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Article

Effects of breathing exercises on young swimmers' respiratory system parameters and performance

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Abstract: Breathing exercises are widely used to enhance respiratory function and athletic performance. This study aimed to assess the efficacy of a modified exercise regimen on respiratory parameters and its effect on the performance of young swimmers in competition. Thirty-one swimmers aged 16–17 from various clubs in Latvia were selected, comprising an experimental group (n = 15, height: 174.36 ± 7.85 cm, weight: 65.80 ± 9.35 kg, body mass index: 21.60 ± 1.54) and a control group (n = 16, height: 180.78 ± 7.05 cm, weight: 69.90 ± 6.49 kg, body mass index: 21.40 ± 1.56). With an average of eight years of experience, participants trained for approximately 43–45 weeks annually (pool and gym sessions), with an average training duration of 20 ± 2 hours per week. Measurements were conducted on days one and 30, involving spirometry and swimming performance assessment based on the best results in the freestyle 100-meter distance. The experiment consisted of a modified breathing exercise performed thrice weekly for four weeks. Significant improvements were observed in the experimental group compared to the control group in forced vital capacity ($p = 0.02$), peak inspiratory flow ($p = 0.001$), and performance ($p = 0.001$), with p-values < 0.05. However, no significant changes were noted in peak expiratory flow ($p = 0.46 > 0.05$). The findings indicate that modified breathing exercises effectively enhance respiratory parameters and performance in competitive swimmers.

Keywords: swimming; spirometry; respiratory parameters; performance

1. Introduction

Swimming requires a complex of strength, endurance, and technical skills. Achieving peak performance in this sport depends on the efficient coordination of various physiological systems [1]. The respiratory demands of swimming are particularly high due to the challenges of breathing in a prone position and the increased resistance from water. As a result, competitive swimmers typically show recognizable anthropometric characteristics compared to other athletes [2].

Underwater segments in swimming races are vital for competitive success. This section allows swimmers to achieve higher speeds due to reduced drag and the initial momentum from starts and turns [3]. World Aquatics (WA) regulations restrict these underwater sections to 15 meters from the starting or turning wall. Elite swimmers generally cover distances of 8 to 14 meters underwater, depending on the event [4,5]. Research has shown that the length of underwater sections can significantly affect overall performance, as faster underwater speeds and smoother transitions to surface swimming led to better results [6,7]. Skilled swimmers have longer and faster underwater phases than the less experienced peers [8]. However, extended underwater swimming can cause increased fatigue due to hypoxia from breath-holding, necessitating a balance between speed and energy use [9].

Swimming efficiency is closely linked to technique and respiratory system capabilities [10]. Swimmers often have higher inspiratory flow volumes than expiratory flow due to their unique breathing patterns [11]. Studies show respiratory muscle fatigue occurs during high-intensity exercise [12–16]. During such activities, respiratory muscles use 10%–15% of total oxygen consumption, accounting for 15% of cardiac output [17]. Fatigue in these muscles can significantly impact performance by activating a metabolic reflex, where metabolite accumulation in the respiratory muscles increases sympathetic activity, causing vasoconstriction in peripheral muscles [18]. This reduces blood flow to the organ, decreases exercise tolerance, increases breathlessness, and impairs performance [17]. Hyperpnea at 70% of maximum respiratory capacity has been shown to raise blood lactate levels, which affects stroke rate and distance per stroke [19]. Inspiratory muscle fatigue has been noted after 100 meters of front crawl swimming [20].

Endurance training for respiratory muscles, with regular swimming practice, is more effective than training alone for improving performance in 50–200-meter events [21,22]. Respiratory muscle training programs are widely used to increase respiratory muscle endurance and strength, improving overall athletic performance [15,23,24]. Latvian swimmers' international achievements have straggled behind those of neighbouring countries, indicating that increasing respiratory function and underwater efficiency could improve performance.

Research indicates that increased respiratory muscle strength enhances FVC, diaphragm thickness, and physical endurance in healthy individuals [25]. Studies on Latvian swimmers have found a strong correlation between competitive swimming times and peak inspiratory flow (PIF) in adult swimmers (r = 0.75) and a similar relationship in 16–17-year-old swimmers (r = 0.55) [26]. This suggests that Latvian swimmers struggle with underwater sections and highlights the need for the coaches to focus more on developing inspiratory muscle strength during training.

Based on the above research, a modified complex of exercises [27,28] was used to develop respiratory system parameters and evaluate its impact on the performance of young swimmers in competition. The hypothesis is that a modified complex of exercises developing the respiratory system parameters will be used in the particular physical preparation of swimmers, improving the time required to complete the distance in swimming competitions.

2. Materials and methods

2.1. Study design

This exploratory study involved two spirometry tests to evaluate respiratory parameters such as FVC, PIF, and peak expiratory flow (PEF). Prior to starting the intervention, all participants attended two introductory sessions to familiarize themselves with the spirometry procedure. The initial test was conducted at the Latvian Academy of Sport Education Research Centre in Riga in March 2022, before the start of the breathing exercise intervention. The second test was in April 2022 after four weeks of breathing exercises. During the four-week study, the control group followed the typical training routine without altering the breathing techniques. The experimental group followed the regular training regimen but incorporated modified breathing exercises. At the 73rd Latvian Under-19 Championship, swimmers' performance (the 100-meter distance) at a 25-meter swimming pool was assessed using world aquatic (WA) points. A specialist monitored all procedures and followed the Declaration of Helsinki. The research was approved by the Ethics Committee of the Latvian Academy of Sport Education (Approval No. 3/51813). Participation was voluntary, with no financial compensation, and informed consent was obtained from all participants' parents.

2.2. Participants

The study included 31 young swimmers (both male and female), aged 16–17, from various swimming clubs and sports schools in Latvia (**Table 1**). All participants were non-smokers with normal lung function. The swimmers were divided into an experimental group (EG) (n = 15) and a control group (CG) (n = 16). Each swimmer had eight years of experience in short and middle-distance events (50–400 meters) and trained for 43–45 weeks per year, averaging 20 ± 2 hours per week in the pool and gym. The best competition results for each swimmer in a 100-meter event in 2022 were recorded using world aquatics points. These results were obtained from the Swimrankings website [29], which logs and automatically saves competition results. The WA's official International Points Score (IPS) system was used to assess performance, with points (P) calculated using a cubic curve formula:

$$P = 1000 \times \frac{B}{T} \quad (1)$$

where T represents the competition results in seconds, while B is the base time in seconds. The base times are updated annually based on the latest world records approved by world aquatics [30].

Table 1. The anthropometric characteristics of the participants engaged in the current study.

Variable	Experimental group (n = 15) (mean ± SD)	Control group (n = 16) (mean ± SD)
Age (year)	16.15 ± 2.4	16.5 ± 2.0
Height (cm)	174.36 ± 7.85	180.78 ± 7.05
Weight (kg)	65.80 ± 9.35	69.9 ± 6.49
Body mass index	21.60 ± 1.54	21.40 ± 1.56

The participants' dietary intake was not monitored; however, they were advised to avoid consuming caffeine and stimulants, such as energy drinks.

2.3. Breathing exercises

The modified breathing exercises were used [27,28] These exercises comprise three components: two performed on land (**Table A1** for exercises targeting breathing muscle development and **Table A2** for breath retention) and one conducted in water (**Table A3** for specialized breath retention exercises tailored for swimmers). It consists of twelve exercises and three weekly sessions (four weeks). Among these, four exercises strengthen respiratory muscles and expand the chest, while four exercises on land and four water-based practices focus on enhancing breath retention. The eight breathing exercises performed on land aim to establish a consistent breathing rhythm, reduce shallow breathing tendencies, facilitate chest expansion, increase lung capacity, and support the strength of inspiratory muscles. It is recommended that respiratory muscle development and breath retention exercises be incorporated into the training routine three times weekly in swimming sessions. The execution duration gradually increases from up to 20 minutes in the first week to 30 minutes by the fourth week, as outlined in Appendix.

The swimming training program incorporates specific techniques designed to increase breath retention among swimmers, as in previous research [28]. These techniques involve reducing the frequency of inhalations during swimming sessions and gradually extending the duration of breath retention. Integrating these practices into the training regimen three times weekly is suggested. The recommended schedule for inclusion is as follows: the first three practices should be incorporated after the warm-up phase or at the beginning of the main training session. Specifically, the first practice is suggested for Mondays, the second for Wednesdays, and the third for Fridays. The fourth exercise, intended for the concluding portion of the training, should be included three times a week, specifically on Tuesdays, Thursdays, and Saturdays.

2.4. Spirometry

To investigate and evaluate the respiratory system of swimmers, participants underwent a comprehensive assessment of respiratory parameters utilizing a Spiro-Scout spirometer (GANSHORN Medizin Electronic GmbH, Germany). This spirometer is a lung function laboratory based on the "GANSHORN" ultrasound flow measurement method.

Before and after four weeks of breathing exercises, the following respiratory parameters were measured under the supervision of a specialist: FVC, which represents the total volume of air forcefully exhaled after a deep inhalation; PEF, indicating the maximum speed of expiration; and PIF, denoting the maximal speed of inspiration. These measurements were conducted under standardized conditions, including a seated position and breathing through a mouthpiece with a nose clip. Participants were instructed to take a deep breath, followed by rapid and deep inhalations and exhalations into the spirometer [31]. Each participant performed three attempts, and the best result was recorded. Prior to the spirometry procedure, participants received detailed instructions. Following the criteria set by the American Thoracic Society/European Respiratory Society (ATS/ERS), the data were processed using the Ganshorn program LFX.

2.5. Statistical analysis

The data collected from the experiments underwent analysis using the Microsoft Office Excel program. Descriptive statistics were used for data processing, including Mean (M) and standard deviation (SD). The Shapiro-Wilk test was utilized to assess the normal distribution of the data. Subsequently, a paired t-test was employed for data analysis, assuming normality. In cases where the normality assumption was not met, the Wilcoxon signed-rank test was conducted. The significance level was set at $p < 0.05$. All statistical analyses were performed using Jeffreys's Amazing Statistics Program (JASP) version 0.17.

3. Results

3.1. Respirometry system parameters

The descriptive statistics of the respirometry system parameters for both groups are shown in **Table 2**. In the experimental group, the mean FVC in the pre-test was (4.62 ± 0.85). After four weeks of modified breathing exercises (post-test), the mean increased by 4%–6%. The results of paired sample *t*-test (**Table 3**) yielded a significant difference, t (14) = −2.57, p = 0.02 < 0.05, Conversely, for the Control group, FVC showed no significant change (2%) from the pre-test to the post-test, t (15) = −0.28, p = 0.78 > 0.05.

Table 2. Descriptive statistics for the experimental and control groups.

IND	Group	Valid	Median	Mean	SD	Min	Max
EG							
FVC (L)	Pre-test	15	4.49	4.62	0.85	3.32	6.22
	Post-test	15	4.62	4.83	0.84	3.63	6.57
PIF (L/s)	Pre-test	15	6.61	6.37	2.05	3.36	9.21
	Post-test	15	8.14	8.10	2.32	4.81	11.50
PEF (L/s)	Pre-test	15	8.38	8.38	1.70	5.76	10.45
	Post-test	15	8.56	8.56	2.12	4.43	11.20
WA points	Pre-test	15	486.00	482.46	46.54	401.00	553.00
	Post-test	15	520.00	514.93	43.22	438.00	579.00
CG							
FVC (L)	Pre-test	16	5.20	5.20	0.78	3.46	6.22
	Post-test	16	5.21	5.21	0.86	3.50	6.30
PIF (L/s)	Pre-test	16	7.51	7.30	1.40	4.86	9.21
	Post-test	16	7.63	7.35	1.25	5.00	9.06
PEF (L/s)	Pre-test	16	7.99	7.73	2.61	2.38	11.02
	Post-test	16	8.11	7.73	2.49	2.69	11.00
WA points	Pre-test	16	509.50	497.10	53.38	412.00	574.00
	Post-test	16	513.50	497.50	52.70	413.00	570.00

IND—indicator, EG—experimental group, FVC—forced vital capacity, PIF—peak inspiratory flow, PEF—peak expiratory flow, WA—world aquatic, CG—control group, SD—standard deviation, Min—minimum, Max-maximum.

Table 3. Results of respirometry's parameters and WA points (pre and post-test) for the experimental and control groups.

	T	DF	W	Z	P
EG Pre-post					
FVC (L)	−2.5	14	-	-	0.022*
PIF (L/s)#	-	-	0.00#	−3.40#	0.001*#
PEF (L/s)#	-	-	46.50#	−0.76#	0.46#
CG					
Pre-post					
FVC (L)	−0.28	15	-	-	0.78
PIF (L/s)	−0.63	15	-	-	0.53
PEF (L/s)	0.01	15	-	-	0.99
WA points EG	−9.51	14	-	-	0.001*
WA points CG	−0.20	15	-	-	0.84

Nonparametric test, *t*-*t* statistics, df-degrees of freedom, Diff-difference, *p*-*p*-value, *Significant ($p < 0.05$).

Regarding PIF, the experimental group exhibited a pre-test mean (6.37 ± 2.05), which increased by 24%–34% after the intervention. The Wilcoxon signed-rank test indicated a significant difference, $W = 0.000$, $z = –3.40$, $p = 0.001 < 0.05$. Conversely, the Control group showed no significant change (3%) in PIF from the pre-test to the post-test, t (15) = –0.63, $p = 0.52 > 0.05$.

Regarding PEF, the experimental group displayed a pre-test mean (8.38 ± 1.70), which slightly increased by 6% for post-intervention. The Wilcoxon signed-rank test revealed no significant difference, $W = 46.50$, $z = –0.76$, and $p = 0.46 > 0.05$. Similarly, the Control group demonstrated no significant change (4%) in PEF from the pre-test to the post-test, t (15) = 0.01, $p = 0.99 > 0.05$.

3.2. Swimming performance

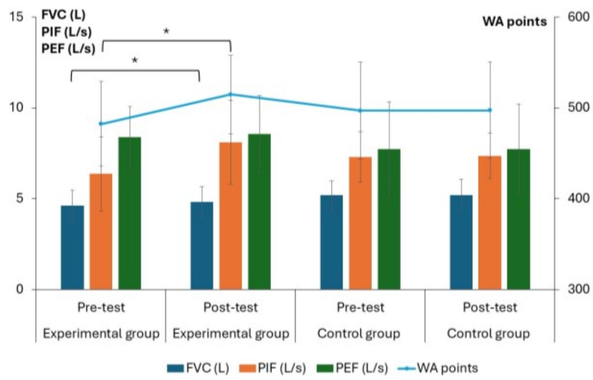

Figure 1. Comparison results of respirometry parameters and WA points.

* $p < 0.05$.

The results of lung function and world aquatic points in 100 meters are shown in **Figure 1** and **Table 3**. In the experimental group, the mean WA points in the pre-test were (482.46 ± 46.54). Following four weeks of modified breathing exercises (post-test), the mean increased by 6%–8%. The paired sample *t*-test revealed a significant difference, t (14) = −9.5, $p = 0.001 < 0.05$.

Conversely, for the Control group, there was no significant change (0%) in mean WA points from the pre-test to the post-test, t (15) = −0.20, $p = 0.84 > 0.05$.

4. Discussion

This study investigated the effects of breathing exercises on the development of respiratory system parameters and the influence on the competitive performance of young swimmers. The results revealed statistically significant associations between breathing exercises and increased FVC, PIF, and performance in the experimental group.

These findings align with previous research indicating that respiratory training can enhance pulmonary functions [32]. It is widely recognized from earlier studies that during swimming activities, the pressure exerted by water on the thorax restricts lung function [33]. In line with the literature [34], the observed increase in FVC can be attributed to the strengthened respiratory musculature.

The elevation in PIF within the experimental group suggests improved breath-holding capacity. This respiratory parameter serves as a metric to assess the potential influence of breathing exercises on enhancing swimmers' performance. Breathing exercises and voluntary breath retention involve controlling breathing cessation and slowing the breathing rate [35], assisting swimmers in regulating the pneumotaxic center and influencing the pontine areas of the brain stem. Mastery of these areas enables individuals to extend the breath-holding duration following inhalation [35].

The difference between our research findings and those studies can be partially attributed to methodological variations. Some studies either lack a control group [36] or utilize a control group engaged in simulated training sessions [37,38]. The difference observed across studies conducted by different authors may stem from the specific concurrent training of inspiratory and expiratory muscles, replicating the respiratory constraints experienced during swimming. This training regimen may facilitate both chest expansion (via inspiratory muscles) and contraction (via expiratory muscles), which is particularly important considering the younger age of our participants (16–17 years).

A study by Wells et al. [10] involving swimmers of comparable age and incorporating inspiratory and expiratory muscle training shows changes consistent with FVC data observed in our study. However, the training duration was longer (12 weeks compared to our four weeks). Such differences in results could be attributed to differences in research design. Previous studies involved elite and adult swimmers [38], whereas our study participants were younger and less trained than those in other studies. This difference in age and training level led to swimmers in our study achieving peak inspiration and expiration more rapidly [39].

In our research, respiratory muscle development and breath retention training were conducted during a specific preparatory phase, whereas in [38], inspiratory muscle training occurred during the competitive phase. For example, the study by Kilding et al. [37] showed a significant impact of inspiratory muscle training and was conducted early in the training regimen. Other studies did not specify the training period during which the research was conducted; however, the efficacy of the inspiratory and expiratory muscle training program may be more related at the onset of the season, aiding swimmers in adapting respiratory function to the demands of swimming [10,40]. During competitive phases, well-trained swimmers may not benefit as much from this intervention. Thus, the training period is a crucial determinant contributing to the differences observed in study results.

While our study did not directly measure respiratory parameters during swimming, this aspect holds significant importance for swimmers. During the brief moments (0.2–0.3 s) when the faces are above water for inhalation, swimmers must maximize the air intake volume. This practice enables them to exhale efficiently while swimming.

Among the first in Latvia, our findings demonstrate that respiratory muscle development and breath retention exercises can enhance respiratory muscle strength and competitive performance in 16–17-year-old swimmers, specifically in the 100-meter distance. These results align with previous research [22,26,37,40], indicating that incorporating inspiratory muscle training alongside swimming activities can enhance respiratory muscle strength among swimmers. Kilding [37] also observed that inspiratory muscle training positively impacts swimming competition results.

An increase in FVC correlates with a reduction in airway resistance and heightened strength of respiratory musculature [41]. This enhancement also contributes to increased physical endurance in healthy individuals [25]. The statistically significant observed inspiratory flow in our study may stem from a relative lack of emphasis placed by Latvian swimming coaches on developing inspiratory muscle strength during training sessions.

Our study demonstrated that using modified respiratory exercises with regular swimming training yielded notable improvements in competition outcomes (measured by WA points) with a significance level of $p = 0.001$. The observed enhancements in other parameters, namely FVC ($p = 0.02$) and PIF ($p = 0.001$), can be partially attributed to the relatively brief duration of the program, spanning four weeks. In comparison, other studies ranged in duration from five weeks [42] to fifteen weeks [43].

One limitation of this study is its limited generalizability due to the inclusion of a relatively small sample size of 31 participants. The sample size was determined based on practical considerations such as participant availability and competition period rather than sample size calculations. Future research should aim to involve larger sample sizes and conduct rigorous sample size calculations to enhance statistical robustness and broaden the applicability of findings. Additionally, the study included female and male swimmers. Post-puberty differences in performance between genders, likely due to hormonal factors such as increased testosterone in male swimmers, which may have influenced our results.

Another limitation is the relatively short duration of four weeks allocated to the modified breathing exercises. Although this period was adequate for enhancing swimming performance and several respiratory parameters, a longer intervention duration might have led to more substantial respiratory adaptations and improved performances.

Furthermore, it is essential to recognize that swimming performance is a multifaceted phenomenon influenced by various factors such as physiological, biomechanical, and psychological factors. Therefore, while modified breathing exercises may have contributed to performance enhancements, attributing improvements to these exercises may overlook the influence of other factors.

5. Conclusions

The study finds that modified breathing exercises to improve respiratory parameters and breath retention in swimming training enhance 100-m competition results. These exercises significantly boost swimmers' performance and are particularly recommended for 16-17-year-olds specializing in distances of 100 m or more.

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Data availability statement: The data supporting this study's findings are available from the corresponding author upon reasonable request.

Ethical approval: The study was conducted by the Declaration of Helsinki and approved by the Ethics Committee of the Latvian Academy of Sport Education (No. 3/51813, 28.10.2021). Informed consent was obtained from all subjects 'parents involved in the study.

Conflict of interest: The authors declare no conflict of interest.

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Appendix

Table A1. Description of the modified exercises to develop breathing muscles (1x a day, 3x a week).

No.	Position	Instruction	Dosage			
			Week 1	**Week 2**	**Week 3**	**Week 4**
1	Standing	Deep breathing: inhale-exhale Breathing should be fluid and even. At the beginning, the diaphragm and abdominal muscles are activated. The lower and middle ribs are involved, and at the end of the inhalation, the upper part of the chest and a little of the neck and back muscles are involved.	8 (4s-In, 4s-Ex)	8 (6s-In,10s Ex)	8 (7s-In,7s Ex)	8 (8s-In, 8s Ex)
2	Standing	Ventilation breathing: Inhale and exhale slightly with resistance through pursed lips. Exhalation should be quick and short.	4 (5s-In,5s Bh, 1s Ex)	4 (6s-In,6s-Bh,1s Ex)	4 (7s-In,7s-Bh,1s-Ex)	4 (8s-In, 7s-Bh,1s-Ex)
3	Standing	Chest expansion: The arms are along the sides. 1—deep breath, breath hold, 2—hands–in front together, 3—hands-back together, 4—exhale quickly and forcefully through the mouth. Repeat the hand movement several times before exhaling.	Eight times	Eight times	Eight times	Eight times
4	Standing	Increasing lung capacity: while hands-on the chest. 1—perform light percussion during a deep breath (light tapping movements with the fingers), 2—carefully clap the hands on the chest during a full inhalation.	Eight times	Eight times	Eight times	Eight times

S—Second, In—Inhale, Ex—Exhale, Bh—Breath holding.

Table A2. Breath retention improvement exercises (1x a day, 3x a week).

No.	Position	Instruction	Dosage			
			Week 1	**Week 2**	**Week 3**	**Week 4**
5	Standing	Hands on hips. Start deep breathing for 4 seconds, 2s breath hold, Then, every 1 second, lean forward, right, left, back, and for 4s-exhale.	Eight times	Eight times	Eight times	Eight times
6	Laying down	The starting position is on the back, with the arms along the body and palms facing down. After the exercise, perform ventilation breathing (2–3 cycles).	8 (4s-Dbi, 2s-Bh, raise legs, 4s-Ex)	8 (4s-Dbi, 2s-Bh, raise legs, 4s-Ex	8 (4s-Dbi, 2s-Bh, raise legs, 4s-Ex)	8 (4s-Dbi, 2s-Bh, raise legs, 4s-Ex)
7	Laying down	The starting position is lying on the back, with the hands along the body, palms down/sitting, and the hands bent on the hips.	20 (5s – In,7s-Bh, 5s-Ex, 3s-Bh)	20 (7s – In,12s-Bh, 7s-Ex, 5s-Bh)	20 (10s –In,15s-Bh, 10s-Ex, 5s-Bh)	20 (12s –In, 17s-Bh, 12s-Ex, 7s-Bh)
8	Laying down	Laying on the back, hands—along the body with palms down/sitting, hands—bent on the hips. Inhale for 5 seconds, exhale for 5s, inhalation retention during exhalation. Inhale and exhale actively, eyes—closed.	3 (30s-Bh)	3 (40s-Bh)	3 (50s-Bh)	3 (60s-Bh)

Dbi—Deep breathing inhale.

Table A3. Special exercises for swimmers to improve breath retention in water (3 times a week).

No.	Name and description of the exercise	Dosage	Notes
9	Swimming in a crawl on the chest, breathing on both sides (bilateral), inhaling for every third stroke, and then 5th, 7th, and ninth.	4 × 400 m The interval method is used to recover at a heart rate of 120 bpm.	It is essential to learn the bilateral breathing technique; this type of breathing naturally makes the movements in the water symmetrical, equalizing the quality of the body's rotation and lunge movements. After mastering the exercise, gradually increase the number of repetitions while holding the breath.
10	Swimming using a swim tube and breathing through the extra/residual volume.	Different distances.	Forced inhalation with extended, deep exhalation. Breathing in and out through the breathing tube is essential.
11	Underwater swimming with flippers will limit the number of breaths.	8 × 50 m Interval method, recovery to a heart rate of 120 beats/m	Forced inhalation, fast and deep. After learning the exercise, gradually reduce the number of inhalations during the distance.
12	"Float" with exhalation. 1—Breathe in, 2—Hold the breath, 3—Immerse the head in the water, pull the legs to the chest, and cover them with the hands. 4—Count to five. 5—Start a slow exhalation in the water.	From one to several repetitions.	Retention of breath during exhalation. Try to exhale as slowly and deeply as possible.