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Development of respiratory function through swimming and apnea exercises in the pool

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Abstract
Background. Swimming is recognized as a beneficial exercise for lung health, having a positive impact on respiratory function.
Aims. This study aimed to evaluate the effect of swimming on lung function by training their respiratory muscles.
Methods. The study involved 22 young students, aged 19 to 24, divided into two groups. One group of 11 participants took part in a swimming and apnea exercise program for eight weeks, three times per week (Monday, Wednesday, and Friday), with each session lasting 50 minutes. The second group, consisting of 11 participants, served as a control group, where only intermediate and final measurements were taken for comparison purposes. Lung function parameters measured included forced vital capacity (FVC, in liters), forced expiratory volume in 1 second (FEV1, in liters), the FEV1/FVC ratio (in %), peak expiratory flow (PEF, in liters/second), FEV25-75 (volume of air expelled between the first and third quarters of vital capacity, in liters/second), FEV6 (forced expiratory volume in 6 seconds, in liters), and the FEV1/FEV6 ratio (in %).
Results. Spirometry test results showed statistically significant differences between initial (TI) and final testing (TF), with respiratory parameters improving by approximately 18% from the initial values before the swimming program began. This increase is attributed to underwater exercises that strengthen respiratory muscles and enhance their efficiency.
Conclusions. Our research demonstrates that the acute effects of swimming training can significantly improve lung function by increasing lung volume and respiratory flow rates.
Keywords: respiratory muscles, training, lung capacity.

Introduction

Two forces act on the body in water: the body's weight (from top to bottom) and the buoyant force pushing it up, which depends on the body's volume, the submerged part, and the density of the liquid. Floating on water is related to the body's specific weight, water density, and hydrostatic pressure, which influences the respiratory system. Women and children float more easily because both categories have lighter skeletal systems than men. The greater the amount of air in the chest through inspiration, the lower the body's specific weight, and floating is much improved. Hydrostatic pressure influences the respiratory system by developing the inspiratory muscles, the chest perimeter, the thoracic cage diameter, and vital capacity (Fitzgerald JR & Houghton LA, 2017).

Swimming is considered a very good exercise for maintaining correct health and also has a profound effect on the lung function of participants. Regular swimming practice has a positive effect on the lungs by increasing lung capacity and improving lung functions. Lung functions are generally determined by respiratory muscle strength, chest cavity compliance, airway resistance, and lung elastic recoil. They can vary based on physical characteristics, age, height, body weight (Hirano, 1995; Udwadia, 1987; Iwamoto 1983), and ambient altitude (hypoxia or low ambient pressure).

When a person swims continuously, physiological changes occur in the body involving practically all muscle groups, and the amount of oxygen consumed by them continuously increases. Breathing is not as free during swimming as in most other types of physical exercises because the pressure of the water on the chest makes it difficult. In these conditions, the load on the functional muscles of the respiratory system increases. In water, breathing must be synchronized with arm and leg movements. It is continuous, but there are moments of apnea (air is held in the lungs) when the chest is blocked. Apnea is interspersed between inhalation and exhalation if breathing is performed every two arm cycles. Prolonged

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apneas are generally found in advanced swimmers in short-distance events.

Aquatic inhalation is executed faster than on land, the favorable moment being relatively short. It is performed through the mouth at the water level and is characteristic of correct swimming. Exhalation is normally a passive act; it becomes active during swimming because hydrostatic pressure must be overcome, except for backstroke breathing. It is executed with progressive intensity, air being expelled first more through the mouth and then through the nose. It must be performed completely. In non-breathing swimming, floating is better due to the position on the water, this exercise being used in preparation for correcting the arm movements' traction (Pyne & Sharp, 2002).

Swimmers perform intense underwater exercises, holding their breath for long periods (Lazovic et al., 2015). The respiratory muscles, including the diaphragm, must develop greater pressure resulting from water immersion during the respiratory cycle, which leads to functional strengthening of the muscles, improved chest wall elasticity, and implicitly a higher level of lung function (Mehrotra et al., 1997).

Objectives

Developing respiratory function through swimming and apnea exercises in the pool can bring multiple health and sports performance benefits. Here are some specific objectives related to these activities:

- improvement of pulmonary capacity
- increase respiratory efficiency
- increase tolerance to carbon dioxide ($CO2$)
- improve respiratory muscle strength
- reduce respiratory rate and save energy
- increase adaptability of the respiratory system to stress conditions

Swimming and apnea exercises can be integrated into a well-structured training program to maximize benefits on respiratory function. It is important to work under the supervision of a qualified coach and ad here to safety principles to avoid risks associated with apneea and intensive swimming.

The aim of the present study was to examine the effect of swimming on pulmonary function in young individuals aged 19 to 24. Previous studies have shown that swimming produces a maximum effect on the lungs compared to any other sport. Pulmonary function is a long-term predictor of overall survival rates in both sexes and could be used as a tool in general health assessment (Clanton & Dixon, 2006).

It is important for the research to be conducted systematically, using standardized evaluation methods and monitoring long-term changes in participants' respiratory capacities. A rigorous study should also consider individual factors such as the level of physical training and previous experience with swimming and apnea exercises.

Hypothesis

The study seeks to determine whether a swimming and apnea exercise program can improve respiratory parameters such as lung capacity and the efficiency of the respiratory muscles.

Material and methods

This research was conducted according to the ethical standards recommended by the World Medical Association (Helsinki). The subjects were informed about the topic of the research, about the way in which the HWC intervention would proceed and the assessment modalities, and then gave their written informed consent.

Each participant provided informed consent to participate in the study, acknowledging the potential risks and benefits involved.

Research protocol

a) *Period and place of the research*

The study was conducted over a period of 8 weeks, during May-July 2022, at the Olympic pool of the Technical University of Cluj-Napoca.

b) *Subjects and groups*

For this study, a group of 22 young individuals aged between 19 and 24 participated, with 11 involved in a swimming program, and the other 11 in other forms of physical activities, for eight weeks, three times a week, with sessions lasting 50 minutes.

Experimental Group (E)

The experimental group consisted of young individuals aged between 19 and 24 years. The participants were selected based on specific inclusion criteria to ensure the homogeneity and reliability of the study results.

Control Group (C)

The control group consisted of young individuals aged between 19 and 24 years, selected to match the experimental group in terms of age, health status, and baseline characteristics. Participants were required to have a similar level of physical activity to the experimental group but without regular engagement in swimming or apnea exercises.

c) *Applied tests (Used instruments)*

The Wilcoxon test is a non-parametric test used to compare two data sets when we cannot assume a normal distribution of differences. Key characteristics of the Wilcoxon test:

- Paired comparisons: The test is intended for paired or dependent data, such as measurements taken before and after an intervention on the same group of subjects.
- Non-parametric alternative to the paired t-test: The Wilcoxon test is the non-parametric equivalent of the paired t-test and is used when the distribution of differences between pairs is not normal.
- Ranking differences: Instead of directly comparing numeric values, the Wilcoxon test uses ranks. Differences between pairs are ordered, and a score is calculated based on the signs and ranks of the differences.
- Applicability: It is widely used in fields such as social sciences, medicine, and scientific research, especially when sample sizes are small or data do not meet the assumptions of parametric tests.

In essence, the Wilcoxon test determines whether there are statistically significant differences between two sets of repeated measurements or paired data. We will apply this test for each variable, comparing the initial and final measurements.

Measurements were made using a laboratory spirometer

(Turninac Pneumotah Pony FX - Cosmed Pulmonary Function Equipment Italy). The parameters considered for pulmonary function testing were FVC (Forced Vital Capacity measured in liters), FEV1 (Forced Expiratory Volume in 1 second measured in liters), FEV1/FVC (forced expiratory ratio calculated in percentages %), PEF (Peak Expiratory Flow measured in liters/second), FEV25-75 (representing the volume of air expelled between the first quarter and the third quarter of the vital capacity measured in liters/second), FEV6 (forced expiratory volume in 6 seconds measured in liters), and FEV1/FEV6 (ratio of forced expiratory volume in 1 second to forced expiratory volume in 6 seconds expressed in percentages %).

The subjects were tested at the beginning of the program to establish baseline values and at the end of the 8-week program to evaluate progress and validate the applied method.

The study involved a structured training program focusing on swimming and apnea exercises. The protocol of E group included:

- *Initial assessment*: baseline measurements of pulmonary function were taken for all participants using spirometry to record parameters such as tidal volume, vital capacity, and forced expiratory volume.
- *Training program:* participants underwent a 8-week training program, consisting of swimming exercises and apnea training sessions. The program was designed to progressively increase in intensity and complexity.
- *Monitoring and adjustments*: participants' progress was monitored weekly, with adjustments made to the training program as needed to ensure safety and optimize outcomes.
- *Final assessment*: At the end of the 8-week program, pulmonary function tests were repeated to measure any changes and improvements in respiratory capacity and efficiency

The C group did not participate in the structured swimming and apnea training program but continued with their usual activities and routines. The protocol included:

- *Initial assessment*: Baseline measurements of pulmonary function were taken using spirometry to record parameters such as tidal volume, vital capacity, and forced expiratory volume, similar to the experimental group.
- *Regular monitoring*: The control group participants were monitored regularly to ensure they did not engage in any new physical activities that could affect the study results. They were asked to maintain their usual lifestyle and physical activity levels.
- *Final assessment*: At the end of the 12-week period, pulmonary function tests were repeated to measure any changes in respiratory capacity and efficiency.

Training program E group

The swim training consisted of sessions 3 times a week, each lasting 50 minutes, divided into two main stages: the warm-up stage and the main stage. Each session was designed to progressively enhance the participants' pulmonary capacity and overall fitness through structured swimming exercises and apnea training. The program was conducted over a 8-week period.

Warm-Up stage: Participants performed specific warm-up exercises for 10 minutes to prepare the circulatory and respiratory systems before entering the pool. The warm-up also focused on stimulating the mobility of both lower and upper limbs to prevent any muscle injuries during swimming.

Main stage: This stage involved approximately 50-60 minutes of swimming training with various exercises conducted weekly in the water. The exercises (Table I) were designed to work at 60-75% of the participants' maximum power capacity, ensuring a moderate level of effort.

One week: Table I

Table I
Experimental group training.

The means used	Volume/ Intensity
Water Acclimatization Exercises: - Keeping the eyes open underwater; - Learning aquatic breathing: taking a deep breath above the water, submerging the head (while holding the breath), and prolonged exhalation (nasal or oral exhalation), at the edge of the pool.	 5 x 5 3-5 min
- Breaststroke kick, arms resting on a float in front.	4 x 25 m
- Freestyle kick while holding the breath; rhythm of 4-6 leg kicks.	25 m
- At the end of each 25 m, pause, where we will: perform the leg kick movement at the pool wall with hands supported by the bar or water drain edge, face down, arms extended, take a breath above water, submerge the head underwater along the water line, and hold the breath. - Same exercise, with exhaling through the nose underwater. - The same exercise with exhaling through the mouth underwater.	3 x10 s 3 x 10 s 3 x 10 s
- Moving forward, breaststroke kick, for 4-6 leg kicks, breathing above water, submerging the face below water level, and exhaling.	4 x 25 m
- Underwater glide, leg kicks, arms extended, without breathing.	5 x 15 m
- Side float with one arm extended in the direction of movement, supported on a float, the other arm extended backward on the opposite leg, leg kicks.	2 x 25 m right arm 2 x 25m left arm

Note: We will take breaks based on pulse and body signals (trembling, purple lips, skin color).

Training Program group C

The **C group** continued their daily activities (Table II) without any training, serving only for comparative data.

Data collection and analysis: Data from the control group were collected at the beginning and end of the study period, mirroring the assessment schedule of the experimental group. The collected data were compared to the experimental group to determine the impact of the swimming and apnea training program. Statistical analysis was performed to evaluate any significant differences between the two groups.

d) *Statistical processing*

Data collection and analysis: data were collected at the beginning and end of the study to compare the effects of the training program on pulmonary function. Statistical analysis was performed in, to determine the significance of the observed changes and to evaluate the effectiveness of the swimming and apnea exercises.

By following this structured approach, the study aimed to provide reliable and valid results on the impact of swimming on pulmonary function in young adults.

At this stage of the analysis, we applied comparison tests to confirm or refute what was observed from the descriptive statistics. Given that measurements were taken on a small sample of subjects (11), it is necessary to apply non-parametric tests. In this regard, considering that the sample size is less than 30 and the distribution of indicators does not follow the normal law, we will apply non-parametric analyses that can provide reliable results even if, for example, the normality assumption is violated. Among these, we applied the Wilcoxon test for the swimming test measurements, which involved two measurements (initial and final). In this case, we present the test values and the obtained probability to evaluate the level of significance and validate the efficiency of the applied procedures.

The SPSS 24 program was used to interpret the obtained results.

Results

We observe (Table II) that for a significance level of 5% ($\alpha=0.05$), the median difference of 0 is rejected (Asymp. Sig. < 0.05), meaning there is a significant difference in the final measurements compared to the initial ones for 5 out of the 7 studied indicators. On the other hand, the median difference of 0 is accepted for 2 indicators, meaning there is no significant difference in the final measurements compared to the initial ones for these indicators (Asymp. Sig.>0.05).

By including a control group that did not participate in the intervention, the study aimed to provide a clear comparison and determine the specific effects of the swimming and apnea exercises on pulmonary function in young adults.

Similarly, we used inferential analysis to see if there are statistically significant differences between the initial and final measurements of the studied indicators for the 11 subjects. Considering that the sample size is less than 30, we applied non-parametric analyses.

We applied the Wilcoxon test with result tables in which we have the ranks for each difference between the final and initial value of the resulting indicators.

We observe (Table III) that for a significance level of 5% ($\alpha=0.05$), the median difference of 0 is rejected (Asymp. Sig.<0.05), meaning there is a significant difference in the final measurements compared to the initial ones for one of the 7 studied indicators. On the other hand, the median difference of 0 is accepted for 6 indicators, meaning there is no significant difference in the final measurements compared to the initial ones for these indicators (Asymp. Sig.>0.05).

Table II
E group, Wilcoxon test results.

Test Statistics[a]							
Statistical indicator	FVC_f – FVC_i	FEV1_f – FEV1_i	FEV1/FVC_f – FEV1/FVC_i	PEF_f – PEF_i	FEF25-75_f – FEF25-75_i	FEV6_f – FEV6_i	FEV1/FEV6_f – FEV1/FEV6_i
Z	-2.936[b]	-2.936[b]	-.534[b]	-2.937[b]	-2.936[b]	-2.934[b]	-.356[c]
Asymp. Sig. (2-tailed)	.003	.003	.593	.003	.003	.003	.722

Table III
C group, Wilcoxon test results.

Test Statistics[a]							
Statistical indicator	FVC_f – FVC_i	FEV1_f – FEV1_i	FEV1/FVC_f – FEV1/FVC_i	PEF_f – PEF_i	FEF25-75_f – FEF25-75_i	FEV6_f – FEV6_i	FEV1/FEV6_f – FEV1/FEV6_i
Z	-1.790[b]	-1.484[b]	-.225[c]	-2.853[b]	-1.924[b]	-.045[c]	-.356[b]
Asymp. Sig. (2-tailed)	.073	.138	.822	.004	.054	.964	.722

Discussion

To further examine whether there are statistically significant differences between the initial and final measurements for the studied indicators, for the 11 subjects in the sample, we used inferential analysis. In this regard, considering that the sample size is less than 30 and the distribution of the indicators does not follow the normal law, we applied non-parametric analyses that can provide reliable results even if, for example, the normality assumption is violated. Thus, taking into account that we have both initial and final measurements (two types) of the studied indicators for the 11 subjects, we will apply the Wilcoxon Signed Ranks Test.

For the experimental group, we note that the median difference of 0 is accepted for the FEV1/FVC indicator (forced expiratory ratio) and FEV1/FEV6 (the ratio between the forced expiratory volume in 1 second and the forced expiratory volume in 6 seconds), for which the descriptive statistics showed a very small or negative relative change for the two studied central tendency parameters (mean and median). Thus, we can say that the preliminary descriptive analysis is supported by the inferential one. And for the control group, we note that for 6 indicators (FVC, FEV1, FEV1/FVC, FEF25-75, FEV6, FEV1/FEV6), there is no significant difference in the final measurements compared to the initial ones for these indicators.

Aside from age, sex, race, height, and weight, lung function in physically normal individuals depends on numerous factors, such as the balance between lung recoil and chest elasticity, i.e., determining the mean position at the end of spontaneous expiration and coordinating neuromuscular function to maintain effort, the strength of thoracic and abdominal muscles, individual posture, and lung elasticity. Unlike other sports, swimming activates the entire muscular system of the body, with an excessive use of the thoracic wall and abdominal muscles, characterized by prolonged breath-holding periods and causing intermittent hypoxia due to the specific training mode (Lavin et al., 2015; Sable et al., 2012). During swimming, external pressure is high; therefore, respiratory muscles along with the diaphragm develop greater pressure for breathing. This leads to improved functional capacity of these muscles. Swimming enhances this ability as it involves keeping the head extended, which is a constant exercise of the erector spinal muscle, resulting in an increase in the anteroposterior diameter of the lungs. The sternocleidomastoid, trapezius, and diaphragm are constantly used (Sable et al., 2012). Long periods of intensive swimming training can increase volume variations in the abdominal region and create more coordination between the compartments involved in respiratory effort (Silvatti et al., 2012).

In general, studies acknowledge that swimming has a positive effect on FVC (forced vital capacity), FEV1 (forced expiratory volume in one second), and pulmonary ventilation (Arafa & Abou, 2020). Khosravi et al., 2013 stated that endurance training (the body's ability to withstand physical efforts) combined with resistance training has a greater effect on lung capacity, FVC, FEV ratings (forced expiratory volume) at 25%-75%, and PEF (peak expiratory flow). Additionally, FVC and FEV1 were found to be higher in swimmers in another study (Santiago & Souza, 2021). The limited ventilation experienced during swimming makes swimmers face intermittent hypoxia. This can lead to alveolar hyperplasia and thus increase FVC and FEV1 (Silva, Santos et al., 2019). According to another study, the results indicated that swimming has a considerable effect on improving an individual's lung functions, as FVC, FEV1, and PEF increased significantly after the swimming session (Brennan & Kinsella, 2018).

Given that significant differences were obtained for most measured indicators in terms of increase from the initial to the final measurement, we can conclude that the applied procedures were effective, leading to the improvement of the subjects' performance. The reason why respiratory parameters were higher after the completion of the program is that the resistance and exercises performed during underwater breathing develop and strengthen the respiratory muscles. This significant increase can be correlated with the effect of swimming on the static and dynamic lung volumes of the tested subjects.

Conclusions

1. From this study, we can conclude that a training program of at least 8 weeks can significantly improve pulmonary function by increasing lung volume and respiratory flow rates. Swimming exercises affect lung volume size because the respiratory muscles, including the diaphragm of swimmers, must generate greater pressure as a result of immersion in water during the breathing cycle
2. The complementary analysis of differential changes in the experimental and control groups also revealed that the improvements were greater in the trained group, and the observed results confirm our initial hypothesis. The significant increase in the strength of the expiratory muscles and its strong correlation with the improvement of certain effort variables strongly suggests a causative role in the increase of respiratory capacity. Although respiratory muscle training is voluntary and may therefore be biased by learning, the absence of changes in the control group strongly supports a real increase in expiratory muscle strength in the trained subjects.
3. According to our study, the following variables showed significant differences after the 8-week swimming training: FVC (forced vital capacity), FEV1 (forced expiratory volume in one second), PEF (peak expiratory flow), and FEV6 (forced expiratory volume in six seconds). Considering that significant differences were obtained for most measured indicators in terms of increase from the initial to the final measurement, we can conclude that the applied procedures were effective, leading to the improvement of the subjects' performance.
4. From this study, we can conclude that a minimum 8-week training program can significantly increase pulmonary function by enhancing lung volume and respiratory flows.

Conflict of interests
We declared that there are no conflicts of interest.

Acknowledgments
The research represents a partial processing of the results

from the doctoral thesis of the first author, currently underway at Babeș-Bolyai University in Cluj-Napoca, Romania.

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