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RESEARCH REGARDING THE IMPACT OF RESISTANCE TRAINING ON SWIMMING PERFORMANCE

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Abstract. *The paper aims to bring to the fore some training methods and equipment that can improve sports performance in swimmers aged 12-14 years. The research, conducted at two swimming centres in Bucharest and Bacău, involved 32 athletes who were divided into two groups as follows: 16 in the experimental group and 16 in the control group. They were elite athletes practising swimming from the age of 5-6 years, 6 to 8 times a week. All of them performed the same in-water training for 14 weeks, but those in the experimental group also used a device to train their respiratory muscles before and after each workout, 3 x 30 inhalations. The research methods used were: literature review, pedagogical observation, experiment, mathematical statistics, and graphical method. The efficiency of the inspiratory muscles was measured using the PowerBreathe K-Series device, which recorded the values of lung capacity, inspiratory muscle strength and power, inspiratory pressure and breathing energy. The obtained results confirm the research hypotheses according to which there is a significant difference (of 36.7%) between the improved times of the two groups in favour of the experimental group, meaning 0.67 hundredths of a second for every 50 m swum in their preferred event after 14 weeks of using the device to train their respiratory muscles.*

Keywords: *lung capacity, inspiratory power, lung power, respiratory muscle training.*

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Introduction

The primary objective of a swimmer is to achieve the fastest possible time in a race. Literature highlights that various anthropometric, physiological, and biomechanical parameters influence optimal performance (Mooney et al., 2016; Dadashi et al., 2015; Vantorre et al., 2010; Ruschel et al., 2007; Hue et al., 2006; Alberty et al., 2006; Smith et al., 1988; Costill et al., 1985).

Swimming demands energy for buoyancy, horizontal movement using arms and legs, and overcoming water resistance. The contribution of anaerobic alactic, anaerobic lactic, and aerobic energy systems varies depending on the competitive event. In the shortest swimming event, the 50m sprint, the relative contributions of each system are as follows: ATP-PC 65%, anaerobic glycolysis (lactate) 30%, and aerobic 5%. For a 200m event, the energy supply comes from ATP-PC 10%, anaerobic glycolysis 20%, and aerobic system 75-80%, while open water swimming or endurance events rely almost exclusively on the aerobic energy system (Australian Swimming Inc., 1996).

Regardless of the form it takes, endurance is an essential quality for swimmers. It defines the ability to sustain prolonged effort at high levels, representing the athlete's capacity to overcome the discomfort induced by prolonged exertion, namely fatigue. In the development of endurance, it is crucial to alternate effort with muscular relaxation; "a muscle in which the phases of action and relaxation are well balanced can work extensively, and an example in this regard is the heart and respiratory muscles" (Lewin, as cited by Hotz, 1985).

Cardiovascular, respiratory, and muscular endurance are crucial factors influencing performance in swimming, regardless of the competition event. Therefore, special attention must be given to the development of aerobic capacity in training.

An athlete's aerobic capacity depends on several factors, including maximal aerobic power measured in relation to the maximum rate at which oxygen is absorbed and used by the body during maximal exercise. This dependence is influenced by the functioning of the pulmonary system, the capacity of the heart, oxygen-carrying capacity and factors associated with the musculoskeletal system (Bassett & Howley, 2000). The pulmonary system, through gas exchange, can substantially limit an athlete's cardiac output (Jones & Carter, 2000) and lactate threshold, where the power and speed that can be sustained at the lactate threshold are important predictors of the endurance capacity (Dumke et al., 2012).

The aerobic training zone encompasses efforts of low and moderate intensity. This zone extends until the rate of lactate production exceeds the rate of elimination. When the lactate accumulation rate rises above the baseline, the aerobic threshold occurs. Once this threshold is surpassed, the swimmer cannot sustain the same pace for an extended period. At this stage, hypoaerobic fibres dominate compared to hyperaerobic fibres. Training above the aerobic threshold affects the muscles' ability to tolerate or buffer acid and eliminate lactate from the intracellular environment (Australian Swimming Inc., 1996).

Studies investigating blood lactate and heart rate responses in relation to swimming speed highlight that the most accurate assessment of anaerobic capacity is obtained in races of 2 × 100m or n × 100m (Keskinen et al., 1989). Metabolic acidosis occurring beyond the anaerobic threshold contributes to performance limitations (Cellini et al., 1986).

An essential aspect of aerobic endurance performance is the ability to sustain the highest percentage of maximum oxygen uptake (%VO_2max) for as long as possible (Bosquet et al., 2002). Additionally, experts have demonstrated that the dynamics of VO_2 can provide valuable information about athletes' long-term physiological adaptations, allowing them to maintain a high %VO_2max in a physiologically balanced state during aerobic endurance performance (Gaesser & Poole, 1996; Poole et al., 1988; Poole and Richardson, 1997).

Consequently, coaches manipulate the training load, whether it is about physical conditioning or technical and tactical improvement (usually described as a combination of volume, intensity, frequency, and dry-land workouts), in different training periods to maximise the performance capacity of their athletes.

In this context, the efficiency of the respiratory system is particularly important in elite swimmers because swimming requires the ability to adjust breathing patterns to higher volumes and flow rates than in other sports, given that water immersion forces athletes to expand their chest wall against greater pressure and increase inspiratory muscle contraction velocity and tidal volume, which could lead to muscle fatigue (Kilding et al., 2010).

Research shows that inspiratory muscle training can be used to improve performance and increase respiratory efficiency in athletes (Illi et al., 2012; Wells et al., 2005).

In order to establish individualised training programmes, it is necessary to monitor vital capacity and inspiratory muscle strength using different techniques or instruments.

The *purpose* of this research is to demonstrate that the use of specific long-distance training once a week (in addition to regular training), together with the use of specific PowerBreathe devices to improve vital capacity, can increase sports performance in swimmers aged 12-14 years.

Research hypothesis

Using a special device to train vital capacity improves the performance of swimmers aged 12-14 years.

Methodology

Methods

The research methods used were: literature review, pedagogical observation, experiment (using the PowerBreathe K-Series device), mathematical statistics (using the t-test and Levene's test) and graphical method.

Procedure

For this research, the PowerBreathe K-Series device was used, which is connected to a computer (Figure 1) and can measure vital capacity or maximum inhaled volume in litres (L), inspiratory power in watts (W), inspiratory flow in litres/second (L/s), inspiratory pressure in cmH2O and breathing energy in joules (J). This device was chosen because it makes 3000 measurements per second, so the provided results are highly accurate and reliable.

Two tests of 10 inhalations were used in the present research. The participants performed two series of 10 inhalations through the device, which then displayed the average score for each athlete.

The tests were performed with this device because it offers the possibility to make measurements during the inspiratory phase (not only when breathing out), and its software automatically calculates the arithmetic mean of the data, so no further calculations are needed after completing the tests. We also believe that it is more relevant to use the data collected during continuous inhalation 10 times than while breathing out as in the case of the spirometer and thus one can obtain the athletes' real results instead of the hypothetical ones. Since swimmers were forced to perform 10 breaths, they could not mislead the device through residual breathing. For this reason, the results provided by the device truly reflect the athletes' vital capacity and power, which are made available to them during competition or training.

All participants did the same dry-land warm-up, dry-land strength training, in-water training and stretching after each workout prescribed by the research leader. The difference between the experimental group and the control group consisted in the use of a respiratory muscle training device by the experimental group athletes before and after each training session, with 3 series of 30 inhalations through the device.

Figure 1. PowerBreathe K-series device connected to a laptop (Breathe Well Physio, n.d.)

Each athlete was instructed to use the device at the maximum bearable power for them during the 3 series of 30 inhalations and exhalations.

Participants

The research participants are 32 elite athletes practising swimming on a daily basis from the age of 5-6 years, who are members of the Steaua Bucharest, SCM Bacău, CSM Bacău and AS Nautica Bacău clubs. They are aged 12-14 years, and many of them are members of the Romanian National Cadet Team, multiple medallists at national and international championships and participants in several major competitions in the country and in Europe.

The present study contains the results and data provided by the PowerBreathe K-Series device. The 32 investigated athletes participated in all existing swimming events, namely: 50 m butterfly, 50 m backstroke, 50 m breaststroke, 50 m freestyle, 100 m butterfly, 100 m backstroke, 100 m breaststroke, 100 m freestyle, 200 m butterfly, 200 m backstroke, 200 m breaststroke, 200 m freestyle, 400 m freestyle, 800 m freestyle and 1500 m freestyle. Specialists distinguish between sprint and long-distance events. Sprint includes all 50 m (butterfly, backstroke, breaststroke, freestyle) and 100 m (backstroke, breaststroke, freestyle) races, except for the 100 m butterfly that is considered a long-distance event. Long-distance events include all 200 m (butterfly, backstroke, bras, freestyle) races, 400 m, 800 m, and 1500 m freestyle, plus the 100 m butterfly, which is thought to be a long-distance event due to its technical difficulty.

Research stages

In the first stage of the research, we went to the clubs located in Bucharest and Bacău, where the athletes and their parents were explained the functioning of the respiratory system and the need to increase vital capacity but especially respiratory muscle strength. We discussed the research hypotheses and how respiratory muscle training could help athletes achieve their goals. The possibility and content of training were discussed with the athletes' parents and coaches, their consent for testing was obtained, and then the initial testing was conducted in Bucharest at the beginning of September. Following the 14 weeks of specific training performed in water and on dry land, at the end of the 2022 season (after the National Cadet Championship in December 2022), the final testing took place.

Results

Table 1. *Comparative analysis of the results obtained by the experimental group vs. the control group at the initial testing - final testing_ Lung volume*

GROUP	Mean	Mean diff.	Median	SD	Minimum	Maximum	Range	Variation coeff
iT Experiment	2.22	0.32	2.16	0.51	1.38	3.39	2.01	23.07
Control	1.90		1.80	0.41	1.24	2.71	1.47	21.37
fT Experiment	2.60	0.45	2,77	0.52	1.85	3,48	1.63	19.87
Control	2.15		1,96	0,42	1,62	2.91	1.29	19,54

Table 2. *Independent T-test control group vs experimental group _ Lung volume*

Testing	Levene test for dispersion equality		t-test			Effect size
	F	Sig.	Mean difference	t	P	
initial	2.71	0.110	0.32	-1.474	0.080	0.695
Final	7.207	0.011	0.45	-2.684	0.011	1.42

The results show a t = -1.474 at the baseline test, at p of 0.080, higher than 0.05, from which we can conclude that *in terms of lung volume of athletes in the experimental group vs control group at baseline testing, the difference is not significant.* At the final test, t = -2.684 at a p-value of 0.011, less than 0.05 highlights that the lung volume of the experimental group is significantly higher than that of the control group at the final test, with a difference of 0.45.

Table 3 *Comparative analysis of the results obtained by the experimental group vs. the control group at baseline test - final test _ Vital power (Watt)*

GRUPS	Mean	Mean diff	Median	SD	Minimum	Maximum	Range	Variation coeff.
iT Experiment	4.86	1.7	2.80	4.49	1.18	11.40	10.22	82.61
Control	3.16		2.62	2.61	0.86	15.53	14.87	92.34
fT Experiment	6.97	2.52	5.62	4.49	2.51	19.29	16.78	64.46
Control	4.45		3.69	2.82	2.24	12.85	10.61	63.43

Table 4. *Independent T-test control group vs experimental group at baseline test - Vital power (Watt)*

Test	Levene test for equal dispersions		Equal dispersions	t-test for equality of means			Effect size
	F	Sig.		Mean difference	t	P	
Initial	1.715	0.200	1.203	1.70	-1.22	0.119	0.478
Final	3.615	0.066	1.782	2.52	-1.803	0.045	1.41

The value of t = -1.22 at a significance threshold of 0.119, greater than 0.05, indicates that concerning the lung power (Watt) of athletes in the two groups, the difference at the initial testing is not significant.

At the final testing, obtaining a t = -1.803 and a significance threshold of 0.045, less than 0.05, highlights that the difference at the final testing is statistically significant.

Table 5. *Comparative analysis of results obtained by the experimental group vs. the control group at initial testing – final testing _ Airflow (CmH2O)*

GRUPS	Mean	Mean diff	Median	SD	Minimum	Maximum	Range	Variation Coefficient
iT Experiment	15.97	2.34	12.31	5.07	7.77	32.52	24.75	48.63
Control	13.63		13.44	7.77	7.95	26.30	18.35	37.19
fT Experiment	21.83		20.07	8.29	11.39	45.21	33.82	37.96
Control	16.52	5.31	14.97	4.70	11.14	28.68	17.51	28.43

Table 6. *Independent T-test control group vs. experimental group at initial testing - Airflow (CmH2O)*

Test	Levene test for equal dispersions		t-test			Effect size
	F	Sig.	Mean difference	t	P	
Initial	1.014	0.321	2.34	-1.007	0.164	0.364
Final	4.971	0.033	5.31	-1.994	0.032	1.414

The results highlight a t = -1.007 at a significance level of 0.164, higher than 0.05, and we can assert that the difference in airflow in CmH_2O between athletes in the control group and the experimental group at the initial testing is not statistically significant.

At the final testing, t = -1.994 at a significance level of 0.032, less than 0.05, indicates a statistically significant difference in the airflow in CmH_2O between athletes in the control group and the experimental group.

Table 7. *Comparative analysis of results obtained by the experimental group vs. the control group at initial testing – final testing _Respiratory Energy (Joule)*

GROUPS	Mean	Mean diff.	Median	SD	Minimum	Maximum	Range	Variation Coef.
iT Experiment	40.16	12.77	31.25	29.84	10.56	117.22	106.66	74.31
Control	27.39		23.17	15.31	10.46	75.01	64.55	55.89
fT Experiment	46.41	12,59	43.33	27.89	18,53	135,91	117.37	60.08
Control	33.82		30.70	19.89	17.65	85.26	67.61	49.95

Table 8. *Independent T-test control group vs. experimental group at initial testing - Breathing energy (Joule)*

Test	Levene test for equal dispersions		Equal dispersions	t-test for equality of means			Effect size
	F	Sig.		Mean difference	t	P	
Initial	2.318	0.138	9.028	12.77	-1.399	0.091	0.565
Final	2.387	0.132	8.906	12.59	-1.476	0.080	1,413

The results highlight a t = -1.399 at a threshold level of 0.091, higher than 0.05, demonstrating that the difference in respiratory energy expressed in Joules between athletes in the control group and the experimental group at the initial testing is not statistically significant.

At the final testing, t = -1.476 at a threshold level of 0.080, still higher than 0.05, leading us to the conclusion that the difference in respiratory energy expressed in Joules between athletes in the control group and the experimental group at the final testing is not statistically significant.

Table 9. *Comparative analysis of the difference in time/event obtained by the experimental group vs. control group at the final testing*

GROUPS	Mean	Mean diff.	Median	SD	Minimum	Maximum	Range	Variation Coef.
Experiment	1.83	0.67	1.75	0.71	0.52	3.27	2.75	38.78
Control	1.16		1.37	0.92	-0.36	2.36	2.72	79.60

Table 10. *Independent T-test control group vs experimental group final test – improved times*

Levene test for equal dispersions		Equal dispersions	t-test for equality of means			Effect size
F	Sig.		Mean difference	t	P	
5.230	0.029	0.471	0.67	-2.494	0.012	0.822

The data entered the analysis reveal a t = -2.494 at a threshold level of 0.012, less than 0.05. This implies that the difference in times obtained by athletes in the experimental group compared to the control group at the final testing is statistically significant.

Results Interpretation:

The statistical analysis reveals important insights into the impact of respiratory muscle training on the performance of elite swimmers aged 12-14 years. Here are the key findings:

1. Lung Volume:

- Initial Testing: The t-value of -1.474 at p = 0.080 (> 0.05) suggests that the difference in lung volume between the experimental and control groups at the start is not statistically significant.
- Final Testing: A t-value of -2.684 at p = 0.011 (< 0.05) indicates a significant increase in lung volume for the experimental group compared to the control group, with a difference of 0.45 litres.

2. Inspiratory Power (Watt):

- Initial Testing: The t-value of -1.22 at p = 0.119 (> 0.05) suggests that there is no significant difference in inspiratory power between the two groups at the beginning.
- Final Testing: The t-value of -1.803 at p = 0.0457 (< 0.05) indicates a statistically significant improvement in inspiratory power for the experimental group compared to the control group.

3. Inspiratory Flow (CmH2O):

- Initial Testing: The t-value of -1.007 at p = 0.164 (> 0.05) suggests no significant difference in inspiratory flow between the two groups initially.
- Final Testing: A t-value of -1.994 at p = 0.032 (< 0.05) indicates a statistically significant difference in favour of the experimental group in inspiratory flow.

4. Breathing Energy (Joule):

- Initial and Final Testing: In both instances, the t-values (-1.399 and -1.476) at p = 0.091 and 0.080, respectively, are greater than 0.05, suggesting that the difference in breathing energy is not statistically significant.

5. Improved Times:

- A t-value of -2.494 at p = 0.012 (< 0.05) demonstrates a significant difference in the improved times of the experimental group compared to the control group at the final testing. This signifies a performance improvement of 36.7% in favour of the experimental group.

Discussions and Conclusions

Data processing and analysis demonstrate that the use of a special device to train vital capacity during each training session have improved the performance of swimming athletes aged 12-14 years.

Our results are also confirmed by other studies and highlighted in the literature. Some examples in this regard will be presented below.

Volianitis et al. (2000) conducted a study on 14 elite female rowers to investigate whether resistive inspiratory muscle training (IMT) influenced their rowing performance. The authors concluded that, after 11 weeks of using an IMT device, inspiratory muscle strength increased by 44 ± 25 cmH2O for the intervention group compared to the control group, whose improvement was only 6 ± 11 cmH2O; also, the time achieved by the intervention group in the

5000 m event decreased by 36 ± 9 seconds compared to only 11 ± 8 seconds for the control group.

The research carried out by McFadden (2011) on 23 trained cyclists found that inspiratory muscle training increased anaerobic power during the final sprint phase of a time trial.

Wilson et al. (2013) conducted a study to determine the effect of specific respiratory muscle warm-up on 15 elite swimmers before the 100 m freestyle race. Each athlete completed four different IME (inspiratory muscle exercise) warm-up protocols as follows: swimming-only warm-up; swimming warm-up plus IME warm-up; swimming warm-up plus sham IME warm-up; IME-only warm-up. According to the research findings, specific respiratory muscle warm-up improved the results by 1.18 seconds compared to IME-only warm-up and by 0.62 seconds compared to swimming-only warm-up.

Rozek-Piechura et al. (2020) examined the effects of inspiratory muscle training (IMT) on 25 long-distance runners during 8 weeks of training. The authors randomly divided the athletes into three groups depending on the type of IMT used: PowerBreathe device (group 1), Threshold IMT device (group 2) and a control group. The assessed lung variables were the following: vital capacity, forced vital capacity, forced expiratory volume in one second and peak expiratory flow. According to the study results, group 1 (which used the PowerBreathe device) showed significant increases in all assessed physical and physiological performance variables, while in group 2 (which used the Threshold IMT device), only oxygen uptake, maximum ventilation and respiratory exchange rate ventilation significantly increased to a similar level as the one noticed in group 1; moreover, in the control group, none of the variables recorded a significant reduction in saturation.

Turner et al. (2011) have demonstrated in a study on 16 highly-trained male cyclists that inspiratory muscle training (IMT) lowers the oxygen cost of breathing during voluntary hyperpnoea. This reduction in the O_2 requirement of the respiratory muscles after a period of IMT can facilitate an increase in O_2 availability to the active muscles during exercise and can thus improve athletic performance.

Romer et al. (2002) examined the influence of specific inspiratory muscle training (IMT) on 16 professional cyclists participating in simulated 20- and 40-km time trials. The authors showed that group mean values for maximum inspiratory mouth pressure decreased by 18% and 13%, respectively, 2 minutes after the end of the race and remained below pre-exercise values at 30 minutes. Significant improvements in these time trials were also observed (3.8 ± 1.7 and 4.6 ± 1.9%, respectively).

Menzes et al. (2018) conducted a review of respiratory muscle training devices and compared 14 such devices by searching databases, books, websites selling rehabilitation-related products and reference lists of the retrieved papers. Their analysis has led to the conclusion that, out of the 14 devices currently available on the market and reported by published studies, it is not possible to choose the best one based only on their technical information and clinical utility. To select the most appropriate device, "it is also necessary to consider the specific health condition, the nature of the impairments, the purpose of the training, and whether it is for use within research or clinical contexts" (Menzes et al., 2018).

Chang et al. (2021) studied the influence of inspiratory muscle training on 20 recreational 800-m college track runners who trained at least 3 times per week for a minimum of 60 minutes. They were divided into an experimental group and a control group that both performed the same skill training and weight training for 4 weeks; however, the control group also performed additional training with a respiratory muscle training device. The results indicated that the 4-week IMT training (twice a day, 5 days per week) significantly improved inspiratory muscle strength and 800 m running performance. The obtained results confirm the research hypotheses and can be of great help in guiding coaches in their daily work.

Through these training sessions, swimming coaches can develop lung capacity at an early age and can achieve better results with their athletes.

The statistical analysis of the results obtained by the athletes in the experimental group highlights a significant difference at the final testing for lung volume (0.49 L), vital power (2.52 Watt), and airflow (5.21 CmH_2O). However, the statistically insignificant difference is recorded in respiratory energy.

Furthermore, a statistically significant difference is observed in the times obtained by the athletes of the two groups, in favour of the experimental group, after the National Swimming Championship in December 2022.

The obtained results confirm the research hypotheses according to which there is a significant difference of 36.7% between the improved times of the two groups in favour of the experimental group, meaning 0.67 hundredths of a second for every 50 m swum in their preferred event after 14 weeks of using the device to train their respiratory muscles.

Conclusions

The data analysis supports the research hypotheses, showing that the use of a respiratory muscle training device enhances the performance of young swimmers. The results align with findings from other studies in various sports, emphasizing the positive impact of inspiratory muscle training on strength and performance.

These improvements in lung volume, inspiratory power, and inspiratory flow are consistent with the literature, showcasing the potential benefits of incorporating respiratory muscle training into the overall training regimen of athletes. The results also highlight the importance of considering specific training protocols and devices for optimal outcomes.

Overall, the study contributes valuable insights to coaches, affirming the effectiveness of the implemented training program in enhancing the respiratory capacity and overall performance of young swimmers. The statistical findings provide a solid foundation for future research and underscore the significance of tailored respiratory muscle training in competitive sports.

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Institutional Review Board Statement: The research was conducted according to the principles stated in the Declaration of Helsinki. Written informed consent was obtained from all patients. The study was approved by the Ethics Committee of the National University of Physical Education and Sport in Bucharest, with no. 86/SG.

Informed Consent Statement: The written informed consent for the participants in this study was obtained.

Data Availability Statement: Data are available upon request to the contact author.

Conflicts of Interest: The authors declare no conflict of interest.

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