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THE EFFECT OF SWIMMING ACTIVITY ON LUNG FUNCTION PARAMETERS AMONG SMOKING AND NON-SMOKING YOUTH – RESEARCH EXTENDED

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ABSTRACT
Purpose. The purpose of this study was to evaluate the effect of regular swimming activity on the respiratory system of smokers and non-smokers. **Methods.** The study included 196 students, aged 19 to 24 years, attending weekly swimming classes. All students underwent pulmonary function testing before and after participating in a swimming program for 10 months. Measurements included forced vital capacity (FVC), forced expiratory volume in one second (FEV_1), and peak expiratory flow (PEF). Maximal inspiratory and expiratory pressure at the mouth (PImax, PEmax) and the percentage carboxyhemoglobin level in blood (%CoHb) were also measured. **Results.** After 10 months of regular swimming activity the values of FVC, PEF, MIP and MEP increased in the non-smoking as well as in the smoking group, while the FEV_1 increased only among smokers. The percentage of CoHB level in the blood decreased in both groups. **Conclusions.** The study confirmed the positive effect of swimming on respiratory system function and the importance of promoting physical activity such as swimming among cigarette smokers as well as non-smokers.

Key words: swimming, respiratory function, smoking

Introduction

Many physical therapists appreciate the benefits of exercises in the aquatic environment because of the specific thermal and mechanical factors operating on the body immersed in the water. The influence of many environmental factors (e.g. the temperature of water, hydrodynamic and hydrostatic pressure, buoyancy and resistance) on the human body makes physical activity in water substantially different from the dry land exercises. For example, the upward buoyant force opposing gravitational force produces an apparent loss of body weight which allows greater freedom of movement and a variety of unloaded exercises. Such a movement state is difficult to achieve on land [1].

The aquatic environment also strongly influences the respiratory system. The hydrostatic pressure of the water causes pressure on the chest which impedes depth and volume of inspiration and simultaneously facilitates greater expiratory volume. Exhaling also can be impeded when breathing out while the face is immersed in the water because of water resistance. This paradox explains how a gradation of the levels of body immersion can enable selective activation of the auxiliary respiratory muscles [2]. The more superior location of the diaphragm while in a supine horizontal body position in the water may predispose thoracic breathing which can increase flexibility and mobility of the chest [2]. In addition, horizontal body position in the water can reduce “physiological deadspace”, can increase the flow of blood in relation to lung ventilation, and can increase the diffusion capacity of the lungs [3]. Furthermore, staying in moderately cool water (21–28°C) may result in deeper breathing, reduced respiratory and heart rate and increased minute ventilation [4].

Despite the large number of scientific reports confirming the positive impact of swimming and water exercises on the respiratory system [5–7], there are reports which call this issue into question [8–11]. Some authors have even questioned the overall impact of physical activity on respiratory parameters. For example, Lakhera et al. [10] did not show any significant difference in the value of forced vital capacity (FVC), forced expiratory volume in one second (FEV_1), inspiratory capacity (IC) and maximal voluntary ventilation (MVV) between subjects taking regular physical activity and subjects who led a sedentary lifestyle. Thus, those authors concluded that the development of the lungs during puberty is influenced mainly by health conditions and nature of the diet, while the impact of physical activity was considered to be less important [10]. Research conducted by Biersteker et al. [8] also did not confirm the relationship between physical activity and the improvement of respiratory parameters. Furthermore, a systematic review conducted by Martin-Valero, Cuesta-Vargas, and Labajos-Manzanares [12] showed no beneficial effect of selected water exercises on lung function in patients with chronic obstructive pulmonary disease.

On the other hand, Holmen et al. [13] confirmed the influence of physical activity on the respiratory system suggested that it is not the type of the activity, but the frequency and intensity that have an impact on the respiratory parameters. The results of the study showed no

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statistically significant difference in the increase of forced vital capacity (FVC) in swimmers compared with those who practice other endurance sports.

Physical training in water might be included in a comprehensive pulmonary rehabilitation program, but first it is necessary to unambiguously confirm or deny the positive impact of water exercises on measures of pulmonary system function. Therefore, we assessed the effectiveness of swim training on respiratory function of young healthy adults. Since cigarette smoking is a variable that has a deleterious impact on the respiratory system, we analyzed the influence of swimming on the respiratory parameters of smokers and non-smokers as independent variable.

Material and methods

The study included 224 college-aged students attending weekly swimming classes. A total of 196 subjects met the inclusion criteria and completed the research: 50 men and 144 women (M_{age} = 20.4 years, age range: 19 to 24 years). Exclusion criteria included lack of consent, cold symptoms, and a history of asthma. Subjects were divided into two groups: current smokers and non-smokers. Current smokers included daily smokers (students who smoked cigarettes at least once a day) and occasional smokers (those who do not smoke every day). Non-smokers included former daily smokers, former occasional smokers and never smokers. Students in the smoking group smoked on average 7 cigarettes per day.

All students underwent pulmonary function testing before and after participating in a ten-month swimming program. To evaluate pulmonary function and respiratory muscle function we measured five variables:

– forced vital capacity (FVC)
– forced expiratory volume in one second (FEV_1)
– peak expiratory flow (PEF)
– maximum inspiratory pressure measured in the mouth (MIP)
– maximum expiratory pressure measured in the mouth (MEP)

Additionally, we performed a breath carbon monoxide test to measure the level of CO in students' exhalation and the percentage level of carboxyhemoglobin in the blood (%COHb).

The measurements were performed with the participant in a sitting position. The procedure for spirometry included maximal inhalation and forced maximal exhalation. The best of three trials was recorded. Testing was completed using a calibrated computerized spirometer (MicroLab, CareFusion, UK). Maximal expiratory and inspiratory pressures were measured using a handheld respiratory pressure meter (MicroRPM; CareFusion, UK) and the breath carbon monoxide test was performed with a breath CO monitor (MicroCO, Micro Medical, Rochester, Kent, UK). All measurements were conducted by the same person using the same equipment.

Swimming classes lasted 90 minutes and were held once a week. Students learned elementary and competitive swimming strokes including front crawl, back crawl and breaststroke. The load, intensity, and frequency of exercises were characteristic for recreational swimming [14]. Average distance covered during each class was about 1200 meters. After ten months of training the measurement of the initial physiological variables was repeated.

In addition to the physiological and physical measures, prior to swim training a questionnaire was administered to estimate physical fitness and a self-reported history of smoking among students. The variables were compared between smokers and non-smokers. Statistical analyses were performed using paired (within group) and indepen-

Table 1. Respiratory muscle function, pulmonary function and breath carbon monoxide test before and after swim training in the whole population

	Before training	After training	Difference	*p* value
Respiratory muscle function				
MIP (cmH_2O)	71.5 ± 33.9	81.8 ± 33.7	10.3*	0.001
MEP (cmH_2O)	94 ± 37.1	113.9 ± 40.2	19.9*	0.001
Pulmonary function				
FVC (L)	4 ± 0.9	4.4 ± 2.8	0.4*	0.02
FVC (%)	93 ± 16.4	103.6 ± 10.8	10.6*	0.02
FEV_1 (L)	3.4 ± 0.9	3.3 ± 1.1	–0.1*	0.03
FEV_1 (%)	104 ± 20.8	102.9 ± 11.34	–1.1*	0.03
PEF (L)	330.9 ± 136.3	339 ± 0.2	8.1	0.3
Breath carbon monoxide test				
CO (ppm)	2.1 ± 3.5	1.8 ± 3.3	–0.3	0.1
%COHb	0.34 ± 0.6	0.29 ± 0.5	–0.05	0.1

MIP – maximal inspiratory pressure, MEP – maximal expiratory pressure, FVC – forced vital capacity, FVC% – predicted FVC, FEV_1 – forces expiratory volume in one second, FEV_1% – predicted FEV_1, PEF – peak expiratory flow, CO – breath carbon monoxide, %COHb – percentage carboxyhemoglobin level in the blood, values are *Mean* ± *SD*, * significant difference ($p < 0.05$)

dent (between groups) Student's *t*-tests and tests for differences, with a Type I significance level of $\alpha \leq 5\%$.

Results

Statistical analyses showed no significant differences in age, height, body mass, or history of prior swim training when comparing between smoking and non-smoking groups before and after the swimming intervention program. Significant improvements in maximum expiratory pressure MEP ($p = 0.001$), maximal inspiratory pressure MIP ($p = 0.001$) and forced vital capacity FVC ($p = 0.02$) were observed in the whole sample after the swimming intervention program. No significant differences were observed for values of PEF ($p = 0.3$). FEV_1 significantly decreased ($p = 0.03$). The results are shown in Table 1.

In the sample 17% of students ($n = 41.21\%$) smoked regularly. The average length of time reported to have smoked was 5.5 years. Among smokers the average concentration of carbon monoxide in the exhaled air was 5.73 ppm (0.92% COHb), while in non-smoking group – 1.1 ppm (0.18% COHb). After ten months of training we did not observe statistically significant differences in levels of carbon monoxide in the exhaled air (Table 2).

In the group of smokers inspiratory and expiratory muscle strength was greater than among non-smokers, both before and after swim training. After ten months of

Table 2. Respiratory muscle function, pulmonary function and breath carbon monoxide test before and after swim training among smokers

	Before training	After training	Difference	*p* value
Respiratory muscle function				
MIP (cmH_2O)	78.8 ± 33.6	89.5± 30.7	10.7*	< 0.001
MEP (cmH_2O)	98.0 ± 17.7	116.3 ± 38.1	18.3*	< 0.001
Pulmonary function				
FVC (L)	4.1 ± 1.1	4.4 ± 1.0	0.3*	0.001
FVC (%)	96.1 ± 17.4	104.9 ± 9.5	8.8*	0.001
FEV_1 (L)	3.5 ± 0.9	3.9 ± 1.2	0.46	0.36
FEV_1(%)	101.2 ± 14.3	108.2 ± 9.8	7	0.36
PEF (L)	342.6 ± 142.4	351.8 ± 174.3	9.2*	< 0.001
Breath carbon monoxide test				
CO (ppm)	5.7 ± 5.5	5.2 ± 5.7	–0.51	0.28
%COHb	0.9 ± 0.9	0.8 ± 0.9	–0.08	0.28

MIP – maximal inspiratory pressure, MEP – maximal expiratory pressure, FVC – forced vital capacity, FVC% – predicted FVC, FEV_1 – forces expiratory volume in one second, FEV_1% – predicted FEV_1, PEF – peak expiratory flow, CO – breath carbon monoxide, %COHb – percentage carboxyhemoglobin level in the blood, values are *Means* ± *SD*, * significant difference ($p < 0.05$)

Table 3. Respiratory muscle function, pulmonary function and breath carbon monoxide test before and after swim training among non-smokers

	Before training	After training	Difference	*p* value
Respiratory muscle function				
MIP (cmH_2O)	69.2 ± 33.9	79.4 ± 34.2	10.2*	0.004
MEP (cmH_2O)	92.8 ± 37.4	113 ± 40.8	20.2*	0.003
Pulmonary function				
FVC (L)	3.9 ± 0.9	4.4 ± 3.2	0.5*	0.02
FVC (%)	92.2 ± 16.1	103.2 ± 11.2	11*	0.02
FEV_1 (L)	3.3 ± 0.9	3.2 ± 1.1	–0.1*	0.02
FEV_1(%)	103.4 ± 22.3	102.9 ± 11.5	–0.5*	0.02
PEF (L)	328.1 ± 134.9	336.5 ± 165.2	8.4	0.23
Breath carbon monoxide test				
CO (ppm)	1.1 ± 1.9	0.9 ± 1.3	–0.2	0.15
%COHb	0.18 ± 0.32	0.15 ± 0.21	–0.03	0.11

MIP – maximal inspiratory pressure, MEP – maximal expiratory pressure, FVC – forced vital capacity, FVC% – predicted FVC, FEV_1 – forces expiratory volume in one second, FEV_1% – predicted FEV_1, PEF – peak expiratory flow, CO – breath carbon monoxide, %COHb – percentage carboxyhemoglobin level in the blood, values are *Means* ± *SD*, * significant difference ($p < 0.05$)

regular physical activity in the aquatic environment expiratory muscle strength in the group of smokers increased by 19% (p <0.001) and in the group of non-smokers increased by 15% (p =0.004). Simultaneously, inspiratory muscle strength increased in both groups (by 14% among smokers and 22% among non-smokers) (Tables 2, 3).

Before the swimming program the predicted values of forced vital capacity and peak expiratory flow between smokers and non-smokers (96.14% vs. 92.23%, 342.59 l/min vs. 328.14 l/min), whereas smokers had FEV_1 values of 101.22% vs. 103.37%. None of these differences between groups were statistically significant (Tables 2, 3).

In both groups there was a statistically significant increase in forced vital capacity. Among smokers predicted values of FVC increased by 8.8% (Table 2), while among non-smokers they increased by 11% (Table 3). Forced expiratory volume in one second increased in the smokers group by 6.95% of predicted values, but decreased in non-smokers' group by 0.43%. The changes in values of peak expiratory flow were not statistically significant for either group (Tables 2, 3).

Discussion

As outlined previously, the impact of physical activity in the aquatic environment on the respiratory system function has been controversial. The results of this study lent support to the hypothesis that swimming and water exercises had a very positive effect on lungs.

The young adults we studied were physiologically mature, which eliminated the impact of lung development changes on respiratory parameters. Before the start of the study none of the participants had participated in any regular physical activity. We considered the possibility of studying respiratory parameters by comparing elite professional athletes with novice amateurs, but the literature showed that the results obtained in the sport may be dependent on the initial capacity of the lungs. According to Wang [15], it is possible that people with more efficient respiratory systems will achieve better results, thus a natural sport selection takes place. For this reason, for this study we chose a group of students of the same age, similar lifestyle (aside from smoking habits), and similar levels of physical fitness.

Statistical analysis showed a statistically significant increase in the parameters of the entire population – forced vital capacity (FVC), maximum expiratory pressure (MEP) and maximum inspiratory pressure (MIP). These results are consistent with prior studies that indicated that water exercises have beneficial effects on the functioning of the respiratory system [5–7].

Comparing smokers and non-smokers, we assumed that smokers would record lower values for forced vital capacity (FVC) and forced expiratory volume in the 1^{st} second of exhalation (FEV_1) than non-smokers [16]. In this study smokers indeed recorded lower values for FEV_1; however, they had higher values of forced vital capacity (FVC), respiratory muscle strength (MIP, MEP), and peak expiratory flow. The percentage carboxyhemoglobin level in the blood was obviously significantly higher among members of the smoking group.

After 10 months of regular swimming, inspiratory and expiratory muscle strength as well as forced vital capacity and peak expiratory flow values increased in both groups. What is interesting is that the improvement was higher in the smoking group. Furthermore, FEV_1 value, initially lower among smokers, after ten months of training significantly increased in this group. On the contrary, FEV_1 among non-smokers showed no significant changes.

Other studies have reported that the value of FEV_1 increases to the age of 25 [17] or even longer, such as until the fourth decade of life [18]. After this time the FEV_1 value plateaus as there is only a slight change in the ratio [17]. After the plateau phase FEV_1 begins to decline. This decrease was linear in non-smokers. However, in smokers FEV_1 reduction starts progressing sooner and at greater speed than in nonsmokers. Kerstjens et al. reported that the annual decline in FEV_1 among male smokers is higher by the average of 15 ml than in non-smoking men [19]. Smoking adversely affected all three determinants of forced expiratory volume in the first second. These determinants are peak value of FEV_1 reached in early adulthood, the length of the plateau phase and the rate of decline in FEV_1. This study indeed showed that the rate of decline in FEV_1 among smokers, even after a relatively short period of smoking (5 years), is higher than among non-smokers. Nevertheless, what is noteworthy, our findings also indicated that swimming and water exercises can delay and slow down the decline in the FEV_1 among smokers.

The positive effect of physical activity in the aquatic environment may be a result of swim training itself: increased respiratory muscle strength, changes in chest wall compliance, alveolar hyperplasia or expansion, or the stimulation of isotropic lung growth [6]. A detailed explanation of the impact of physical activity on the tobacco smoke impaired respiratory system was presented by Menegali et al. [20]. Their study, conducted on mice, showed that smoking causes swelling and destruction of the alveolar epithelium, increase in the number of macrophages and neutrophils, increased production of collagen, reduction in the amount of elastic fibers, and increased free spaces in lungs. Nevertheless, in animals subjected to swim training, partial improvement of measured parameters, reduction of the oxidant production, and increase in the activity of antioxidant enzymes all were observed [20].

Results obtained in this study indicated the importance of promoting swimming activity among smokers in order to delay the effects of smoking on lungs and to improve pulmonary system function. Our results were consistent with another study conducted by [21] which reported that smokers with moderate to high level of regular physical activity were associated with lower pulmonary function decline compared to smokers leading a sedentary lifestyle. Encouraging participation in swimming also could be useful in smoking cessation programs [22]. What is more, the improvement in measured respiratory parameters, observed as a result of regular swim training, confirmed the validity of the use of water exercises and swimming as part of any rehabilitation process for people with chronic respiratory diseases.

Conclusions

After 10 months of swim training there was a significant increase in forced vital capacity and maximum inspiratory and expiratory muscle strength among both smokers and non-smokers. Regular physical activity in the aquatic environment can slow down the adverse effects of smoking on the pulmonary system of youth and encourage them to fight the addiction. Regular physical activity in the aquatic environment should be used as a complementary form of rehabilitation in conditions involving reduced forced vital capacity and respiratory muscle strength decrease.

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