods.

Mathematical model (A_2)	$\Delta \dot{V}O_{2[end-2]}$ 20sbefore 2min and final	$\Delta \dot{V}O_{2[end-3]}$ 20sbefore 3min and final	$\Delta \dot{V}O_{2[end-2]}$ 30sbefore 2min and final	$\Delta \dot{V}O_{2[end-3]}$ 30sbefore 3min and final	$\Delta \dot{V}O_{2[end-2]}$ 40sbefore 2min and final	$\Delta \dot{V}O_{2[end-3]}$ 40sbefore 3min and final
5.8 ± 3.4	4.0 ± 1.7	0.2 ± 2.0*	4.5 ± 1.9	0.2 ± 1.8*	4.8 ± 2.1	0.3 ± 1.9*
	$\Delta \dot{V}O_{2[end-2]}$ 20s+20s around 2 min and 20s before final	$\Delta \dot{V}O_{2[end-3]}$ 20s+20s around 3 min and 20s before final	$\Delta \dot{V}O_{2[end-2]}$ 20s+20s around 2 min and 30s before final	$\Delta \dot{V}O_{2[end-3]}$ 20s+20s around 3 min and 30s before final	$\Delta \dot{V}O_{2[end-2]}$ 20s+20s around 2 min and 40s before final	$\Delta \dot{V}O_{2[end-3]}$ 20s+20s around 3 min and 40s before final
	3.0 ± 1.7	0.3 ± 1.9*	2.8 ± 1.8	0.1 ± 1.5*	2.8 ± 1.7	0.1 ± 1.6*

** $p<0.05$ for differences between A_2 and the respective method of rigid intervals.*

In fact, our results also point the fact that the amplitude of the SC using the 3rd min of exercise is, in all cases, different from that obtained from the mathematical model. Looking at Table 1, we can also see that the SC begun 104.51s±6,47s (TD2) into exercise, clearly below the 3 min (180s).
Our results also hint for the fact that using the 2nd min of exercise for the SC assessment does not present statistically significant differences with the mathematic model, meaning that the SC onset may be close to the 2nd min of heavy exercise (6).

CONCLUSIONS

(i) The present study confirms the existence of a $\dot{V}O_2$ SC in elite freestyle swimmers performing in the heavy intensity domain; (ii) there were statistically significant differences between the mathematical model for the SC amplitude and all methods of rigid time intervals using the 3rd min; (iii) there were not statistically significant differences between the mathematical model for the SC amplitude and all methods of rigid time intervals using the 2nd min; (iv) in our understanding it seems reasonable to admit that the mathematic model is the most interesting and correct method for the assessment of the $\dot{V}O_2$ SC in elite swimmers, since it allows an individual analysis of each subject and its evolution with training, as well as allowing the analysis of other important parameters for the SC definition. Nerveless, the utilization of the 2nd min of exercise for the estimation of the SC amplitude seems to be a good compromise solution for a day-to-day basis, having in mind that the mathematical model involves more complex calculations, although with modern computers it takes less than a second to perform them.

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STROKE PERFORMANCE DURING BUTTERFLY AND BREASTSTROKE SWIM AT THE LOWEST SPEED CORRESPONDING TO MAXIMAL OXYGEN CONSUMPTION

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The aim of this study was to analyse if TLim-v$\dot{V}O_2$max, tested for the first time in breaststroke and butterfly, is also influ-

enced by stroke rate (SR), stroke length (SL) and stroke index (SI). Ten elite swimmers (7 males of 19.58±2.9 yy, 176.±5.0 cm and 70.5±6.2 kg, and 3 females of 17.6±1.5 yy, 166.3±5.1 cm and 60.9±6.5 kg) performed, in their best simultaneous technique, an intermittent incremental protocol for $\dot{V}O_2$max assessment. 48 hours late, subjects swam until exhaustion at their pre-determined velocity, to assess TLim-v$\dot{V}O_2$max., SL=v.SR^{-1}, SR (cycles.min^{-1}) and SI=SL*v. Regarding the relationship between TLim- v$\dot{V}O_2$max and the different stroke parameters, it was not found any relationship for each technique. However, when both techniques were considered, it was observed an inverse relationship between TLim- v$\dot{V}O_2$max and SR and between TLim- v$\dot{V}O_2$max and v$\dot{V}O_2$max.

Key Words: time limit, $\dot{V}O_2$max, simultaneous swimming strokes, stroke parameters.

INTRODUCTION

One of the most recent topics of interest in swimming training and performance diagnosis is the concept of Time Limit, i.e., the time duration during which a certain intensity of exercise can be sustained until exhaustion (1). This concept was been studied mainly at intensities corresponding to maximal oxygen uptake (TLim-v$\dot{V}O_2$max). Time Limit was previously studied in cycling and in running. In swimming it was firstly conducted in swimming-flume (2, 3, 4). However swimming in these conditions can impose particular mechanical constraints when compared to free swimming in a conventional poll. So, there been only a few studies that were care down in a conventional poll (e.g. 5, 10). The main findings of the above-mentioned studies were: (i) TLim-v$\dot{V}O_2$max seems to be direct and positively influenced by accumulated oxygen deficit, the $\dot{V}O_2$max slow component and the swimming economy; (ii) TLim-v$\dot{V}O_2$max seems to be inversely influenced by v$\dot{V}O_2$max and 3,5mmmol l^{-1} blood lactate anaerobic threshold; (iii) TLim-v$\dot{V}O_2$max seems to be a kind of effort very well related to the 400 m freestyle performance.

All of the above-mentioned studies and consequent results were conducted only for front crawl swimming. Therefore, to our knowledge, there is no study that considered other swimming techniques. Arguing that the aerobic energy supply contributes relevantly in all maximal efforts of durations higher than 75sec (7), including the 200m event in all techniques, we think that it is quite important to study this topic in all swimming techniques.

So, the aim of present study was to identify some of the factors that determined the TLim-vVO_2 in simultaneous swimming techniques, specifically some stroke parameters related with swimming economy (SR, SL and SI).

METHODS

Subjects

Ten elite swimmers of the Portuguese National Team participate in this study, 7 male and 3 female. They were divided into two groups, according with their best swim technique: (i) a group of 4 butterfly swimmers (3 males and 1 female) and (ii) a group of 6 breaststroke swimmers (4 males and 2 females). Mean and standard deviation (mean ± sd) values for their physical characteristics and swimming frequency of training are described in Table 1.

Table 1. Mean and standard deviation values of physical characteristics and weekly training frequencies.

	Butterfly		Breaststroke	
Parameters	Male (n=3)	Female (n=1)	Male (n=4)	Female (n=2)
Age	20,70±3,37	17,42	19,09±2,69	17,63±2,11
Weight	70,13±8,50	54,2	70,45±5,41	64,2±4,24
Height	179,3±5,03	165	173±3,70	167±7,07
Weekly training frequency	9	9	9	9

Test Protocol

All the test sessions took place in a 25 m indoor swimming pool. Each swimmer performed, in their best simultaneous technique, an individualized intermittent incremental protocol for v$\dot{V}O_2$max assessment; with increments of 0.05 m s^{-1} each 200 m stage, and 30 s intervals until exhaustion (5). VO_2 was directly measured using a telemetric portable gas analyzer (K4b^2, Cosmed, Italy) connected to the swimmer by a respiratory snorkel and valve system (9, 11). Expired gas concentrations were measured breath-by-breath (BxB). Swimming velocity was controlled using a visual pacer (TAR. 1.1, GBK-electronics, Aveiro, Portugal) with flashing lights on the bottom of the pool. All equipment was calibrated prior to each experiment.

$\dot{V}O_2$max was considered to be reached according to primary and secondary traditional physiological criteria (8), v$\dot{V}O_2$max was considered to be the swimming velocity correspondent to the first stage that elicits $\dot{V}O_2$max.

The second test session occurred 48 hours later. All subjects swam at their previously determined v$\dot{V}O_2$max to assess TLim-v$\dot{V}O_2$max. This protocol consisted in two different phases, all paced: (i) a 10 min warm-up at an intensity correspondent to 60% v$\dot{V}O_2$max, followed by a short rest (20 s) for earlobe blood collection, and (ii) the maintenance of that swimming v$\dot{V}O_2$max until volitional exhaustion or until the moment that the swimmers were unable to swim at the selected pace. TLim-v$\dot{V}O_2$max was considered to be the total swimming duration at the pre-determined velocity.

In the second test the general biomechanical parameters were assessed by the counting of strokes and the time that the swimmer needed to perform 25m. To calculate the general biomechanical parameters were used the traditional formulas: SR= cycles.min^{-1}, SL=v.SR^{-1}, and SI=SL*v.

Swimmers were instructed to use a surface open turn, always performed to the same lateral wall side, without underwater gliding. In-water starts were also used. Swimmers were verbally encouraged to perform as long as possible during the tests. Both tests were carried out in the same conditions for each subject (i.e. water and air temperature, and time of the day) and all were instructed not to exercise hard before and between the evaluations.

RESULTS AND DISCUSSION

The main value that we obtain for the TLim-vVO_2, v$\dot{V}O_2$max and the stroke parameters for each technique are described in Table 2.

Table 2. Main Values of Tlim- v$\dot{V}O_2$max, v$\dot{V}O_2$max and stroke Parameters.

Parameters	Butterfly N=4	Breaststroke N=6
Tlim-v$\dot{V}O_2$max (sec)	277,6±85,6	331,4±82,7
v$\dot{V}O_2$max, (m/sec)	1,29±0,0	1,10±0,1
SR (cycle/min)	36,48±1,2	29,96±2,7
SL (m/cycle)	2,14±0,1	2,23±0,2
SI [(m^2/(cycle*sec)]	2,76±0,1	2,48±0,4

To our knowledge, this is the first study in which Tlim-v$\dot{V}O_2$max was determined in simultaneous swimming techniques. Thus, we have to compare this results with the ones previously obtained for front crawl swimming. The main value of Tlim-v$\dot{V}O_2$max obtained in butterfly seems to the similar to the majority of values previously published for front crawl swimmers (2, 4, 5, 6). For breaststroke swimming, we find out that the main value of Tlim-v$\dot{V}O_2$max was higher than the one previously described for front crawl, perhaps due to the inverse relationship between Tlim-v$\dot{V}O_2$max and v$\dot{V}O_2$max, already reported by previously mentioned studies. This inverse relationship suggested that the swimmers with lower v$\dot{V}O_2$max can sustain that exercise intensity for a longer period of time. The relationships between Tlim-v$\dot{V}O_2$max and v$\dot{V}O_2$max, and between Tlim-v$\dot{V}O_2$max and the stroke parameters (SR, SL and SI) are described in table 3.

*Table 3. Relationships between Tlim- v$\dot{V}O_2$max and v$\dot{V}O_2$max, and between Tlim- v$\dot{V}O_2$max and the stroke parameters (SR, SL and SI). Significant differences are shown: * ($p \leq 0.10$) and ** ($p \leq 0.05$).*

	v$\dot{V}O_2$max	SR	SL	SI
		Butterfly (n=4)		
Tlim-v$\dot{V}O_2$max	-0,427	-0,628	0,515	0,069
		Breaststroke (n=6)		
Tlim-v$\dot{V}O_2$max	-0,497	-0,625	0,229	-0,07
		Simultaneous Techniques (n=10)		
Tlim-v$\dot{V}O_2$max	-0,482*	-0,580**	0,335	-0,158

Analysing the relationship between TLim-v$\dot{V}O_2$max and v$\dot{V}O_2$max, and between TLim-v$\dot{V}O_2$max and the different stroke parameters, it was not found any significant relationship for each technique. However, an inverse non-significant tendency was found between TLim-v$\dot{V}O_2$max and v$\dot{V}O_2$max and between TLim-v$\dot{V}O_2$max and SR in both techniques (table 3).
This fact can be explained by the low number or swimmers studied for each technique. Though, when both simultaneous techniques were pooled together, n raised, and we could observe an inverse relationship between TLim-v$\dot{V}O_2$max and v$\dot{V}O_2$max ($r=-0,482$, $p \leq 0.10$) - Figure 1 - and TLim-v$\dot{V}O_2$max and SR ($r=-0,580$, $p \leq 0.05$) - Figure 2. These relationships are similar to the ones previously obtained for front crawl.

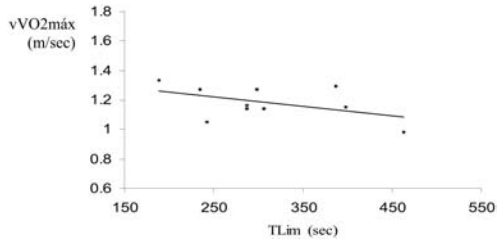

Figure 1. Inverse relationship between Tlim-v$\dot{V}O_2$max and v$\dot{V}O_2$max for both simultaneous techniques.

This inverse relationship has already been reported by some studies conducted in front crawl (2, 4, 5), and suggests that swimmers' with lower level of maximal aerobic metabolic rate present a larger capacity to sustain that exercise intensity.

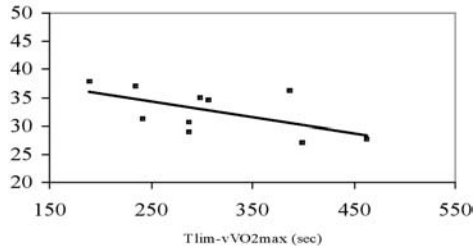

Figure 2. Inverse relationship between Tlim-v O_2max and v O_2max for both simultaneous techniques.

This inverse relationship suggests that the swimmers with lower SR are able to achieve higher TLim-v$\dot{V}O_2$max. This finding is in agreement with previous studies (6), and suggests that the most economic swimmers are the ones that can sustain for more time the exercise intensity corresponding to $\dot{V}O_2$max.

CONCLUSION

We can conclude that Tlim-$\dot{V}O_2$max value obtain for butterfly is similar to the previously reported for front crawl. For breaststroke we find a higher value for Tlim-$\dot{V}O_2$max compared to those already reported for front crawl. When we consider both simultaneous techniques pooled results, inverse relationships between Tlim-$\dot{V}O_2$max and $\dot{V}O_2$max, and between Tlim$\dot{V}O_2$max and SR were observed. These findings seem to bring new insite related to one relevant performance determinant factors in middle distance swimming.

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DIAGNOSING OF PERFORMANCE BY THE APPLICATION OF SWIMMING TESTS

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Determining the level of preparedness, as a significant factor in training, represents the feedback information about the current condition of an athlete. It plays an important role since it provides the information about the changes of the athlete's conditions caused by the training load and other factors with the objective to regulate the impact the training process on the athlete. To monitor the level of both endurance and pace, a set of swimming tests has been compiled. Some of the tests used by the Slovak Swimming Federation have been taken into consideration. The paper deals with the 3000 meters crawl results, which have been carried out on sample of 105 swimmers aged 13-16 years, and the 4 x 50 meters freestyle test realized on the sample of 53 swimmers aged 13 – 16 respectively. The average blood lactate level, when using the 3000m test, was 5,67 mmol/l for boys aged 13-14 and 4,67 mmol/l for boys aged 15-16. The blood lactate level was lower when measured for girls; 4,50 mmol/l for 13-14 years old and 3,20mmol/l for 15-16 years old, respectively. When using the 4x50m test, the values were following: boys aged 13-14 were at 0,02 mmol/l, 15-16 years old at 11,22 mmol/l, girls aged 13-14 at 10,20 mmol/l and finally, girls aged 15-16 at 10,58 mmol/l.

Key Words: swimming, diagnostics of performance, blood lactate.

INTRODUCTION

Diagnosing in sport is the process which is focused on the evaluation of the preparedness of the athletes in relation to the training load as much as other various factors, in order to control the training process (6). This process is continuous and intentional so that it the effectiveness of the training process can be improved.

Functional tests with the appropriate load are being carried out in the natural environment of the athlete. These tests are an important means of the complex diagnosis of the special preparedness and also the prerequisite of the effective management of the training process. The response of the organism to the training load thus provides the information about the athlete's preparedness. In case of the functional test the elements that are most important for the performance in a particular discipline are selected. These elements are being practiced on regular basis during the training and they are easily measurable and can be easily repeated if needed for further evaluation. The choice of the working load relatively simple when considering the cyclical sports, such as swimming, cross-country skiing, cycling, etc.

Despite the fact that at present there is no adequate structure of the swimming performance being set, it is possible to state, based on the up-to-date information, that the limiting factors are endurance and force capabilities, functional predispositions, somatic predispositions, technique factors and personal disposition (1, 2, 9).

One of the basic functional parameters for evaluation of the general aerobic endurance is the maximum oxygen consumption ($\dot{V}O_2$max). Its value reflects to a great extent the genetic predisposition and its dynamics of development is time-restricted. In recent years the monitoring of the development of the aerobic abilities by the determination of the anaerobic threshold has been becoming widely spread. Anaerobic threshold can be measured by the determination of the blood lactate level, however, it can also be monitored by the respiratory indicators' values. The indicator of the anaerobic threshold is considered to be a more sensitive indicator of the preparedness level than the $\dot{V}O_2$max (5). Most of the authors relate the anaerobic threshold to the lactate level 4mmol/l which represents so called conventional anaerobic threshold. The others relate it to the beginning of the sudden, exponential increase of lactate when it comes to the disturbance of the lactate curve – individual anaerobic threshold (10). The anaerobic threshold is an important functional indicator that reflects the changes in a particular performance better than the maximum oxygen consumption. This can be visible especially in endurance sports (3). The advantage of this indicator is the possibility of direct implementation into the control of the training process. The anaerobic threshold, as the intensity of the working load at which the dynamic balance between the production and removal of the lactate from blood is kept, appears to be a suitable criterion when selecting the intensity of the working loads aimed at the development of the aerobic endurance. It is actually the working load at the anaerobic level is considered (3) to be a suitable training means for development of the endurance abilities.

Anaerobic endurance activates the lactate system, involving mostly the fast glycolytic muscle fibers and to a lesser extent

fast oxidative muscle fibers. The intensity above the $\dot{V}O_2max$ level puts higher demands on the anaerobic processes, where they reach the threshold values of the acidosis at the lactate level 20-25 mmol/l. The athletes with highly developed anaerobic abilities have usually only average, even below-average aerobic abilities, and vice versa. The development of the anaerobic abilities has a blunting effect on the development of the aerobic ones and vice versa. The objective of the study is the verification of the performance diagnosis through the means of selected swimming tests used by the Slovak Swimming Federation.

METHODS

In co-operation with the National sport center, Slovak swimming federation and selected swimming clubs in Trnava, Trencín and Bratislava the testing of 61 swimmers aged 13-14 years (34 boys and 28 girls) and 44 swimmers aged 15-16 years (27 boys and 16 girls) took place during March and April, using the 3000m test. This test has been adopted by Olbrecht et al. (8) from the Institute of the Sport Medicine in Cologne, Germany. The date of the testing had been deliberately introduced at the end of the special training period in the summer macro-cycle of the training cycle of 2004/05 (January – July 2005). The capillary artery blood samples took place after the 3rd and 10th working load.

The testing of 33 swimmers aged 13-14 years (17 boys and 16 girls) and 20 swimmers aged 15-16 years (13 boys and 7 girls) took place in June 2005, using the 4x50 meters freestyle test. The date of the testing had been deliberately introduced during the main period of the summer macro-cycle 2005. The capillary artery blood samples took place after the 3rd and 5th working load. The following are the parameters observed and monitored during the research: blood lactate level, quiet-mode PF between input and output training load. The blood lactate level has been monitored and determined with the aid of Biosen 5130 apparatus. This device enables to take blood samples with constant capacity of 20 μl of capillary blood and allows for divergence of < 3% at 12mmol/l. The capillary blood sampling has been conducted with the assistance of the Accusport blood sampling set, using entirely standard procedure. PF has been measured with the Polar S 610i sport testers with the 5s interval of records.

RESULTS AND DISCUSSION

The lactate values provide the information about the activation and proportional distribution of both anaerobic and aerobic mode, and the information about their performance in combination with the swimming speed. Measuring of the blood lactate then enables the high-probability determination of the real working load. The lactate is one of the best reflection of the training intensity. In order that the lactate test is reliable it is important to take the capillary artery blood sample from an ear-lobe or a finger and find the highest concentration of the lactate, i.e. to record the highest after-working-load values, for instance of 1st, 3rd and 5th minute after the load has been carried out. The values gathered in this manner provide the information about the lactate production in muscles. Chart 1 provides the information gained from the 3000m freestyle test. The results have been categorized according to the age groups, which had been observed.

Table 1. Basic statistic characteristics of the 3000m test results.

	Men		Women	
T3000	13-14y. (n=34)	15-16y. (n=28)	13-14y. (n=27)	15-16y. (n=16)
Test results (min.)	38:25-58:30	38:40-51:15	41:40-56:21	38:25-49:33
Swimming speed ($m.s^{-1}$)	0.855-1,284	0.976-1.402	0.890-1.200	1.010-1.302
Blood lactate level (mmol/l)	1.87-8.42	2.06-6.96	2.00-6.21	2.14-5.08
Average blood lactate level (mmol/l)	5.67	4.67	4.50	3.20
Standard deviation (s)	5.24	3.83	2.66	1.75

The results signify that some boys aged 13/14 years are capable of achieving the values high above the conventional anaerobic threshold, which is being set at 4 mmol/l. The findings of the Olbrecht research (8) are being confirmed, where the anaerobic threshold had oscillated at 1-6 mmol/l.

The relatively high blood lactate values can be explained in a number of ways. Stemming from the fact that it is very difficult to measure the heart beat frequency by means of the sport testers, especially with boys, it is therefore a problematic task to maintain the similar tempo throughout the 3000m. The findings of the raised lactate levels in this test can thus be greatly determined by the disturbance of the tempo and possible speeding up, especially in the final phase. Another interpretation of these values could be the anaerobic threshold's determination not only by the preparedness and nature of the working load, but also by age and sex (5). Children's anaerobic threshold is higher that that of the adults. The reason for this is the shorter time of the oxygen's 'reception' and consumption. The low blood lactate levels after the swim can be results of the low motivation in case of the low average swimming speed, or by the higher aerobic capacity level at higher speeds, when the shift of the anaerobic threshold towards the lower blood lactate values takes place. Hamar et al. (4) determined the level of anaerobic threshold when constantly swimming at the threshold speed 1.364 $m.s^{-1}$.

The blood lactate values, observed in the group of swimmers in the midst of specialized phase of the training process, were taken after the 3000m freestyle test and are extensively variable. Due to the high values of the directive deviation the statistical processing of the date will be much more complicated in the further phase of the research.

The input measuring of the blood lactate level suggests that 4x50m test freestyle is the real reflection of the mixed anaerobic-aerobic working load series, and which ability to tolerate the lactate is probably reflected in the anaerobic capacity of the swimmer.

Table 2: Basic statistic characteristics of the 4x50m test results.

	Men		Women	
T 4x50 meters	13-14y. (n=17)	15-16y. (n=16)	13-14y. (n=13)	15-16y. (n=7)
Test result (min.)	2:03 - 2:27	1:55 - 2:17	2:09 - 2:48	2:19 - 2:33
Swimming speed ($m.s^{-1}$)	1.625-1.353	1.739-1.450	1.546-1.186	1.435-1.300
Blood lactate level (mmol/l)	6.58 – 13.38	7.91 – 14.60	5.00 – 15.84	7.40 – 12.47
Average blood lactate level (mmol/l)	10.02	11.22	10.20	10.58
Standard deviation (s)	2.02	1.90	2.77	1.72

The findings suggest that in order to further process data gathered by the test these have to be differentiated in the following pattern. Either they have to be divided into 2 groups, one being crawl, back-stroke and butterfly, and the other one being breast-stroke, or maybe it will be even necessary to divide the results into 4 different groups, where every group will represent a single swimming stroke. Even divide the results 4 groups. Therefore we do not list the breaststroke results in the table 2, since they significantly misinterpreted the overall results. From the relative homogeneity point of view the 4x50m test results came out much better than the 3000m test.

CONCLUSION

Based on the results of the applied 3000m test with men and women for particular age groups during the specialized phase of the training process it is possible to assume that these provide a relatively precise estimate of the swimmer's tempo at the anaerobic threshold level. These results have been achieved on the basis of the appropriate proportion between the length and intensity of the working load. The swimmers are with great probability not able to swim, at this volume of the working load, at the intensity which would disturb the balance between the lactic acid production and its disposal from muscles. This test proves to be the appropriate method for the evaluation of aerobic capacity of both senior and junior swimmers. The succeeding research will need to implement the pulse frequency in order to control and sustain the steady tempo throughout the test, even though it is much more complicated in swimming at present.
Based on the findings from the 4x50m freestyle test it is possible to maintain that it likely reflects the anaerobic lactate system level. However, the values of the blood lactate recorded by us were not getting close to the threshold values of 20-25 mmol/l. The findings point out the necessary differentiation of the recorded values according to a particular swimming style.

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DOES THE LONG-TERM ORAL CREATINE SUPPLEMENTATION IMPROVE REPEATED SPRINT PERFORMANCE IN ELITE SWIMMERS?

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This study investigated the effects of high-dose/long-term oral creatine supplementation on repeated sprint swimming performance in elite male swimmers. Twelve subjects, all swimmers, were separated randomly into creatine group (n = 6) and placebo group (n = 6). Swimmers of the creatine group were supplemented creatine (12 g/day) during 8 weeks. Supplementation was performed using double-blind method. Before and at the end of supplementation, ^{31}P-NMR spectroscopy of the triceps muscle of the arm, blood analysis, and intermittent repeated sprint swimming tests were conducted. Eight-week creatine supplementation tended to increase the muscle PCr content (p = 0.055). However, no significant improvement was shown for repeated sprint swimming performance. These results suggest that high-dose/long-term creatine supplementation increased muscle PCr content with no disadvantage to physiological functions in elite male swimmers. However, it was difficult to prove an ergogenic effect on repeated sprint performance in elite male swimmers.

Key Words: creatine, long-term, sprint performance.

INTRODUCTION

It has been reported that the intramuscular phosphocreatine (PCr) and serum creatine contents were increased through creatine supplementation (6). It is generally acknowledged that these increments engender delayed PCr depletion and enhance dependence upon the ATP-PCr energy system during exercise. In addition, creatine supplementation might improve the ability of buffering lactate because the ATP-PCr energy system uses the generated proton (H^+) (7). Consequently, performance during high-intensity intermittent exercise and short duration single performance might be improved through creatine supplementation (1, 2, 3, 5, 6, 8, 12).
Numerous studies have demonstrated the ergogenic effect of creatine. Most of those studies adopted high-intensity intermittent exercise method (1, 2, 3, 5, 6, 8, 12). They have reported that creatine supplementation can inhibit the reduction of power and performance at the latter set/event of prescribed trial. In contrast, studies that have not reported the ergogenic effect of creatine evaluated single-exercise performance (4, 9, 13).
A few studies have investigated the effect of creatine supplementation in swimmers. Mujika et al. (9) and Burke et al. (4) reported that short-term creatine supplementation (20 g/day, 5 days) did not improve single swimming performance (25 m, 50 m, 100 m). Thompson et al. (13) also reported that long term creatine supplementation (2 g/day, 6 weeks) did not improve single swimming performance (100 m, 400 m). In contrast, Grindstaff et al. (5) reported that intermittent performances (swimming and cycling) were improved after creatine supplementation (21 g/day, 9 days). Although many studies have described the ergogenic effect of creatine supplementation on intermittent swimming performance, Nagasawa et al. (10) reported that short-term creatine supplementation (24 g/day, 6

days) did not improve intermittent swimming performance in females. In light of all of those disparate findings, the ergogenic effects of creatine supplementation are controversial irrespective of exercise method in swimming.
This study investigated the effects of long-term oral creatine supplementation on repeated sprint performance using a swimming flume that can be used to control the intensity and duration of trial.

METHODS

Subjects

Twelve highly trained male swimmers participated in this study. They were separated randomly into a creatine group (Cre: n = 6, age = 20.0 ± 0.9 years, height = 177.8 ± 1.7 cm, weight = 71.6 ± 3.9 kg) and a placebo group (Pla: n = 6, age = 20.5 ± 1.1 years, height = 177.8 ± 2.0 cm, weight = 71.4 ± 4.9 kg). They were informed of the purpose and potential risks of participating. No swimmers had ingested creatine during the month preceding supplementation.

Supplementation

A double-blind study was performed. The creatine group ingested four doses of 3 g of creatine (total 12 g) per day for 8 weeks, whereas the placebo group ingested the same dosage of a glucose placebo.

Determination of muscle PCr

Measurements taken using ^{31}P-nuclear magnetic resonance (NMR) from the triceps muscle of the arm at rest were conducted using MR apparatus (Gyroscan ACS-NT; Philips Co.). The arm was positioned with a magnet over a 10 cm diameter surface coil. The coil was turned to either the proton or the phosphorus frequency: ^{31}P-NMR signals were acquired at 1500 Hz with a repetition period of 3000 ms. Acquired spectrum data were analysed using spectral-analysis software "NHI image version 1.62" (National Institutes of Health, USA), which integrated the PCr, Pi and ATP spectral peaks. The muscle PCr contents were represented as a ratio to the integration value of ATP spectrum because muscle ATP content is putatively constant.

Performance test

Repeated swimming trials using the swimming flume were conducted before and after the supplementation period. Performance tests consisted of 30 s sprint swimming and a 30 s rest. The swimming velocity was set at 85% of each subject's 100-m-best record. Subjects continued repeated swimming trials to exhaustion: the point at which subjects became unable to maintain the velocity. Executed sets were evaluated as repeated swimming performance. Blood from the fingertip was taken 1 min and 3 min after the trial and the blood lactate was determined. The heart rate and RPE were also measured immediately after the trials.

Blood analysis

Blood samples were drawn from the antecubital vein at rest on the mornings before and after the supplementation period. Subjects were instructed to ingest nothing except water for 8 h. Collected samples were centrifuged and analyzed in the laboratory.

Statistical analysis

Results are represented as means (± SD). Data before and after the supplementation period were compared using Student's t-test for dependent samples. Statistical significance was accepted at the 0.05 level ($p<0.05$).

RESULTS

Exercise Performance

Repeated swimming performance did not improve in either group (executed sets of Cre: pre 2.95 ± 1.21, post 2.89 ± 1.02, Pla: pre 4.59 ± 3.71, post 4.33 ± 1.60, Fig. 1). Blood lactate, heart rate and RPE after the post-trial did not change from pre-trial levels in either group (Blood lactate after 1 min Cre: pre 13.2 ± 1.2 mmol/l, post 12.5 ± 0.6 mmol/l, Pla: 13.2 ± 2.3 mmol/l, post 13.8 ± 1.6 mmol/l, 5 min Cre: pre 14.0 ± 1.3, post 14.0 ± 1.9 mmol/l, Pla: pre 13.3 ± 2.5 mmol/l, post 14.0 ± 1.9 mmol/l, Heart rate Cre: pre 174.5 ± 2.5 bpm, post 174.3 ± 4.1 bpm, Pla: pre 174.2 ± 6.9 bpm, post 174.0 ± 6.0 bpm, RPE Cre: pre 18.00 ± 1.55, 17.67 ± 1.21, Pla: pre 16.50 ± 1.38, 16.67 ± 1.03, Table 1).

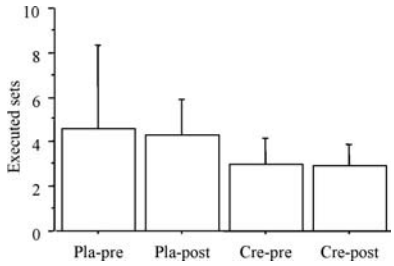

Figure 1. Repeated swimming performance using the swimming flume before and after the supplementation period.

Table 1. Heart Rate, Bla and RPE after repeated swimming trials before and after the supplementation period

		Pla-pre		Pla-post		Cre-pre		Cre-post	
		mean	±SD	mean	±SD	mean	±SD	mean	±SD
HR	bpm	174.2	6.9	174.0	6.0	174.5	2.5	174.3	4.1
Bla(1min)	mmol/l	13.1	2.2	13.8	1.6	13.2	1.2	12.5	0.6
Bla(5min)	mmol/l	13.3	2.7	14.0	1.9	14.0	1.3	13.4	0.5
RPE		16.5	1.4	16.7	1.0	18.0	1.6	17.7	1.2

Physiological index

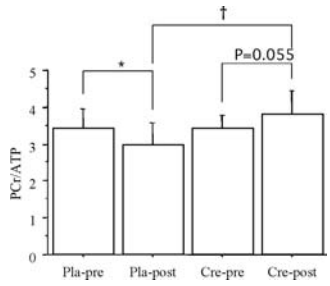

*Figure 2. The PCr/ATP ratio-determined spectra before and after the supplementation period. Significant differences between before and after supplementation period (*p<0.05). Significant differences between Cre and Pla (†p<0.05).*

PCr content in triceps muscle tended to be increased by high-dose (12 g/day) and long-term (8 weeks) creatine supplementation (pre 3.42 ± 0.37, post 3.38 ± 0.61, $p = 0.055$, Fig. 2). Contrarily, PCr content of Pla decreased significantly (pre 3.44 ± 0.53, post 3.00 ± 0.57, $p < 0.05$). The serum creatine concentration, GPT and LDH in Cre increased significantly after the supplementation period (Serum creatine: pre 1.00 ± 0.11 mg/dl, post 1.55 ± 0.44 mg/dl, GPT: pre 11.00 ± 3.03 IU/L, post 22.50 ± 4.81 IU/L, LDH: pre 327.2 ± 46.8 IU/L, post 430.2 ± 65.1 IU/L, $p < 0.05$, Table 2). The serum creatine concentration was greater than the normal range, but the GPT and LDH concentrations were in the normal range. The serum creatine concentration in Pla decreased after the supplementation period but the concentration did not change significantly (pre 1.02 ± 0.13 mg/dl, post 0.70 ± 0.35 mg/dl, $p > 0.05$). The groups showed no significant difference of the change of body composition during the supplementation period.

Table 2. Blood analysis data before and after the supplementation period.

			Pla-pre		Pla-post		Cre-pre		Cre-post	
		normal range	mean	±SD	mean	±SD	mean	±SD	mean	±SD
GOT	IU/L	11-35	19.8	5.7	22.2	1.2	20.2	4.3	25.8 †	1.6
GPT	IU/L	6-39	12.3	5.2	15.0	7.7	11.0	3.0	22.5 *	4.8
LDH	IU/L	180-460	285.8	56.8	337.2	23.7	327.2	46.8	430.2 *†	65.1
CPK	IU/L	48-259	173.3	119.3	154.8	58.3	162.5	90.6	201.2	40.6
creatine	mg/dl	0.1-1.2	1.02	0.13	0.70	0.35	1.00	0.11	1.55 *†	0.43
creatinine	mg/dl	0.8-1.3	0.98	0.18	1.03	0.16	1.05	0.14	1.12	0.12

*Significant difference between before and after supplementation (P<0.05)
†Significant difference between Cre and Pla (P<0.05)

DISCUSSION

Many studies have investigated the ergogenic effect of creatine supplementation for athletes (1, 2, 3, 5, 6, 8, 13). It has been established clearly that high-dose oral creatine supplementation might elevate muscle creatine and PCr content (8). Furthermore, creatine supplementation might improve performance during high-intensity intermittent exercise (1, 2, 3, 5, 6, 8, 12), but not single events (4, 9, 13). The present study showed that high-dose (12 g/day) and long-term (8 weeks) creatine supplementation tended to elevate the muscle PCr contents ($p = 0.055$). This result is supported according to the increment of serum creatine concentrations in Cre. Nevertheless, performance during high-intensity repeated swimming using swimming flume was not improved in elite male swimmers. Exercise intensities were comparable in all trials because the heart rate and RPE after the post-test were not changed in comparison to pre-tests in both groups. The blood lactate after the repeated swimming test in Cre tended to be reduced by creatine supplementation ($p > 0.05$, not significant). Balsom et al. (1, 2) reported that high-dose (20–25 g/day) creatine supplementation can reduce the blood lactate concentration after high-intensity intermittent cycling tests. They suggested that creatine supplementation elevates the contribution of ATP-PCr energy system during high-intensity exercise. The present study showed that the contribution of the ATP-PCr energy system during repeated swimming test was likely to have been elevated by the increment of muscle PCr content. Blood lactate levels at post-testing in Pla tended to be higher than those of pre-testing ($p > 0.05$, not significant). Grindstaff et al. (5) and Theodorou et al. (12) reported that creatine supplementation improves intermittent swimming performance. They set the exercise intensity as the maximal effort. The present study adopted 85% velocity of subjects' respective best records in 100 m events as the exercise intensity. This intensity was determined so as to execute at least two sets in trials. Consequently, subjects might not need a maximal effort to swim at velocity, especially early sets of trials. Reportedly, urinary creatine and serum creatinine concentration (11), GOT, GPT and LDH activity (8) were elevated by high-dose creatine supplementation. In the present study, the serum creatine concentration, GPT and LDH activity were elevated through high-dose (12 g/day) creatine supplementation. However, it seems unlikely that creatine supplementation would be harmful to renal and hepatic functions in male swimmers because those values after the supplementation period were in the normal range.

CONCLUSION

Long-term creatine supplementation increased muscle PCr content without harm to health in elite male swimmers, but it did not improve their repeated swimming performance. The contribution of the ATP-PCr energy system during repeated swimming in this study might have been elevated by creatine supplementation as it was in previous studies. However, it is difficult to prove that creatine supplementation affected high-intensity swimming performance.

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EVIDENCE OF INSUFFICIENT PULMONARY VENTILATION DURING CRAWL SWIMMING WITH MAXIMAL AND SUPRAMAXIMAL INTENSITIES

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The aim of the study was to establish whether limited pulmonary ventilation due to biomechanical characteristics of front crawl swimming causes insufficient elimination of CO_2 from the lungs during breathing, which induce hypercapnia. Twelve male swimmers performed 4 swims on 200 m crawl at intensities from 80%, 90%, 100% to 110% on separate days with a swimming snorkel. Respiratory parameters (V_E, Vco_2, Vo_2) and some parameters in the blood ([LA^-], Pco_2, Po_2) were measured. From results we were able to demonstrate that limited V_E during exercise in swimming occur and that is a possible influence on increased acidosis during maximal and supramaximal swimming. We found notable excess Vco_2 after exercise at these intensities. We can also not conclude that hypercapnia was caused because values of Pco_2 were similar to those during rest; however, it has to be considered that these values were obtained with significantly increased V_E.

Key Words: swimming, front crawl, ventilation, pH, hypercapnia.

INTRODUCTION

Respiration during front crawl swimming is limited with swimming technique and the duration of the inspiratory phase is reduced. A previous study (2) found no indication of hypoventilation during swimming, however only saturation of blood with oxygen was measured. In the same study maximal pulmonary ventilation during swimming was significantly lower than during running by elite swimmers. A study with controlled frequency breathing from 2 to 8 strokes during swimming (5) found increased $PaCO_2$ in swimming with progressively reduced breathing frequency. In the same study it was also found that stroke rate increases proportionately with breathing restriction. A similar study (1) found that carbon dioxide production, respiratory exchange ratio, and heart frequency did not change significantly in response to controlled frequency breathing (CFB) swimming. Estimated alveolar partial pressure of O_2 (PaO_2) decreased and $PaCO_2$ increased significantly during CFB. However, estimated saturation of arterial blood with O_2 (SaO_2) was essentially undiminished during CFB. These responses do not indicate hypoxia, but rather hypercapnia during CFB. The aim of the research was to establish whether limited pulmonary ventilation due to biomechanical characteristics of front crawl swimming with different intensities causes insufficient elimination of CO_2 from the lungs during breathing, which induce hypercapnia.

METHODS

Twelve male swimmers aged 24 ± 3 yrs, of a height of 181 ± 9 cm and mass of 77 ± 13 kg volunteered to participate in this study. All subjects had a minimum of eight years competition swimming experience and considered front crawl their best stroke. The subjects were informed of the risks involved in the experiment before they agreed to participate.
All swims were performed using the front crawl stroke in a 25 m indoor swimming pool. The temperature of the water was 27∞ C. Each swimmer performed 4 swims on 200 m crawl at intensities from 80%, 90%, 100% to 110% on separate days with a swimming snorkel (4). First, swimmers performed maximal 200 m front crawl swim. Thereafter, swimmers performed submaximal swims with 80% and 90% of maximal 200 m front crawl swim velocity. Finally, swimmers performed a supramaximal swim with 110 % velocity until exhaustion. A light leader was used to keep even pace during swimming with submaximal and supramaximal intensities.
Arterialised blood samples (20 µl) were collected from the earlobe after a warm up and in 1, 3 and 5 minute of recovery after swimming and analysed for blood lactate concentration ([LA^-]) using a Kodak Ektachrome analyser. At the same time, arterialised blood samples (60 - 80 µl) were collected and analysed for PCO_2 and PO_2 with an ABL5 analyser (Radiometer Copenhagen). Calibration of the equipment was performed before each measurement.
Ventilation (V_E), O_2 uptake (VO_2) and CO_2 output (VCO_2) were measured using a portable respiratory gas analyzer METAMAX 2 (Cortex, Germany). Average data for 10-s period were recorded with a swimming snorkel (4) after warm up, during swimming and 5 minute after the end of each swim. The flow meter was calibrated with a syringe of known volume (3.0 l). The gas analyzer was calibrated by known standard gases. Excess CO_2 output per unit time (Vco_2 excess) was calculated by subtracting the VO_2 values from the Vco_2 values. The Vco_2 excess was integrated from the start of exercise to the end of exercise, and from the end of exercise to 5 min postexercise. The sum of Vco_2 excess from the start of the exercise to the 5 min of postexercise was defined as the total excess CO_2 output (CO_2 excess).
Means and standard deviations were computed for all variables. Individual one-way repeated measures ANOVAs were employed to test for any significant differences between the measured parameters. Significance was accepted when $p<0.05$. Bonfferonies post-hoc tests were performed if significant differences were apparent.

RESULTS

The average velocity of maximal swimming was 156.2 ± 13.1 s. Swimmers were able to swimm with 110 % intensity 113.8±17 meters or on average for 81.3 ± 12.7 seconds.

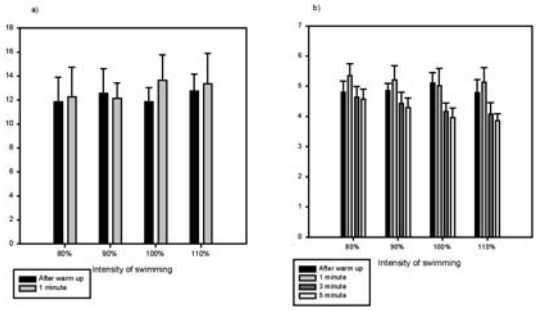

Figure 1a,b. Po_2 (a) and Pco2 values after warm up and in the 1st minute after swimming with different intesities (for Pco_2 also values in the 3rd and 5th minute are shown (b). Values are means±SD.

There were no differences between the values of Po_2 and Pco_2 measured when resting after warm up and those measured during the 1st minute after exercise.
In the 3. minute after exercise there were no differences between the values at 80 % (4.6 kPa ± 0.4) and 90 % intensity of swimming (4.5 kPa ± 0.4) for Pco_2. At 100 % intensity of swimming there was signifficant decrease of Pco_2 (3.9 kPa ± 0.7) ($p<0.05$). Similar tendencies were found also at 5th minute after exercise (fig. 1b).

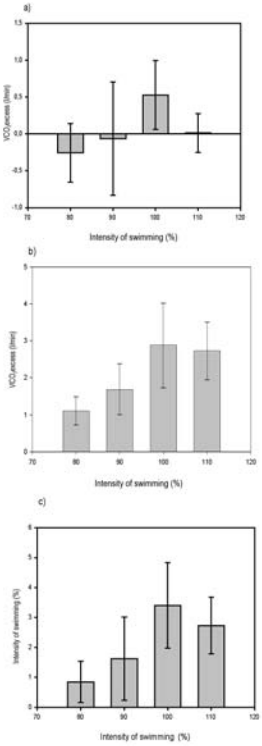

Figure 2a-c. Vco_2 excess during swimming (a), after swimming (b) and total Vco_2 excess (c).

There was a tendency to increase of excess Vco_2 during swimming from 90% (-0.09±0.7 l) to 100% (0.53±0.47 l) and then again decrease during swimming at 110 % intensity (Fig. 2 a). Excess Vco_2 after exercise increased most notably from 90% (1.69±0.7 l) to 100% (2.72±0.7 l) ($p<0.01$) intensity; at 110% intensity it was similar to 100% intensity (Fig. 2 b). Total excess Vco_2 showed tendency to increase from 90% (1.62±1.39 l/min) to 100% (3.41±1.42 l/min) intensity ($p<0.05$); at 110 % intensity it was similar to 100 % intensity (Fig. 2 c).

Table 1. Comparision of average maximal measured values of V_E, VCO_2 and VO_2 during swimming with different intensities (± SD).

	80 % intensity	90 % intensity	100 % intensity	110 % intensity
V_E	78.2±13.5 lxmin^{-1}	91.4±13.6 lxmin^{-1}	117.4±18.0 lxmin^{-1}	108.7±17.2 lxmin^{-1}
Vo_2	3.09±0.51 lxmin^{-1}	3.44±0.49 lxmin^{-1}	3.81±0.51 lxmin^{-1}	3.70±0.51 lxmin^{-1}
Vco_2	3.17±0.43 lxmin^{-1}	3.59±0.64 lxmin^{-1}	4.44±0.59 lxmin^{-1}	4.21±0.62 lxmin^{-1}

Maximal V_E increased at intensities ranging from 80% (78.2±13.5 l/min) to 100% (117.4±18 l/min) ($p<0.05$), but at 110% intensity it was similar to the values at 100% intensity. Something similar happened with Vo_2 (80% = 2.65±0.5 l/min, 100% = 2.76±0.6 l/min) ($p<0.05$) and Vco_2 (80% = 3.17±0.4 l/min, 100% = 4.44±0.6 l/min) ($p<0.05$).

Table 2. Comparision of average maximal obtained values of [LA$^-$] during swimming with different intensities (± SD).

	80 % intensity		90 % intensity		100 % intensity		110 % intensity	
	1. min	Max	1. min	Max	1. min	Max	1. min	Max
[LA$^-$]	5.7±1.1	6.1±1.5	7.4±1.0	7.8±1.4	12.7±2.4	14.2±2.5	9.9±1.5	12.0±1.9

The most notable change of [LA$^-$] in the 1st minute after exercise and also for the maximal measured values was from 90 % to 100 % intensity ($p<0.001$) (Table 2.). Between 100% and 110% intensity there were no changes.

DISCUSSION

In our research we were not able to demonstrate that limited V_E during exercise in swimming is a limiting factor to performance; however, we were able to demonstrate that it does occur and that limited V_E is a possible influence to increased acidosis during maximal and supramaximal swimming because of insufficient elimination of CO_2 from the body. Metabolic CO_2 dissolved in the body fluids forms carbonic acid, which than dissociates H^+ ($CO_2 <=> H_2O <=> H_2CO_3 <=> H^+ + HCO_3$). Because V_E affects H^+ concentration (or pH), V_E affects acid-base balance. We found notable excess Vco_2 after exercise at these intensities (100% and 110%), which was much more pronounced than during swimming (Figure 2. b). In heavy exercise, it is known that the concentration of HCO_3 changes in reciprocal fashion to that of [LA$^-$] in arterial blood, and that $PaCO_2$ first increases and then decreases to below the resting level (6). In supramaximum exercise, it has been observed that CO_2 is not completely excessively expired during exercise but after the end of exercise, although lactic acid begins to be produced from the start of exercise (6). Results of our study suggests that Vco_2 excess after the exercise was much more increased after maximal and supramaximal swimming in comparison to the Vco_2 excess during swimming and was not only [LA$^-$] dependent (Fig. 2 a, b and Table 2.), but probably occurred also because of

limited V_E. We can neither conclude that during swimming hypercapnia was caused because values of Pco_2 were similar to those during rest; however it has to be considered that these values were obtained with significantly increased V_E. Our results seem to be in accordance with the results of previous studies (2, 5). However, in this interpretation it should be considered that because of the protocol of collecting samples from the earlobe, approximately 30 seconds were needed and in that time according to measured V_E during maximal and supramaximal swimming on average about 60 l of the air was exchanged in the lungs. This could influence obtained results of Pco_2 and Po_2. It should also be considered that in the study where swimmers performed 200 m freestyle at maximum effort and haemoglobin saturation was measured using a finger pulse oximeter swimmers developed exercise induced arterial hypoxemia (3). Controlled respiratory parameters during exercise when swimming with swimming snorkel (V_E, Vco_2, Vo_2) increased with the swimming intensity from 80 % to 100 % intensity; however, during 110 % intensity, the swimmers were no longer able to sustain the previously defined swimming velocity at the moment the mentioned respiratory parameters reached almost similar values to the ones at 100 % intensity (table 1.). It is thus evident that limited pulmonary ventilation due to biomechanical characteristics of front crawl is probably the factor which mostly limits the observed parameters (V_E, Vco_2, Vo_2), and therefore the limits of values are probably not absolute but specific for each individual swimmer.

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KINETIC RESPONSE OF SALIVARY IGA TO SEVERAL EXERCISE PROTOCOLS PERFORMED BY WELL TRAINED SWIMMERS

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The relationship between training load and the mucosal immune responses has been a recent focus of research. Intense training and the psychological stress associated with competition seems to lower the salivary IgA (sIgA) levels in athletes. Salivary IgA antibodies provide protection against infections and play a significant anti viral role at the mucosal surface. Salivary IgA deficient persons are susceptible to recurrent infections, mostly of the upper respiratory and gastrointestinal tracts. The purpose of this study was to monitor the salivary IgA response to different aerobic and anaerobic land tasks and two aerobic swimming protocols, using several time points in order to study the time effects of the exercise loads in the mucosal immunity of the athletes.

Key Words: mucosal immunity, salivary IgA, training load, swimmers.

INTRODUCTION

The influence of training load on the immunity status has been the subject of extensive research in different environments of sporting participation (2, 3, 4, 5). Due to less invasive methodology, one of the most commonly immunity marker used in this kind of research is the salivary IgA (sIgA). Several studies reported immune suppression with low values of sIgA associated with intense training, contrasting with the reinforcement of sIgA levels associated with moderate exercise (3, 4, 5). Different loads induce specific physiological adaptations. It was hypothesized that the immune response behaves differently adjusting to specific training loads. The purpose of this study was to monitor the salivary IgA response as an immunological marker, using several time points after different tasks and at rest to follow the influence of the training load on this parameter. Two swimming aerobic protocols of identical intensity and volume but with different procedures, namely continuous and intermittent loads, one running test aiming to estimate the $\dot{V}O_2$max and the Wingate anaerobic test were selected.

METHODS

Twelve male swimmers of Portuguese national level (17 ± 0.9 years old, height 177 ± 7 cm, weight 66.5 ± 7.2 kg, 7.3 ± 0.9 years of training), participated in this study. The subjects were informed about the implications of the study and gave their consent. During 10 days they accomplished four different protocols : two swim aerobic tasks – a 20min continuous swim and an intermittent 5 x 400 m with 45 s rest swim and two land protocols - the Luc Léger running test aiming to estimate the VO_2 max, and the Wingate Anaerobic Test (WanT) used to determine the maximal anaerobic power. Swimming, Wingate and Luc-Léger exercices were preceded by a normalized warm-up. The schedule used on this study alternated land and water protocols, with at least 48 hours between testing sessions. All sessions took place at the same hour of the day (7.00 pm). During the study, athletes underwent a normal training schedule corresponding to a stabilizing workload period. Each testing session was preceded by at least 12 hours of rest.

1ª protocol	→	2ª protocol	→	3ª protocol	→	4ª protocol
5 x 400L	48 h	Wingate aanaerobic test	48h	T20	48h	Luc-Léger aerobic test

Figure 1. Study schedule.

Capillary blood samples were taken after exercise to evaluate the lactate (La) concentration. Heart Rate (HR) and perception of effort (Cr10) (2) were also controlled at each protocol. Saliva samples were colleted for determination of IgA concentration, flow rate and IgA secretion rate. The collecting time points were: immediately before de exercise; 15 min, 1.5 hours and 2.5 hours after; in the next morning at wakeup and 24 hours after the test. Obeying to the same timetable on the nearest weekend free from either training workouts or competitions, saliva samples were collected, aiming to get the sIgA response on a recovery day with the purpose to control for possible circadian effects. Saliva collection was done using salivette tubes (Sarstedt, Portugal). Salivary IgA levels were determined by nephlometry (BN2 Analyzer, Dade Behring, USA). To determine the IgA secretion rate (srIgA), the subjects were told to chew on the cotton swab for 2 min. The volume of saliva collected was measured and the secretion rate calculated according to the following equation: *IgA sr=([IgA]*Vsal)/ t*, were Vsal (µl) is the volume de saliva collected, and *t* is the time of collection (s) (1). To compare the behaviour of sIgA and srIgA between moments and protocols, the non-parametric Wilcoxon test was used, with a confidence level of 95%. This statistical option avoids the errors associated with the small dimension of the sample and prevents the absence of a normal distribution of some of the variables.

1º time point	2º time point	3º time point	4º time point	5º time point	6º time point
Before test	15 min after	1.5 h after	2.5 h after after	**Next** morning Wake up	24 h after

Figure 2. Time points of saliva sample collection.

RESULTS AND DISCUSSION

As expected, significant higher values of HR, [La] and perception of effort (Cr10) were found on the Luc Léger test when compared to all the other protocols. The same parameters were higher in the Wingate Anaerobic Test compared to the swimming tasks. Between these last two situations, there were no significant differences, however, the intermittent protocol showed slightly higher levels of these markers (Table1). The intensity used at the two swimming situations was respectively 71.0 % ± 2.3 for T20, and 74.2 % ± 3.1 for the5x400m, of the maximal velocity obtained on a maximal test of 15 m (v15).

Table 1. Mean and Standard Deviation (SD) for the perception of effort (Cr.10 Borg), Lactate (La) heart rate (HR), predicted $\dot{V}O_2max$ from the Luc Léger test, peak power of the Wingate Anaerobic test, intermittent aerobic task (Int Aer. Task), percentage of maximal swimming velocity used on swimming protocols, and T20".

	Luc Léger		Wingate		Int Aer. task		T 20	
	Mean	SD	Mean	SD	Mean	SD	Mean	SD
Cr10	8	1.3	6.6	1.1	4.4	1.8	3.5	0.7
La	13.6	4.0	10.0	2.0	3.6	1.5	2.9	0.6
HR	197	7	165	10	161	9	157	11
$\dot{V}O_2max$ ($ml.kg.m^{-1}$)	52.3	2.8						
Peak Power (W)			656	97				
% max. Velocity ($m.s^{-1}$)					75.0	2.3	74.2	3.1

The sIgA concentration values (table 2) show identical patterns at different experimental conditions. With the Wingate Anaerobic test and the two swimming aerobic protocols the sIgA concentration showed a significant increase ($p<0.05$) (6) after testing followed by a decrease 1.5h and 2.5h after the test. This decrease was significant ($p<0.05$) in the response to the intermittent aerobic swim protocol. In the land tasks this decrease was significant 2.5h after ($p<0.05$). Next morning fasting saliva showed significantly ($p<0.01$) higher values of sIgA. 24h after testing, sIgA levels had recovered to the initial values in all situations ($p<0.01$).
With the Luc Léger test, sIgA, showed an initial decrease after test which was significant ($p<0.05$) for the srIgA values, followed by an elevation 1.5h after and again a significant ($p<0.05$) decrease 2.5h after. The morning and the 24h after values followed the same pattern of the other situations (1, 7). At rest situation, an identical behavior for the sIgA values was found but with less diurnal variation. The only significant alteration of sIgA and srIgA values on the resting day was found in the morning with a slight elevation. These results agree with the idea of exercise influencing the sIgA behavior.

Table 2. Mean and Standard Deviation (SD) of salivary IgA concentration ($mg.dl^{-1}$) for all the time points (TP) selected of the different protocols and at rest situation.

	TP 1		TP 2		TP 3		TP 4		TP5		TP 6	
	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD
T20 Swim	5.45	2.92	7.55	4.12	3.63	2.25	4.03	1.77	23.7	25.4	3.94	1.30
Aer Int Swim	6.41	4.84	8.37	6.03	4.73	3.58	5.85	4.65	27.5	24.2	8.13	6.72
L.Leger	8.15	5.76	5.60	3.31	7.19	4.39	3.53	1.59	18.1	10.7	7.59	4.04
WanT	5.40	4.11	8.60	6.19	3.90	2.44	2.35	0.81	32.2	46.1	5.30	5.16
Rest	7.10	7.37	7.23	5.80	5.27	4.45	10.1	8.6	12.2	14.2	6.2	3.1

When the salivary IgA response between protocols was compared, a statistical significant difference was found between time points 1 and 4, respectively before and 2.5h after in all the tasks. In the Luc Léger test, the sIgA concentration 1.5h after (3º time point) showed higher values when compared to the swimming protocols and the Wingate test. After the Wingate test, the sIgA concentration 2.5h after (4º time point) was significantly lower when compared to the same time point in the intermittent swimming protocol. For the 24h recovery time point, the continuous swim protocol (T20), showed significant lower values of sIgA when compared to the same time point for the intermittent swim and the Luc Léger tests.
In spite of significant differences in lactate levels, heart rate, and perception of effort (Cr10) between the land and water tasks, 24 hours after testing the sIgA concentration and secretion rate values were similar to the ones found before testing (1^{st} time point).
When the sIgA values were compared at rest situation (nearest rested weekend), with the different protocols tested, significant differences were only found for the 4^{th} time point with Wingate test. Both sIgA concentration and secretion rate were lower at this time point for the other three protocols but they failed to reach statistical significance. Rest values show minor variations related to the diurnal cycle when compared to the ones obtained after the tests.

Table 3. Mean and Standard Deviation of Salivary IgA secretion rate (µg.mn-1), for all time points (TP) selected for the different protocols and rest situation.

	TP 1		TP 2		TP 3		TP 4		TP 5		TP 6	
	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD
T20	50.27	33.97	61.65	37.26	34.83	22.80	39.29	18.60	181	154	41.78	18.97
Aer Int												
Swim	51.44	49.56	59.85	53.31	35.26	29.20	41.21	33.62	153	88	60.13	41.33
L.Léger	57.6	40.81	39.77	29.52	62.16	43.15	28.53	16.58	129	75	57.91	40.34
WanT	35.46	24.73	55.78	44.89	39.18	36.32	29.42	21.21	226	238	43.3	46.3
Rest	55.93	63.11	55.71	44.41	48.78	50.91	70.27	55.9	102	116	49.88	23.64

The IgA secretion rate generally followed an identical pattern to the sIgA concentration reinforcing the importance of the variation of this immune parameter (1).
When percentual variation of sIgA values were analysed, in all the protocols studied, the negative impact of the load was located 2.5hours after the test, with values that were 50 to 85% of the initial ones. Only for the continuous swimming protocol, the sIgA recovery values were under the initial ones. This may be related with the longer time spent on the task which probably conduced to a greater utilization of glycogen. In spite of the similar duration of the intermittent aerobic swimming protocol. the managment of the load does not have an identical impact on the glycogen stores.
Identical results are found on studies aiming to understand the acute response of salivary IgA to exercise. The protocols selected for this study aim to reproduce some of usual training loads done by athletes namely swimmers at their preparation (2). Most studies with swimmers only use swim tasks but land work is also an important tool in swim training. With these specific loads our results show that 24 hours are sufficient for the recovery of the sIgA values.
The relevance of this study resides on the recognition of an immune alteration regarding salivary IgA in response to exercise, mostly 1.5 hour to 2.5 hours after the training session. Coaches and swimmers must be aware of this variation, as it seems that because of the kind of the exercise done (with some intensity), they may be more prone to infection during this period. Keep way from crowded places and wrap up when you leave, is good advice to avoid infections of the upper respiratory tract.

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INSULATION AND BODY TEMPERATURE CHANGES BY WEARING A THERMAL SWIMSUIT DURING LOW TO MODERATE INTENSITY WATER EXERCISE

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This study investigated thermal swimsuit (TSS) effects on body temperature and thermal insulation during low-intensity and moderate-intensity water exercise. Nine male subjects were immersed in water (23°C) and pedalled on an underwater ergometer for 30 min with a TSS or a normal swimsuit (NSS) at two exercise intensities. Oesophageal temperatures (T_{es}) were maintained higher in TSS than in NSS at both intensities. Moderate exercise decreased the tissue insulation (I_{tissue}) compared to low-intensity exercise. However, the increased metabolic heat production at moderate intensity and added suit insulation (I_{suit}) were sufficient to offset the decrement of I_{tissue} and T_{es}. The proportion of I_{suit} to total insulation and skin-fold thickness showed a negative correlation, indicating that subjects with lower body fat can benefit more from wearing TSS. Results suggest that TSS in cool water was especially useful for subjects with low body fat.

Key Words: thermal insulation, body temperature, thermal swimsuit, water exercise.

INTRODUCTION

Several investigators have shown that moderate exercise facilitates overall heat loss during cold water immersion (5, 10) because the increased blood circulation to muscle tissues raises the conductive heat transfer from the body core to the skin, thereby reducing tissue insulation (12). Furthermore, in this moderate exercise conditions, body movements through the water accelerate convective heat loss from the skin surface to the water. However, vigorous physical activity seems to maintain the core body temperature (5, 11) because the increased metabolic heat production is sometimes sufficient to offset the heat loss. The intensity of water exercise for improving physical fitness or learning swimming techniques is lower than that for competitive swimming training. Therefore, we must develop some means to maintain the core body temperature without increasing the exercise intensity. An additional layer of insulation on the skin surface is a convenient strategy to reduce convective heat loss without an increment of exercise intensity. Many investigators have reported that wetsuits' additional insulation layers mitigate the decrease of core body temperature and facilitate longer immersion periods (1, 3, 13). However, the wetsuits investigated in those reports were pro-

duced for use in severe cold water environments for occupational divers or military specialists. In contrast, thermal swimsuits (TSS), which are a partial-coverage wetsuits, were developed to use in cool water environment for improving physical fitness or learning swimming techniques, and no data has been published so far regarding its insulation features. In this sense, the main purpose of this study was to investigate the effects of a thermal swimsuit on body temperatures and thermal insulation during low-intensity and moderate-intensity water exercise.

METHODS

Nine healthy male subjects volunteered for this study. Table 1 shows their physical characteristics. Body-fat percentages were measured using bioelectrical impedance analysis (BC-118; Tanita, Japan). The mean skin-fold thickness (MSFT) was averaged from six body regions measured using a skin-fold calliper. The body surface area (*SA*) was estimated using the DuBois equation ($SA = 0.007184 \cdot BW^{0.425} \cdot H^{0.725}$), where *BW* is the body weight and *H* represents height.

Table 1. Physical characteristics of subjects.

	Age (year)	Height (cm)	Weight (kg)	% Fat (%)	MSFT (mm)	SA (m^2)
mean	25.4	175.7	70.6	19.1	9.5	1.86
SD	2.1	4.2	4.5	2.3	2.8	0.08

After subjects sat in room air (22–24°C) for 5 min, they were immersed in water (23°C) up to their chest on an underwater cycle-ergometer for 8 min. Then, they pedalled at 50 rpm for 30 min. Each subject carried out the protocol four times: with normal swimsuit (NSS) and with a TSS (206776-09; Footmark Co. Ltd., Japan) and at two submaximal exercise intensities (low: $\dot{V}O_2$= 11–12 ml·min^{-1}·kg^{-1}, moderate: $\dot{V}O_2$= 20–22 ml·min^{-1}·kg^{-1}). The TSS used in this study was made of nylon-faced neoprene (2 mm thick), covering the thighs, trunk, upper arms, and neck. During experiments, oesophageal temperature (T_{es}) and 10 skin temperature regions were measured using thermistor sensors. The mean skin temperature (T_{es}) and mean body temperature (T_b) were calculated using the following equations: $\overline{T}_{sk} = 0.07T_{head} + 0.35(T_{chest} + T_{abdomen} + T_{back}) / 3 + 0.14(T_{upperarm} + T_{forearm}) / 2 + 0.05T_{hand} + 0.19T_{thigh} + 0.13T_{calf} + 0.07T_{foot}$, $\overline{T}_{\bar{t}} = 0.67\ T_{es} + 0.33\ \overline{T}_{sk}$.

Expired gases were continuously assessed using a mass spectrometer (WEMS2000; Westron Corp., Japan). Values of the oxygen uptake ($\dot{V}O_2$), carbon dioxide elimination ($\dot{V}O_2$), and respiratory exchange ratio (*RER*) were averaged every 1 min. Total metabolic heat production (*M*) was calculated from $\dot{V}O_2$ and *RER*. Metabolic heat production from the unit skin surface (M_s) was calculated as $0.92 \cdot M / SA$, where the respiratory heat loss was assumed to be 8% of *M*. Body heat storage (S_s) was calculated from $\Delta\overline{T}_{\bar{t}}$, *BW* and the human body specific heat capacity (C_b) ($S_s = C_b \cdot \Delta\overline{T}_{\bar{t}} \cdot BW / SA$). Heat loss from the skin to the water (H_s) was calculated by subtracting S_s from M_s ($H_s = M_s - S_s$). Total insulation (I_{total}) and tissue insulation (I_{tissue}) were estimated respectively by dividing the temperature difference between the oesophagus and water or the oesophagus and skin with H_s ($I_{total} = (T_{es} - T_w) / H_s$, $I_{tissue} = (T_{es} - \overline{T}_{sk}) / H_s$). Suit insulation ($I_{suit}$) was calculated by subtracting I_{tissue} from I_{total} ($I_{suit} = I_{total} - I_{tissue}$).

Cardiac output ($\dot{Q}_C$) was measured using a mass spectrometer with acetylene rebreathing technique (2) every 10 min. Systolic (SAP) and diastolic (DAP) arterial blood pressures were recorded every 5 min. Mean arterial blood pressure (MAP) was calculated as DAP + (SAP – DAP) / 3. Total peripheral resistance (TPR) was calculated as MAP /$\dot{Q}_C$ to estimate the extent of peripheral vasoconstriction.

Statistical significances ($p<0.05$) between TSS and NSS at the same intensity were shown with an asterisk (*); and significances between low and moderate intensity with the same suit were shown with a dagger (†) in Figures and Tables.

RESULTS

Changes in T_{es} and $\overline{T}_{sk}$ are shown in Fig. 1. At the beginning of water immersion, $\overline{T}_{sk}$ dropped rapidly with NSS at both intensities; however, a slower decrease was found with the TSS. After the onset of water exercise, $\overline{T}_{sk}$ decreased gradually for approximately 10 min, then stabilised until the end of immersion in all conditions. At each intensity, $\overline{T}_{sk}$ was significantly higher with TSS than with NSS throughout the exercise ($p<0.05$). During low-intensity exercise, T_{es} with both swimsuits decreased; T_{es} was significantly higher with TSS than with NSS from 25 min to 30 min ($p<0.05$). During moderate intensity exercise, T_{es} with both swimsuits increased from pre-immersion baseline, and no difference were observed between suit conditions.

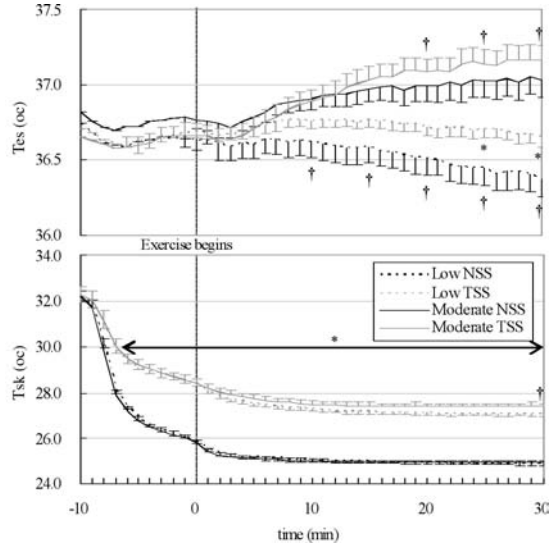

Figure 1. Body temperature change during immersion and exercise in water (mean ± SE).

Average values of $\dot{V}O_2$, $\dot{Q}_C$, MAP cnd TPR during water exercise are shown in Table 2.

The $\dot{V}O_2$, $\dot{Q}_C$, and MAP at moderate intensity were significantly higher than those at low intensity ($p<0.05$). The TPR were significantly lower at moderate intensity than at low intensity ($p<0.05$). Values of $\dot{V}O_2$, $\dot{Q}_C$, MAP and TPR showed no differences between TSS and NSS conditions at both intensities.

The M_s, S_s and H_s during 30 min water exercise are shown in fig. 2. The M_s were significantly higher at moderate intensity than at low intensity with both swimsuits ($p<0.05$). The M_s

showed no differences between TSS and NSS conditions at both intensities. The S_s were significantly lower in TSS than in NSS at both intensities ($p<0.05$). At both intensities, TSS showed significantly lower H_s than in the NSS condition ($p<0.05$).

Results of I_{total}, I_{tissue} and I_{suit} during water exercise are shown in fig. 3. The I_{total} was significantly higher in the TSS than in the NSS condition at both intensities ($p<0.05$). The I_{tissue} at moderate intensity was significantly lower than that at low intensity with both suits ($p<0.05$). The I_{tissue} showed no differences between TSS and NSS conditions at both intensities.

Table 2. Cardiovascular responses during water exercise (mean ± SE).

	Low intensity		Moderate intensity	
	NSS	TSS	NSS	TSS
$\dot{V}_{O2}$ (ml·min^{-1}·kg^{-1})	11.78 ± 0.67	10.71 ± 0.35	21.74 ± 1.42†	20.61 ± 1.51†
$\dot{Q}_c$ (l·min^{-1})	6.45 ± 0.27	6.20 ± 0.51	9.45 ± 0.38†	9.47 ± 0.61†
MAP (mmHg)	94.7 ± 3.0	95.7 ± 3.9	101.7 ± 3.6 †	103.2 ± 3.5 †
TPR (mmHg·min·l^{-1})	15.0 ± 0.7	16.4 ± 1.5	10.8 ± 0.3 †	11.2 ± 0.6 †

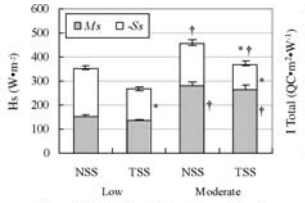

Figure 2 M_s, S_s and H_s during 30 min water exercise (mean ÂSE)

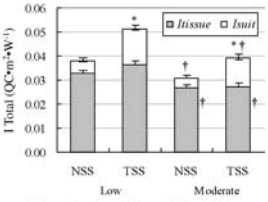

Figure 3 I_{tissue}, I_{suit} and I_{total} during 30 min water exercise (mean ÂSE)

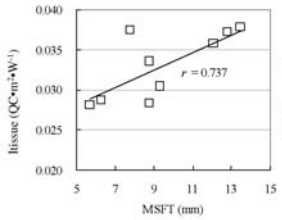

Figure 4 The relationship between MSFT and the I_{tissue} at low-intensity exercise with the NSS

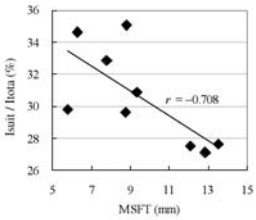

Figure 5 The relationship between MSFT and I_{suit}/I_{total} at moderate - intensity exercise with the TSS

Fig. 4 shows the relationship between MSFT and the I_{tissue} at low intensity with NSS. The I_{tissue} were correlated significantly with the MSFT (p<0.05, r = 0.737). Fig. 5 shows the relationship between the MSFT and the proportion of I_{suit} to I_{total} (I_{suit}/I_{total}) at moderate intensity with the TSS. The I_{suit}/I_{total} showed significantly negative correlation with the MSFT ($p<0.05$, $r = -0.708$).

DISCUSSION

In the present study, the I_{tissue} at moderate intensity with both suits was significantly lower than that at low intensity ($p<0.05$). The decrease in I_{tissue} agrees with the results of previous studies (7, 8). Sagawa et al. (8) reported that I_{tissue} was inversely proportional to the increase in water exercise intensity at T_w of 28.8 – 36°C. Similarly, Park et al. (7) reported that I_{tissue} declined as an exponential function of the exercise intensity in water of 28 – 32°C. They (7, 8) indicated that exercise increased blood circulation to the working muscles and thereby reduces I_{tissue}. In accordance with other studies, we found a higher $\dot{Q}_c$ and lower TPR during moderate intensity exercise, which indicated the increase in the blood circulation to the working muscles. However, the exercise-induced heat production was greater than the heat loss attributable to the decreased I_{tissue}; therefore, moderate intensity exercise was able to maintain T_{es}.

Kang et al. (4) observed that, in divers working at T_w of 22.5°C and wearing wetsuits, I_{tissue} were slightly lower than those of suitless divers. In addition, Shiraki et al. (9) observed a similar tendency of decline of I_{tissue} in wetsuit-protected divers during diving work at T_w of 27°C. They suggest that these I_{tissue} levels reflected the higher peripheral blood flow attributable to less cold-induced vasoconstriction in divers with wetsuits. On the other hand, in our study, the I_{tissue} showed no differences between TSS and NSS conditions at both intensities, which suggests that the TSS has no effects on peripheral blood flow unlike in the case of wetsuits. Our data of $\dot{Q}_c$, MAP and TPR showed no cardiovascular differences between suit conditions as like as I_{tissue}, which could ascertain that the TSS has no effect on the peripheral blood flow. We postulated that the partial-coverage form and thinner layer of the TSS was one reason for the different effect on I_{tissue} between the TSS and wetsuits. Thermal input from the exposed distal extremities might attenuate the predicted peripheral vasodilatation with TSS. From these results, we could reveal the difference between the TSS and wetsuits.

The significant correlation between MSFT and I_{tissue} in NSS condition indicated that subjects with low body fat had a thinner insulation layer than that of obese subjects (3). This result suggests that wearing a TSS is advantageous for subjects with low body fat to compensate for the smaller I_{tissue}. Because of the relationship between MSFT and I_{tissue}, a negative correlation was observed between MSFT and I_{suit}/I_{total} at moderate intensity exercise. The I_{suit}/I_{total} for each subject reflects the TSS contribution to the subject's total insulation. The negative correlation suggests that the lower fat subjects could have more benefit of TSS to I_{total}. No previous wetsuit studies have assessed suit-attributable differences among subjects' physical characteristics using the I_{suit}/I_{total} parameter. The greater I_{suit} of wetsuits compared to TSS might obscure the individual suit contribution differences. We can suggest greater usefulness of wearing TSS for subjects with low body fat by indicating the negative correlation between MSFT and I_{suit}/I_{total}.

CONCLUSION

During immersion in 23°C water, moderate intensity exercise reduced I_{tissue} compared to low-intensity exercise resulting from higher blood circulation to working muscles. Wearing a TSS served to increase I_{total} by adding I_{suit}, thereby reducing heat loss from subjects' skin to the water. Consequently, subjects with TSS were able to maintain higher body temperatures than those same subjects with NSS. Results showing negative correlation between I_{suit}/I_{total} and MSFT suggest that subjects with lower body fat might receive more benefit from TSS to I_{total} during water exercise in cool water.

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