Inspiratory muscle training improves the swimming performance of competitive young male sprint swimmers

Article *in* The Journal of sports medicine and physical fitness · January 2021

DOI: 10.23736/S0022-4707.21.11769-4

6 authors, including:

Rodrigo Yañez-Sepúlveda
Universidad Andrés Bello
63 PUBLICATIONS 101 CITATIONS

Ildefonso Alvear-Ordenes
Universidad de León
42 PUBLICATIONS 294 CITATIONS

Alvaro Tapia
Universidad Tecnológica de Chile
1 PUBLICATION 1 CITATION

Humberto Verdugo
Sports Medicina Deportiva
3 PUBLICATIONS 6 CITATIONS

The Journal of Sports Medicine and Physical Fitness
EDIZIONI MINERVA MEDICA

Inspiratory muscle training improves the swimming performance of competitive young male sprint swimmers

Rodrigo YAñEZ-SEPULVEDA, Ildefonso ALVEAR-ORDENES, Alvaro TAPIA-GUAJARDO, Humberto VERDUGO-MARCHESE, Carlos CRISTI-MONTERO, Marcelo TUESTA

The Journal of Sports Medicine and Physical Fitness 2021 Jan 22
DOI: 10.23736/S0022-4707.21.11769-4

Article type: Original Article

Article first published online: January 22, 2021
Manuscript accepted: January 7, 2021
Manuscript revised: December 22, 2020
Manuscript received: September 14, 2020

Inspiratory muscle training improves the swimming performance of competitive young male sprint swimmers

Running title: Swimming performance after inspiratory muscle training

Rodrigo Yañez-Sepulveda[1, 2], Ildefonso Alvear-Ordenes[2], Alvaro Tapia-Guajardo[3], Humberto Verdugo-Marchese[4], Carlos Cristi-Montero[5,] Marcelo Tuesta[4,6,*]

1. Physical Education School. Universidad de Viña del Mar, Chile

2. Applied Physiology Laboratory (FISAP). Institute of Biomedicine (IBIOMED), Universidad de León, Spain.

3. Physical Education School, Universidad Andres Bello, Viña del Mar, Chile.

4. Laboratory of Sport Sciences, Centro de Medicina Deportiva Sports MD, Viña del Mar, Chile.

5. IRyS Group, Physical Education School, Pontificia Universidad Catolica de Valparaíso, Valparaíso, Chile.

6. School of Kinesiology, Universidad Andres Bello, Viña del Mar, Chile.

*Corresponding author:

PhD. Marcelo Tuesta

School of Kinesiology, Universidad Andres Bello

Quillota 980, 2531015, Viña del Mar, Chile.

email: marcelo.tuesta@unab.cl

ABSTRACT

BACKGROUND: Inspiratory muscle training (IMT) stimulates the strengthening of the respiratory muscles by placing a resistance to the entry of air into the lung. The objective was to observe the effect of IMT on swimming performance, and its relationship with inspiratory strength and lung function. **METHODS:** Fifteen male swimmers (age=15.1±1.1 years) were divided into an experimental group (EG; n=9) and a sham control group (SCG; n=6). Lung flows/volumes using spirometry, dynamic inspiratory strength (S-Index), maximum inspiratory flow (MIF), and swimming tests (50-m, 100-m and 200-m) were measured before and after a four-week aerobic swimming training program (R1-R2) and IMT. An initial load at 50% and 15% of S-Index was adjusted for EG and SCG respectively. Only the EG increased the initial load by 5% each week. **RESULTS:** The S-Index and MIF were only increased in the EG after IMT (ΔS-Index=18.0±8.8 cmH_2O and ΔMIF=0.7±0.33 $L \cdot min^{-1}$; $p<0.05$). The same occurred for FVC (Δ=0.3±0.2 l), and MVV (Δ=6.9±3.6 $l \cdot min^{-1}$) ($p<0.05$). For swimming performances, the EG swimming times decreased significantly respect to CG for 50-m (Δ_{EG}=-1.2±0.3 s vs Δ_{CG}=-0.1±0.2 s), 100-m (Δ_{EG}=-2.9±1 s vs Δ_{CG}=-0.7±0.5 s) and 200-m (Δ_{EG}=-7.3±2.8 s vs Δ_{CG}=-2.0±1 s) with $p<0.05$. Finally, the S-Index and MIF had a negative correlation with swimming performances for 50-m (S-Index, r=-0.72; MIF, r=-0.70) and 100-m (S-Index, r=-0.65; MIF, r=-0.62) with $p<0.05$. **CONCLUSIONS:** A short-period IMT increases the maximum S-Index, ventilation and MIF which positively influence the swimming performance of young swimmers.

Key words: Inspiratory capacity, pulmonary function, swimming, sports performance.

INTRODUCTION

Inspiratory muscle training (IMT) has increased in popularity among athletes and trainers. The increase in physical performance produced by IMT has been observed in various sports such as rowing [1], handball [2], rugby [3], and swimming [4].

Previous studies have shown that the muscles of respiration can become fatigued during swimming, thus limiting sports performance [5]. This effect is attributed in part to the action of the metabolic reflex. This reflex involves the stimulation of metabolic (group iv) and mechanical (group iii and iv) respiratory receptors, which trigger a vasoconstrictive sympathetic response in the muscles of the limbs that are active and inactive, by producing a redistribution of the cardiac output to the respiratory muscles [6]. This effect will cause a decrease in the oxygenation and lactate elimination of the muscle of the limbs, limiting the muscle work [7, 8]. As an adaptation to IMT, less accumulation of H^+ will be found, lactate clearance will increase, and inspiratory strength/endurance during exercise will improve. Likewise, respiratory work and demand for blood flow will decrease, by delaying respiratory fatigue and maintaining the capacity to produce energy in the active musculature [9].

To prescribe IMT, it will be necessary to measure the maximum inspiratory muscle force. Currently, there are two methods for evaluating muscle strength in athletes: the traditional quasi-isometric assessment of maximum inspiratory pressure (MIP), and the dynamic assessment using the S-Index [10]. The latter has gained popularity due to the comfort of its use, since it allows a small passage of air in the equipment, by removing or minimizing the risk of the onset of uncomfortable symptoms such as pressure in the ears, dizziness, and dyspnea, among others. Furthermore, the equipment that measures the S-Index can be used for training. Even though this index does not allow the real MIP to be determined, this equipment has an adequate reliability to assess the inspiratory muscle force [11, 12]. However, most studies on the effects of IMT in sports have used at least a four-week program of respiratory muscle activation training and the most frequently used equipment to this end includes linear resistance features [13-16].

In swimming, IMT has been shown to improve the sports performance of competitive adults, mainly in the shorter tests, improving times by 1.7%, 1.5% and 0.6% in 100-m, 200-m and 400-m respectively [4]. Along with the above, IMT has also shown improvements in lung function [17]. Mickleborough et al. (2008) observed an increase in FEV_1, FVC and TLC after twelve weeks of IMT in elite swimmers [18]. Four-week IMT improvements in performance have also been previously observed in young swimmers who wore swim fins, in whom the performance under water was compared during apnea [15]. Although the intensity of effort plays a determining role in respiratory work, the use of the upper extremities in swimming has been shown to increase respiratory fatigue [5]. Thereby, a developing swimming technique, most likely observed in young swimmers, could promote respiratory fatigue [19]. In this sense, IMT in this group of athletes becomes a real alternative to improve sports performance. Therefore, the aim of this study was to determine the effect of a four-week IMT program on performance in the 50-m, 100-m, and 200-m swim tests in the freestyle of young swimmers, and its relationship with maximum dynamic inspiratory strength and changes in lung function.

METHODS

Ethics statement

Participants and their parents or guardians were informed about the experimental protocols and questions were clarified. Before starting the assessments, both participants and their parents or guardians had to sign the written informed consent and assent forms, respectively. Data confidentiality was ensured through the encoding of the participants' names, whose results were always saved on the same computer with the researcher's fingerprint code. The research protocol was approved by the bioethics committee of the University of Viña del Mar (code R62-19a). The research was carried out following the recommendations outlined in the Declaration of Helsinki for human studies.

Participants and experimental design

To determine the sample size, an *a priori* calculation was made using the mean and standard deviation differences in swimming performance between experimental and control groups (100-m test: -1.7±1.4 s) from Kilding et al. [4], an alpha error of 5% and a statistical power of 80%. A minimum of 6 subjects per group were required (G*Power statistical software 3.1.9.7, Germany). A total of 19 male swimmers of national competitive level were recruited and randomly divided into 2 groups; i) experimental group (EG), n= 10, and ii) sham control group (SCG), n= 9. As inclusion criteria, participants had to have a minimum of 3 years of systematic training with more than 10 hours of weekly training and no previous experience with IMT. Those participants who showed restrictive or obstructive respiratory disorders, those who did not perform more than 90% of the IMT sessions - according to the experimental protocol-, or those who had suffered a serious injury within the previous 6 months were excluded from the study. Both groups continued their regular aerobic swimming training program in the preparatory phase, which was supervised by a trainer certified by the International Swimming Federation (FINA for its French initials). Aerobic training consisted of an impact microcycle (R1) and three aerobic loading microcycles (R2) with a total volume of 108.3 km. In the gym, 3 weekly training sessions were carried out with a load (60% -70% of 1RM) to improve resistance strength in the upper and lower extremities (1 h), and functional movements (30 min) to stabilize the core musculature. Then, only the participants in the EG included the IMT on a daily basis during the four microcycles (four weeks), while the participants in the SCG performed a simulated routine with a load considered non-adaptive for the respiratory system. Previously, participants had attended a session to become familiarized with the inspiratory resistance equipment and were given recommendations for proper equipment maintenance and adjustment of load parameters. The week before and after the IMT period, lung function measurements were performed using spirometry, dynamic inspiratory muscle strength (S-Index) and performance assessment in 50-m, 100-m, and 200-m swimming tests. Before, during and after the experimental period, instructions and reminders were given to participants to maintain the recommendations given by the trainer for extra physical activity in addition to swimming training, to maintain their usual diet and to not use ergogenic or stimulant supplements.

PROCEDURES AND MEASUREMENTS

Spirometry

Following the guidelines described in the American Thoracic Society and European Respiratory Society, the following lung function parameters were obtained with spirometry using a MicroLab equipment (Viasys®, Healthcare): forced expiratory volume in the first 1 second (FEV_1); forced vital capacity (FVC); peak expiratory flow (PEF); relationship between FEV_1 and FVC or Tiffeneau index ($VEF_1 \cdot FVC^{-1}$); forced expiratory flow between 25% and 75% of the maximal flow ($FEF_{25\%-75\%}$); and maximal voluntary ventilation (MVV) [20]. The subjects had to be seated with their backs straight on a chair fixed to the floor wearing a clamp on their noses while they inhaled and exhaled to their maximum capacity. The best values obtained after three spirometry tests that met the quality criteria of the American Thoracic Society and European Respiratory Society were recorded. The MVV was obtained by multiplying $FEV_1 \cdot -37.5$. The spirometer was calibrated with a 3-L syringe.

Maximum inspiratory muscle strength

A POWERbreathe Kinetic K5® device (HaB International Ltd., UK) was used to determine the maximum dynamic muscle strength (S-Index) and maximum inspiratory flow. This device has a small air leak to avoid glottic closure during the procedure. Participants were then asked to perform maximum inhalations starting from the residual volume. The highest value of the 3 highest efforts was chosen, out of a maximum of 10 efforts, whose differences between them were not greater than 10%. A rest interval of 1 min was allowed between consecutive efforts. To avoid the learning effect, a warm-up of the respiratory muscles was carried out as recommended by Volianitis group [21].

Swimming performance test

Participants performed three freestyle swimming tests of 50-m, 100-m and 200-m, in an Olympic pool, one each day for three consecutive days. The performance was considered as the time that the swimmer took to complete the distance, which was recorded with an electronic stopwatch (Colorado Time Systems®, USA). All assessments were supervised by a judge accredited by the International Swimming Federation (FINA®). Prior to each test, a 10-minute warm-up with standard swimming joint mobility exercises was done.

Inspiratory muscle training

For 4 weeks, the subjects in the EG carried out two daily IMT training sessions (one in the morning and one in the afternoon) with POWERbreathe Classic Competition® devices (PWB) (HaB International Ltd., UK). In each session, participants had to perform 30 dynamic inhalations to their maximum capacity at an adjusted load per week according to the S-Index. For the EG, the load was adjusted to 50% of the S-Index and for the SCG to 15% of the S-Index. The load for the EG was increased by 5% each week, however, the SCG maintained the load at 15%. If the subject reached the maximum load before four weeks, then he had to maintain it until the end of the training period. Before each training session, the subjects of both groups had to perform 30 maximum inhalations at an intensity of 15% of the S-Index as a warm-up. Participants were asked to keep a record of their training and write down if they felt any symptoms or detected any signs of discomfort caused by the training (for example: headache, muscle pain, feeling of shortness of breath, among others). If any of the above symptoms appeared, the training would be suspended.

Statistical analysis

All data are presented as mean ± and standard deviation. The Shapiro-Wilk test that was initially applied showed a normal distribution of all variables. To observe the effect of IMT on the variables of dynamic inspiratory muscle strength, lung function and sports performance pre-post differences within the groups, a two-way ANOVA analysis with the Bonferroni test for multiple comparison were used. The differences in variation were compared (post-pre= Δ) between both groups using the Student's *t*- test. Moreover, Cohen's *d* statistic was applied with the relative magnitude of any difference expressed using the standard criteria: small= 0.2 – 0.59, medium/moderate= 0.6 – 0.79, large= > 0.8. The Pearson correlation test was used to observe the association between respiratory parameters (inspiratory strength and lung function) and changes in swimming performance. The magnitude of the correlation effect was based on the following scale: trivial (<0.10), small (0.10 – 0.29), moderate (0.30 – 0.49), high (0.50 – 0.69), very high (0.70 – 0.89), almost perfect (≥ 0.90), and perfect (r= 1.00) [22]. A statistical significance was considered for all tests with $p < 0.05$. The analyses were carried out with the software GraphPad Prism 8.0.2 for Windows.

RESULTS

Out of the 19 young swimmers, four withdrew from the study. One swimmer from the EG withdrew from the study due to experiencing dizziness after conducting the first IMT, another withdrew from the SCG for failing to complete at least 90% of the training sessions, and two swimmers withdrew as they did not attend the second assessment within the post-study week (due to illness). Almost all athletes completed the 56 training sessions (100%), except one who completed 54 sessions (96%). In Table 1, the general characteristics of the swimmers are shown.

In Table 2, averages of IMT-induced changes in muscle strength, lung function, and performance are shown. When comparing the baseline results of all measurements, only the sports performance in the 200-m was significantly higher in the EG if compared to the SCG with 144.1 ± 5.2 s versus 156.4 ± 8 s, respectively ($p=0.003$). When comparing within groups, only the participants in the EG had a substantial increase of the S-Index ($p=0.0003$), the inspiratory flow ($p=0.0008$), VEF_1 ($p=0.007$), FVC ($p=0.0004$), PEF ($p= 0.01$), $FEF_{25-75\%}$ ($p=0.03$), and MVV ($p=0.0001$). Likewise, only the participants in this group reduced swimming times in 50-m ($p=0.0001$), 100-m ($p=0.0001$) and 200-m ($p=0.0001$). Regarding the comparison between groups of changes induced by IMT, we found significant and large effects in respiratory muscle strength (S-Index) (ES: 1.29 $CI_{95\%}$: 0.15 to 2.38; $p=0.03$) and MIF (ES: 1.31 $CI_{95\%}$: 0.16 to 2.42; $p=0.02$). Moreover, large reductions in swimming times in all three tests such as 50-m (ES: -2.29 $CI_{95\%}$: -3.86 to -0.68; $p=0.002$), 100-m (ES: -1.75 $CI_{95\%}$: -3.04 to -0.40; $p=0.008$) and 200-m (ES: -2.12 $CI_{95\%}$: -3.61 to -0.59; large effect; $p=0.003$) were observed.

Table 1

Table 2

According to the correlations, Figure 1 shows that as the absolute improvement of the inspiratory musculature strength was greater, the swimming times in the 50-m tests (r= 0.72; p=0.003) and 100-m (r= 0.65; p=0.008) were shorter. Likewise, a higher maximum inspiratory flow was related to shorter swimming times in 50-m (r= 0.7; p=0.003) and 100-m (r= 0.62; p=0.01). The other respiratory parameters did not show any associations with swimming performance.

Figure 1

DISCUSSION

The main findings of this study indicate that short-term (four-week) IMT improves swimming performance in short (50-m and 100-m) and medium-length (200-m) freestyle tests in competitive young swimmers, associated with an increase in the maximal inspiratory strength and maximal inspiratory flow.

Our results are consistent with the effects observed in previous studies, such as increased respiratory muscle strength [14, 15], improved MVV [14] and performance in swimming tests [4, 14]. In contrast to other studies, we used the S-Index (measured with the PWB device) instead of MIP to assess the improvement in inspiratory strength as well as to prescribe the training load. This index assesses the maximum dynamic strength of the inspiratory musculature, unlike MIP that assesses the quasi-isometric strength.

Our results showed an improvement in the S-Index after IMT in young swimmers, whose changes were associated with performance improvements in the 50-m and 100-m short-length, but not in medium-length (200-m) swimming tests. It is possible that the four weeks of IMT were unable to improve strength endurance. In addition, in our IMT protocol, the maximum inspiratory flow also improved during the dynamic inspiratory strength testing with the PWB, and an association with shorter swimming times for 50-m and 100-m was found. The aforementioned is particularly important for swimmers, since a higher inspiratory flow during the race will allow them to increase the volume of air during the short time, they have to bring their heads out of the water to take air during the competition. Thus, our IMT protocol was able to activate a faster maximum inhalation, which has possibly been attributed to an increase in the velocity of the shortening of respiratory musculature and an improvement in swimming performance [17, 18]. Furthermore, better inspiratory times, when the head is out of the water, favor synchronization with the arm stroke swimming technique, thus limiting the onset of fatigue [5]. In particular, this may have been significantly beneficial in our young participants with an underdeveloped swimming technique when compared to competitive adult swimmers, which resulted in better performances in all tests. However, during the 50-m swimming test almost no breaths are taken. Thus, it is possible that the improvement in performance during this test can be attributed to increased buoyancy due to a higher lung volume after IMT. This can be confirmed with the significant increase in FVC observed in EG, but not in SPG. Another issue related to the adaptation to IMT in swimmers is training volume. Although, Lomax et al. (2019) observed an increase in the MIP in all assessed swimmers, the improvement in the test performance of 100-m and 200-m only occurred in those with a training volume lower than 31 km·week^{-1} [23]. These results are similar to those of our study, since the training volume of our swimmers does not exceed the limit described by Lomax et al. (27.1 km·week^{-1}). Despite the fact that swimming training by itself is recognized for improving inspiratory strength and lung function, the absence of changes in the SCG in any parameter of respiratory function or pressure, unlike the EG, suggests that the observed benefits in our study are only attributable to IMT.

Along with the increased inspiratory flow, participants in the EG increased the FVC and MVV. The foregoing involves increases in respiratory reserve volumes that were not observed in the SCG, which could represent a significant benefit for respiratory compensation of metabolic acidosis induced during the performed physical effort.

The main strength of our study was that it used dynamic inspiratory strength for the assessment of inspiratory strength and inspiratory flow adaptations, which is more closely related to lineal resistance inspiratory training and sporting movement than to quasi-isometric strength. However, due to the low final number of participants that finished the study, the results should be used with caution. Further studies will be needed to assess the benefits of different IMT modalities on lung volumes and dynamic muscle strength, and its relationship with technique and sports performance.

In conclusion, short-term IMT improves the dynamic strength of respiratory muscles of young swimmers, directly influencing the improvement of sports performance in 50-m and 100-m freestyle swimming tests.

Authors` contributions: Rodrigo Yañez-Sepulveda, Ildefonso Alvear-Ordenes and Alvaro Tapia-Guajardo carried out the design of the work, experimental protocols, statistical analysis, interpretation of data and writing the paper; Marcelo Tuesta, Carlos Cristi-Montero and Humberto Verdugo-Marchese carried out statistical analysis and interpretation of data. All authors read and approved the final version of the manuscript.

Funding.

This research received no external funding.

Disclosure Statement.

No potential conflict of interest was reported by the authors.

REFERENCES

1. Klusiewicz A, Borkowski L, Zdanowicz R, Boros P, Wesołowski S. The inspiratory muscle training in elite rowers. J Sports Med Phys Fitness. 2008;48(3):279-84.

2. Hartz CS, Sindorf MAG, Lopes CR, Batista J, Moreno MA. Effect of Inspiratory Muscle Training on Performance of Handball Athletes. J Hum Kinet. 2018;63:43-51.

3. Archiza B, Andaku DK, Caruso FCR, Bonjorno JC, Jr., Oliveira CR, Ricci PA, et al. Effects of inspiratory muscle training in professional women football players: a randomized sham-controlled trial. J Sports Sci. 2018;36(7):771-80.

4. Kilding AE, Brown S, McConnell AK. Inspiratory muscle training improves 100 and 200 m swimming performance. Eur J Appl Physiol. 2010;108(3):505-11.

5. Lomax M, Tasker L, Bostanci O. An electromyographic evaluation of dual role breathing and upper body muscles in response to front crawl swimming. Scand J Med Sci Sports. 2015;25(5):e472-8.

6. Amann M. Pulmonary system limitations to endurance exercise performance in humans. Exp Physiol. 2012;97(3):311-8.

7. Sheel AW, Boushel R, Dempsey JA. Competition for blood flow distribution between respiratory and locomotor muscles: implications for muscle fatigue. J Appl Physiol (1985). 2018;125(3):820-31.

8. Harms CA, Wetter TJ, St Croix CM, Pegelow DF, Dempsey JA. Effects of respiratory muscle work on exercise performance. J Appl Physiol (1985). 2000;89(1):131-8.

9. Segizbaeva MO, Timofeev NN, Donina Zh A, Kur'yanovich EN, Aleksandrova NP. Effects of inspiratory muscle training on resistance to fatigue of respiratory muscles during exhaustive exercise. Adv Exp Med Biol. 2015;840:35-43.

10. Silva PE, de Carvalho KL, Frazão M, Maldaner V, Daniel CR, Gomes-Neto M. Assessment of Maximum Dynamic Inspiratory Pressure. Respiratory Care. 2018;63(10):1231-8.

11. Langer D, Jacome C, Charususin N, Scheers H, McConnell A, Decramer M, et al. Measurement validity of an electronic inspiratory loading device during a loaded breathing task in patients with COPD. Respir Med. 2013;107(4):633-5.

12. Minahan C, Sheehan B, Doutreband R, Kirkwood T, Reeves D, Cross T. Repeated-sprint cycling does not induce respiratory muscle fatigue in active adults: measurements from the powerbreathe® inspiratory muscle trainer. J Sports Sci Med. 2015;14(1):233-8.

13. Karsten M, Ribeiro GS, Esquivel MS, Matte DL. The effects of inspiratory muscle training with linear workload devices on the sports performance and cardiopulmonary function of athletes: A systematic review and meta-analysis. Phys Ther Sport. 2018;34:92-104.

14. Shei RJ, Lindley M, Chatham K, Mickleborough TD. Effect of flow-resistive inspiratory loading on pulmonary and respiratory muscle function in sub-elite swimmers. J Sports Med Phys Fitness. 2016;56(4):392-8.

15. Vašíčková J, Neumannová K, Svozil Z. The Effect of Respiratory Muscle Training on Fin-Swimmers' Performance. J Sports Sci Med. 2017;16(4):521-6.

16. Wylegala JA, Pendergast DR, Gosselin LE, Warkander DE, Lundgren CE. Respiratory muscle training improves swimming endurance in divers. Eur J Appl Physiol. 2007;99(4):393-404.

17. Clanton TL, Dixon GF, Drake J, Gadek JE. Effects of swim training on lung volumes and inspiratory muscle conditioning. J Appl Physiol (1985). 1987;62(1):39-46.

18. Mickleborough TD, Stager JM, Chatham K, Lindley MR, Ionescu AA. Pulmonary adaptations to swim and inspiratory muscle training. Eur J Appl Physiol. 2008;103(6):635-46.

19. Wilson EE, McKeever TM, Lobb C, Sherriff T, Gupta L, Hearson G, et al. Respiratory muscle specific warm-up and elite swimming performance. Br J Sports Med. 2014;48(9):789-91.

20. Miller MR, Crapo R, Hankinson J, Brusasco V, Burgos F, Casaburi R, et al. General considerations for lung function testing. Eur Respir J. 2005;26(1):153-61.

21. Volianitis S, McConnell AK, Jones DA. Assessment of maximum inspiratory pressure. Prior submaximal respiratory muscle activity ('warm-up') enhances maximum inspiratory activity and attenuates the learning effect of repeated measurement. Respiration. 2001;68(1):22-7.

22. Hopkins WG, Marshall SW, Batterham AM, Hanin J. Progressive statistics for studies in sports medicine and exercise science. Med Sci Sports Exerc. 2009;41(1):3-13.

23. Lomax M, Kapus J, Brown PI, Faghy M. Impact of Weekly Swimming Training Distance on the Ergogenicity of Inspiratory Muscle Training in Well-Trained Youth Swimmers. J Strength Cond Res. 2019;33(8):2185-93.

Tables

Table 1. General characteristics of the swimmers.

Variables	EG (n=9)	SCG (n=6)
Age (years)	15.5 ± 1.15	14.7 ± 1.09
Weight (kg)	62.8 ± 7.31	61.3± 6.57
Height(cm)	174 ± 5.16	173 ± 8.14
BMI ($kg{\cdot}m^{-2}$)	20.7 ± 1.73	20.5 ± 1.34
Swimming experience (years)	7.0 ± 1.12	6.0 ± 0.89

EG: Experimental group; SCG: sham control group

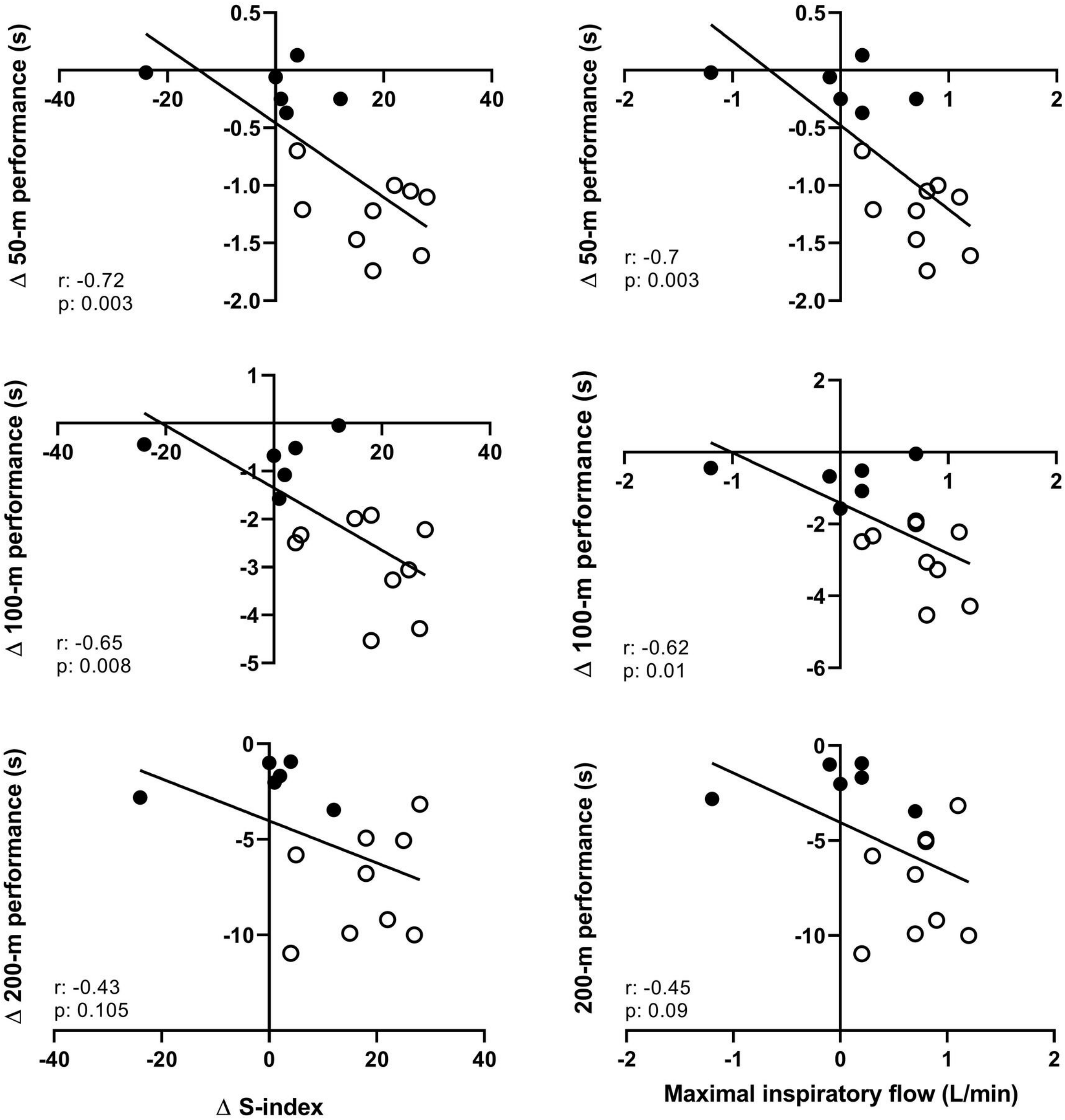
Table 2. Effects of the 4-week inspiratory muscle training on dynamic inspiratory strength, pulmonary function and swimming performance.

Variables	EG (n= 9)			SPG (n= 6)			Cohen's *d* effect
	Basal	Post-training	Δ	Basal	Post-training	Δ	(CI 95%)
Inspiratory muscle strength							
S-Index (cmH_2O)	124.8 ± 28.7	142.8 ± 31.4*	18.0 ± 8.8	124.5 ± 21.8	123.7 ± 15.7	-0.8 ± 12.1**	1.29 (0.15 to 2.38)
MIF ($L \cdot min^{-1}$)	6.9 ± 1.4	7.7 ± 1.5*	0.7 ± 0.33	6.9 ± 1.1	6.9 ± 0.8	0.0 ± 0.63**	1.31 (0.16 to 2.42)
Pulmonary function							
FEV_1 (l)	4.4 ± 0.7	4.6 ± 0.7*	0.1 ± 0.1	4.2 ± 0.6	4.2 ± 0.6	0.04 ± 0.04	-0.27 (-0.55 to 1.07)
FVC (l)	5.2 ± 0.7	5.4 ± 0.8*	0.3 ± 0.2	4.7 ± 0.7	4.8 ± 0.7	0.1 ± 0.1	0.74 (-0.19 to 1.63)
PEF ($l \cdot m^{-1}$)	465.2 ± 98.8	490.8 ± 93.7*	25.6 ± 17.6	484.2 ± 77.4	504.2 ± 76.4	20.0 ± 30.5	-0.01 (-0.80 to 0.79)
$FEV_1 \cdot FVC^{-1}$ (%)	84.6 ± 7.7	84.0 ± 7.3	-0.6 ± 1.5	88.8 ± 5	88.0 ± 4.6	-0.8 ± 1.8	0.06 (-0.73 to 0.86)
$FEF_{25\%-75\%}$ ($l \cdot s^{-1}$)	4.5 ± 1	4.6 ± 1*	0.1 ± 0.1	4.8 ± 0.9	4.9 ± 0.9	0.1 ± 0.1	-0.26 (-1.06 to 0.56)
MVV ($l \cdot min^{-1}$)	166.7 ± 26.3	173.6 ± 27.3*	6.9 ± 3.6	156.3 ± 21.9	158.5 ± 18.6	2.2 ± 3.5	0.87 (-0.11 to 1.80)
Swimming performance							
50-m crawl (s)	29.4 ± 0.9	28.1 ± 0.8*	-1.2 ± 0.3	30.0 ± 1.6	29.9 ± 1.7	-0.1 ± 0.2**	-2.29 (-3.86 to -0.68)
100-m crawl (s)	64.8 ± 2.1	61.9 ± 2.2*	-2.9 ± 1	69.1 ± 4.5	68.3 ± 4.4	-0.7 ± 0.5**	-1.75 (-3.04 to -0.40)
200-m crawl (s)	144.1 ± 5.2	136.8 ± 5.3*	-7.3 ± 2.8	156.4 ± 8	154.4 ± 8.7	-2.0 ± 1**	-2.12 (-3.61 to -0.59)

EG: Experimental group, FEV_1: Forced expiratory volume in first 1 second, FVC: Forced vital capacity, $FEV_1 \cdot FVC^{-1}$: relationship between FEV_1 and FVC (Tiffeneau index), $FEF_{25-75\%}$: Forced expiratory flow between 25% and 75% of the maximal flow, MIF: maximal inspiratory flow, MVV: maximal voluntary ventilation, PEF: Peak expiratory flow, SCG: Sham control group, S-Index: Dynamic inspiratory muscle strength, Δ: post-pre variation. *differences within group, $p<0.05$, **differences between post-pre variation (Δ) groups, $p<0.05$.

Figure Legend

Figure 1. Correlations between post-pre variations (Δ) of the dynamic inspiratory muscle strength (S-index) and swimming performance (white circle: Experimental group; black circle: Sham control group).


Δ 50-m performance (s)
r: -0.72
p: 0.003
Δ 50-m performance (s)
r: -0.7
p: 0.003
Δ 100-m performance (s)
r: -0.65
p: 0.008
Δ 100-m performance (s)
r: -0.62
p: 0.01
Δ 200-m performance (s)
r: -0.43
p: 0.105
200-m performance (s)
r: -0.45
p: 0.09
Δ S-index
Maximal inspiratory flow (L/min)