CAN HIGH INTENSITY WORKLOADS BE SIMULATED AT MODERATE INTENSITIES BY REDUCED BREATHING FREQUENCY?

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ABSTRACT: Objectives: This study was designed to investigate whether reduced breathing frequency during moderate intensity exercise produces similar metabolic responses as during exercise with spontaneous breathing at higher absolute intensity. Methods: Eight healthy male subjects performed a constant load test with reduced breathing frequency at 10 breaths per minute to exhaustion (B10) at the peak power output obtained during the incremental test with RBF (peak power output increased every two minutes for 30 W). The subjects then performed a constant load test with the spontaneous breathing to exhaustion (SB) at peak power output obtained during the incremental test with spontaneous breathing. Results: Respiratory parameters ($\dot{V}_E$, P_{ETO_2}, P_{ETCO_2}), metabolic parameters ($\dot{V}O_2$, $\dot{V}CO_2$) and oxygen saturation (SaO_2) were measured during both constant load tests. Capillary blood samples were taken before and every minute during both constant load tests in order to measure lactate concentration ([LA^-]) and parameters of capillary blood gases and acid base status (P_{O_2}, P_{CO_2}, pH). Regardless of the type of comparison (the data obtained at the defined time or maximum and minimum values during the exercise), there were significant differences between SB and B10 in all respiratory parameters, metabolic parameters and SaO_2 ($p \leq 0.01$ and 0.05). There were significantly lower [LA^-] and P_{CO_2} during B10, when compared to SB ($p \leq 0.01$). However, there were no significant differences in pH during the exercise between different breathing conditions. Conclusion: It can be concluded that reduced breathing frequency during exercise at lower absolute intensity did not produce similar conditions as during the exercise with spontaneous breathing at higher absolute intensity.

KEY WORDS: reduced breathing frequency, respiratory acidosis, constant load exercise

INTRODUCTION

While performing the front crawl, swimmers can use different breathing patterns. They usually take a breath every second stroke cycle. However, they could reduce their breathing frequency with taking a breath every third, fourth, fifth, sixth or eighth stroke cycle [20]. The lower breathing frequency may have some biomechanical advantage for a swimmer's performance [18] which could result in faster swimming [23]. Taking this into consideration, reduced breathing patterns are often used during the final part of the competition races, when swimmers try to finish as fast as possible. However, swimmers should be able to precisely regulate their velocity and BF during maximal front crawl swimming so as to create the appearance of critical acidosis only at the end of swimming [28]. Therefore, swimming with different a breathing pattern is often used during regular swimming training [20]. Training with reduced breathing frequency (RBF) was developed in 1970s, as "hypoxic training" [16]. It was thought that by limiting inspired air, the reduction of oxygen available for muscular work would result and therefore cause muscle hypoxia. In addition, these conditions would increase anaerobic glycolysis and hence improve lactic acid tolerance.

In some previous studies, swimmers reduced their breathing frequency during tethered front crawl swimming [3, 24, 29], during front crawl interval sets [8], during front crawl swimming at OBLA velocity [13] and during maximal front crawl swimming [14]. These studies were unable to demonstrate hypoxia conditions by analysing the air expired during the exercise [3, 8, 29] or by measuring capillary blood sampled after the exercise [13, 14]. Considering the obtained higher partial pressure of CO_2, they concluded that this kind of training is more likely hypercapnic training. Due to the technical limitations of measuring respiratory and blood parameters during swimming, the idea of RBF during exercise on land has been also investigated; examples include cycle ergometry [12, 25, 32] and treadmill running [21]. These studies confirmed marked hypercapnia as result of RBF during exercise. In addition, they also obtained hypoxia by measuring capillary blood sampled and oxygen saturation (SaO_2) during exercise with RBF. All of the reported studies compared the subjects' response during exercise with different breathing conditions (spontaneous and RBF) at the same absolute intensity. However, the question is whether RBF during moderate exercise, which could also induce respiratory acidosis [14], is sufficient to produce similar influences on an athlete's acid-base status, such as the influences of the metabolic acidosis present during heavy exercise. Indeed, due to athletes' distress reported after the exercise with RBF, it has been speculated that high intensity workloads can be simulated at moderate intensities by RBF [31]. In addition, some swimming coaches believe that training with RBF performed at lower swimming velocity could adapt swimmers to higher arterial partial pressure of CO_2 (P_{CO_2}) which appeared during high and/or maximal front crawl swimming [15]. The latter is one of the consequences of generally restricted (technique-dependent) breathing during front crawl swimming. Therefore, the study was designed to investigate whether RBF during moderate intensity exercise produces similar metabolic responses as during exercise with spontaneous breathing at higher absolute intensity. In the present study cycle ergometry was used due to the mentioned technical limitations of measuring respiratory and blood parameters during the swimming. RBF, defined as 10 breaths per minute, induced hypoventilation [12] similar to the one occurring at swimmers that reduced their breathing frequency from taking breath every second stroke cycle to taking breath every fifth [3] or sixth [29] stroke cycle. This kind of breathing is often used during swimming training with RBF.

MATERIALS AND METHODS

Subjects. Eight healthy male subjects (age 24 ± 1 years, height 181 ± 4 cm, weight 79 ± 7 kg peak oxygen uptake ($\dot{V}O_2$peak) 44.8 ± 3.85 ml/kg/min, forced vital capacity of 5.99 ± 0.58 l and forced expiratory volume of 4.76 ± 0.59 l in 1 s) volunteered to participate in this study. None of the subjects were smokers, and were free of respiratory disease at the time of the study. The subjects were fully informed of the purpose and possible risks of the study before giving their written consent to participate. The study conforms to the Helsinki Declaration and was approved by the University's Research Ethics Committee.

Procedures. RBF was defined as 10 breaths per minute and was regulated by a breathing metronome. The breathing metronome was composed of a gas service solenoid valve 24 VDC (Jakša, Ljubljana, Slovenia) and a signal with red and green lights. Both were controlled by micro-automation Logo DC 12/24V (Siemens, Munich, Germany). The subjects were instructed to exhale and inhale during a two-second period of the open solenoid valve (the green signal light was switched on) and to hold their breath, using almost all lung capacity (holding breath near total lung capacity), for four seconds when the solenoid valve was closed (the red signal light was switched on). Prior to the exercise testing, the subjects were familiarized with breathing with the breathing metronome. After familiarization, each subject performed four exercise tests on an electromagnetically braked Ergometrics 900 cycle ergometer (Ergoline, Windhagen, Germany) with pedal cadence at ~60 revolutions per minute (rpm). Tests were performed in a prescribed order, each of them on a different day.

Preliminary tests. The subjects initially performed an incremental exercise test to obtain peak power output (PPOSB) and $\dot{V}O_2$peak. The test began at 30 W and increased by 30 W every two minutes until volitional exhaustion. $\dot{V}O_2$peak was defined as the highest O_2 uptake averaged over a 60-second interval. A minimum of 48 hours later, the subjects performed an incremental exercise test with RBF to obtain peak power output in reduced breathing conditions (PPOB10). Except for the breathing, the protocol of this test was identical to the protocol of the previous incremental exercise test. At both incremental exercise tests, peak power output was defined as the highest work stage that each subject completed. From these results, the work rate for the constant load tests with spontaneous and, with RBF, was chosen for each subject.

Experimental protocol. After preliminary testing, a constant load test with RBF (B10) was performed to exhaustion at PPOB10. This test started with a five minute warm-up at 50 W. After that, the resistance was increased in a maximum of five seconds to match the subject's peak power output and the subject continued to exhaustion. The constant load test was completed by 10 minutes of active recovery at 20 W with spontaneous breathing. Finally, the subjects performed a constant load test with spontaneous breathing (SB). This test was performed to exhaustion at PPOSB. The protocol (warming up, recovery) of this test was otherwise identical to the protocol of B10.

Measurements. During the constant load tests, the subjects breathed through a mouthpiece attached to a pneumotachograph. The subject's expired gas was sampled continuously by a V-MAX29 metabolic cart (SensorMedics Corporation, Yorba Linda, USA) for a breath-by-breath determination of respiratory parameters: pulmonary ventilation ($\dot{V}_E$), oxygen uptake ($\dot{V}O_2$), carbon dioxide output ($\dot{V}CO_2$), end-tidal pressure of oxygen (P_{ETO_2}) and carbon dioxide (P_{ETCO_2}). The pneumotachograph and the O_2 and CO_2 analysers were calibrated prior to the test with a standard three-litre syringe and precision reference gases, respectively. For further statistical analysis, breath-by-breath data were averaged for each 10-second interval. During the constant load tests, oxygen saturation (SaO_2) was measured using a TruStatTM Pulse Oximeter (Datex-Ohmeda, Madison, USA). The pulse oximeter is an indirect oximetry instrument, which displays SaO_2 every fourth seconds. An ear probe was attached to the earlobe after cleaning the area with alcohol.

Measures of parameters of capillary blood gases and acid base status included partial pressure of blood O_2 (P_{O_2}) and CO_2 (P_{CO_2}) and pH during the warm-up and in the second and fourth minute during the exercise. Capillary blood samples (60–80 μl) were taken via micro-puncture from an earlobe. Earlobe capillary blood was arterialized by the application of hyperemic cream (Finalgon, Boehringer-Ingelheim, Reims, France) at least 20 minute before the first capillary sample. Earlobe samples were collected in heparinized glass capillary tubes and introduced into a blood gas analyser ABL5 (Radiometer, Copenhagen, Denmark) for gas analysis at 37° C. Blood lactate concentration ([LA^-]) was measured during the warm-up and in the first, third and fifth minute during the exercise. In addition, [LA⁻] was measured also in the second and fourth minute during the recovery after the exercise. Capillary blood samples (60–80 μl) were taken by micro-puncture from a hyperemied earlobe. Blood samples for measuring [LA-] were diluted in a LKM41 lactate solution (Dr. Lange, Berlin, Germany) and analysed using the MINI8 photometer (Dr. Lange, Berlin, Germany).

Statistics. The results are presented as means and standard deviations (SD). A paired t-test was used to test the statistical differences in respiratory parameters and SaO_2 between SB and B10 during entire exercise period. The data obtained at the beginning and every 40th second of exercise was included in these comparisons. In addition, the paired t-test was also used to compare the data of blood parameters between SB and B10. Statistical significance was accepted at the $p \leq 0.05$ level. All statistical parameters were calculated using the statistics package SPSS (version 15.0, SPSS Inc., Chicago, USA) and the graphical statistics package Sigma Plot (version 9.0, Jandel, Tübingen, Germany).

RESULTS

Table 1 shows the peak power output at incremental exercise tests (PPO_{SB}, $PPOB_{10}$) and the time to exhaustion ($Tmax_{SB}$, $Tmax_{B10}$) at constant load tests with two different breathing conditions. According to experimental protocol, peak power output obtained at incremental tests determined work rate at constant load tests. There were no significant differences between $Tmax_{SB}$ and $Tmax_{B10}$.

Regardless of the test, the minimum Tmax was 280 second. This means that the data obtained during the first 280 second period of exercise were collected at all subjects and further statistically analysed (Figures 1 to 6).

Figure 1 demonstrates that B10 resulted in a profound reduction in $\dot{V}_E$ ($p \leq 0.01$), in comparison to SB. Considering lower absolute intensities; there were significantly lower $\dot{V}O_2$ and $\dot{V}CO_2$ during B10 than during SB ($p \leq 0.01$; Figure 2 and 3). As expected, the marked hypoventilation induced significantly P_{ETO_2} and an increase in P_{ETCO_2} during B10 in comparison with SB ($p \leq 0.01$; Figure 4 and 5).

TABLE 1. THE PEAK POWER OUTPUT (PPO_{SB} AND $PPOB_{10}$) OBTAINED AT INCREMENTAL EXERCISE TESTS AND THE TIME TO EXHAUSTION $Tmax_{SB}$ AND $Tmax_{B10}$ OBTAINED AT CONSTANT LOAD TESTS WITH DIFFERENT BREATHING CONDITIONS.

Subjects	Incremental exercise tests		Constant load tests	
	PPO_{SB} (W)	$PPOB_{10}$ (W)	$Tmax_{SB}$ (s)	$Tmax_{SB}$ (s)
1	330	210	447	283
2	300	150	337	1032
3	270	240	427	420
4	330	210	341	354
5	300	210	367	358
6	330	180	299	408
7	270	210	315	479
8	300	150	341	1158
M (SD)	304 (25)	195 (32)	359 (52)^{NS}	562 (336)^{NS}

note: ^{NS} - no significant differences between SB and B10.

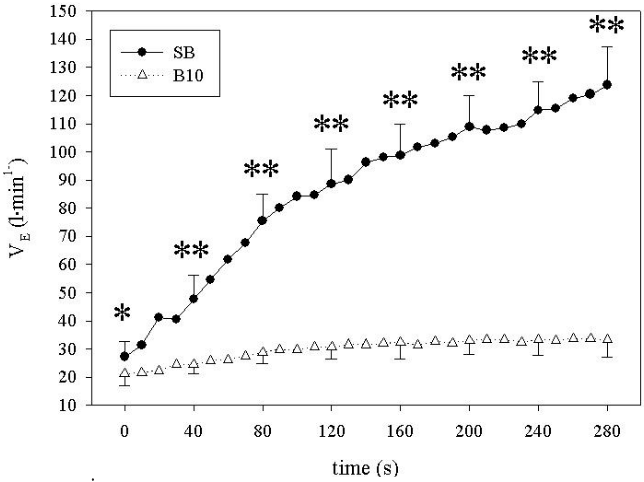

FIG. 1. $\dot{V}_E$ DURING SB (CLOSED CIRCLES) AND B10 (OPEN TRIANGLES) (** - $p \leq 0.01$).

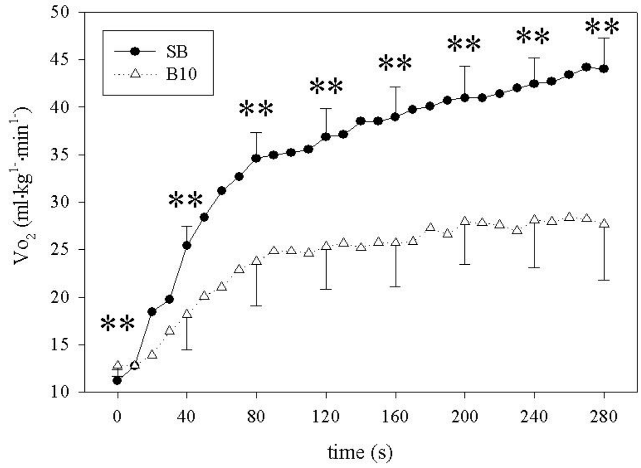

FIG. 2. $\dot{V}O_2$ DURING SB (CLOSED CIRCLES) AND B10 (OPEN TRIANGLES) (** - $p \leq 0.01$)

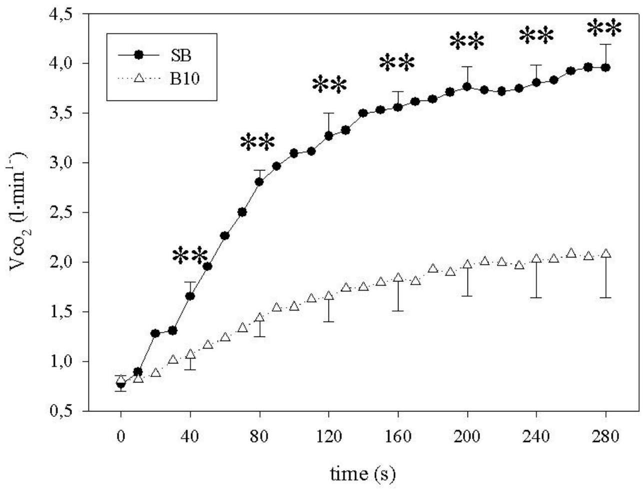

FIG. 3. $\dot{V}CO_2$ DURING SB (CLOSED CIRCLES) AND B10 (OPEN TRIANGLES) (** - $p \leq 0.01$).

In addition, there were significant differences between SB and B10 in SaO_2, measured last from 120 second during the exercise ($p \leq 0.01$ and 0.05; Figure 6).

According to the comparison of maximum and minimum values of respiratory parameters, the metabolic parameters and SaO_2 measured during the exercise, there were significant differences in all parameters between SB and B10 ($p \leq 0.01$; Table 2).

Table 3 demonstrates that there were significant lower [LA-], P_{O_2} and higher P_{CO_2} during the B10 exercise, when compared to SB exercise ($p \leq 0.01$).

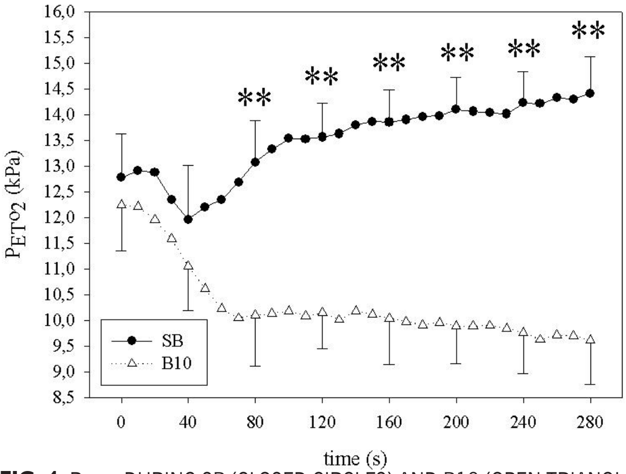

FIG. 4. P_{ETO_2} DURING SB (CLOSED CIRCLES) AND B10 (OPEN TRIANGLES) (** - p≤0.01).

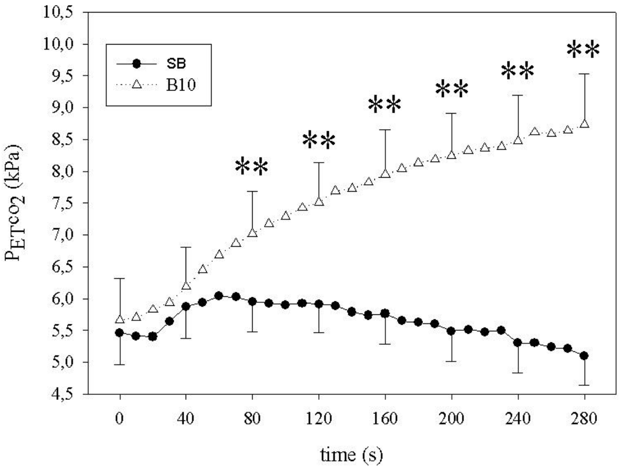

FIG. 5. P_{ETCO_2} DURING SB (CLOSED CIRCLES) AND B10 (OPEN TRIANGLES) (** - p≤0.01).

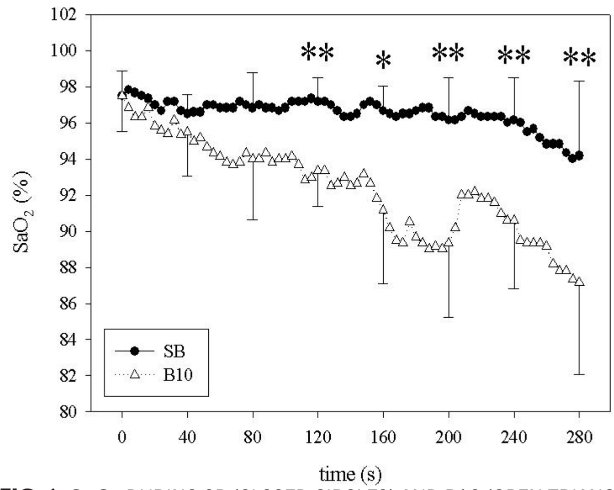

FIG. 6. SaO_2 DURING SB (CLOSED CIRCLES) AND B10 (OPEN TRIANGLES) (** - p≤0.01).

DISCUSSION

This study was designed to investigate whether reduced breathing frequency during moderate intensity exercise produces similar metabolic responses as during exercise with spontaneous breathing at higher absolute intensity. This was different from the previous studies, which concentrated on RBF during cycle ergometry [12, 25, 32], treadmill running [21] and during swimming [3, 8, 29, 13]. In these studies, the subjects' responses during exercise with different breathing conditions were compared at the same absolute intensity. Marked hypoventilation, hypercapnia and hypoxia was confirmed as result of RBF during exercise. Due to hypoxia conditions, it was speculated that high intensity workloads can be simulated at moderate intensities by RBF [31]. In the present study, the intensity at B10 was lower by approximately 36% compared to the intensity at SB (Table 1). In addition, there were significant differences in almost all

TABLE 2. MAXIMUM VALUES OF V_E, $\dot{V}O_2$, $\dot{V}CO_2$ AND P_{ETCO_2} AND MINIMUM VALUES OF P_{ETO_2} AND SaO_2 DURING SB AND B10.

	SB	B10
V_E (l/min)	134.6 (12.5)	35.3 (5.6) **
$\dot{V}O_2$, (ml×kg1-×min1-)	46.2 (3.3)	31.8 (4.4) **
$\dot{V}CO_2$ (l/min)	4.1 (0.2)	2.3 (0.4) **
P_{ETO_2} (kPa)	11.9 (1.0)	8.9 (0.7) **
P_{ETCO_2} (kPa)	6.2 (0.5)	9.4 (0.7) **
SaO_2 (%)	93 (3)	82 (7) **

note: ** p≤0.01, respectively between SB and B10.

TABLE 3. COMPARISONS OF [LA-], pH, P_{O_2} and P_{CO_2} DURING THE WARM-UP AND EXERCISE BETWEEN SB AND B10.

		SB	B10
[LA-] (mmol/l)	warm-up	1.1 (0.2)	1.3 (0.3)
	1st min during the exercise	1.7 (0.2)	1.4 (0.4)
	3rd min during the exercise	6.5 (0.5)	3.4 (0.9) **
	5th min during the exercise	10.0 (1.4)	4.9 (1.9) **
pH	warm-up	7.41 (0.02)	7.43 (0.04)
	2nd min during the exercise	7.34 (0.01)	7.34 (0.01)
	4th min during the exercise	7.28 (0.04)	7.28 (0.02)
P_{O_2} (kPa)	warm-up	11.3 (0.9)	11.2 (0.8)
	2nd min during the exercise	11.5 (0.8)	9.3 (0.6) **
	4th min during the exercise	11.3 (0.7)	8.9 (1.1) **
P_{CO_2} (kPa)	warm-up	5.1 (0.5)	5.2 (0.6)
	2nd min during the exercise	5.6 (0.3)	6.4 (0.4) **
	4th min during the exercise	5.1 (0.5)	6.9 (0.5) **

note: ** p≤0.01, respectively between SB and B10.

measured data between SB and B10, regardless of the type of comparison (the data obtained at the defined time or maximum and minimum values during the exercise). Therefore, it could be concluded that RBF during constant load exercise at lower absolute intensity did not produce similar conditions as during the constant load exercise at higher absolute intensity with spontaneous breathing.

Considering the experimental protocol and the subjects' reports, both experimental conditions (spontaneous breathing and RBF) produced similar sensations of fatigue (effort). The work rates for constant load test with selected breathing patterns were determined with peak power output obtained at incremental testing with similar breathing conditions. Moreover, both tests were performed to exhaustion. Therefore, the subjects' efforts (intensity and duration) during constant load tests were maximal for selected breathing conditions. The pH values, measured during the fourth minute of the tests (Table 3), indicate the maximality of constant load exercises in both breathing conditions. These results were close to results of Stringer et al. [27] who measured arterial pH during constant load cycling exercise at very heavy intensity. It is generally accepted that acidosis (low pH) in the body causes several effects associated with fatigue [1, 4]. However, the origin for acidosis during constant load tests was different with regards to different breathing conditions. The intensity (resistance during cycling) and duration of the exercise at SB was high enough to induce metabolic acidosis with high [LA$^-$]. The dramatic increase of $\dot{V}_E$ (Figure 1) and consequently the decrease of P_{CO_2} to the warm up level (Table 3) are well documented phenomena during intense cycle ergometer exercise with spontaneous breathing [27]. In contrast, RBF during B10 induced hypoventilation (Figure 1) and higher P_{CO_2} (Table 3). Due to similar results Stanford et al. [26] concluded that RBF during exercise resulted primarily in an inhibition of normal respiratory compensation that occurred during exercise with spontaneous breathing. CO_2 was retained in muscle, plasma and erythrocytes [17]. Due to significantly lower [LA$^-$] in comparison with SB (Table 3) it seemed that higher P_{CO_2} was the main reason for low pH during B10. Therefore, RBF during constant load exercise induced respiratory acidosis in capillary blood.

Considering obtained results, it could be suggested that the effects of swimming training with usual breathing and with controlled breathing frequency (taking breath every fourth, fifth, sixth or eighth stroke cycle) would be different despite similar effort. Training with RBF could not be realized at higher swimming velocity due to additional stress caused by such breathing. Therefore, this kind of training could not adapt swimmers to swim at high or maximal velocity. However, there could be some other advantages of training with RBF. Considering hypercapnia as a result of RBF during exercise it could be suggested that this kind of training could improve tolerance to high alveolar CO_2 [3, 24] and consequently adapt swimmers to swim with fewer breaths.

Possible study limitations. Due to the technical limitations of measuring respiratory and blood parameters during swimming, the idea of RBF during exercise was investigated during cycle ergometry in the present study. Therefore, the different impacts on breathing during both exercises (cycle ergometry and swimming), which are mainly the result of different environments and body positions, should be considered. In comparison to land activities, immersion during swimming increases hydrostatic compression around the chest. It pushes the chest wall inwards when the inspiratory muscle are relaxed [5] and produces the additional pressure against which the chest wall needs to expand [9]. Therefore, the respiratory muscle must perform additional work [2]. It was discovered that the magnitude of inspiratory muscle fatigue and the speed with which it developed were greater and swifter after swimming than after land exercise [19]. In addition, some of the respiratory muscles are also used for swimming. For example, the abdominal muscles are used extensively to stabilize the body during front crawl and backstroke and to create wave-like motion during butterfly and breaststroke. The chest wall muscles create the stable structure from which the shoulder muscles act during stroke motion. Furthermore, differences in body position produce gravitational-mediated alterations in hemodynamics. The supine body position is associated with shift in blood volume from lower extremities into the chest. This pulmonary engorgement reduces lung compliance [7] and increases ventilatory work for given tidal volume [22]. Some previous studies discovered that these alterations in hemodynamics influenced different ventilatory [6], cardiovascular [30] and $\dot{V}O_2$ [10, 11] responses to exercise in different body positions. Due to these differences between cycle ergometer and swimming exercises, it must be emphasised that the conclusions of the present study should be considered for only cycle ergometer exercises.

CONCLUSIONS

In summary, reduced breathing frequency during exercise at lower absolute intensity did not produce similar conditions as during the exercise with spontaneous breathing at higher absolute intensity.

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