The effect of inspiratory muscle training on swimming performance, inspiratory muscle strength, lung function, and perceived breathlessness in elite swimmers: a randomized controlled trial

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Abstract

**Background:** According to studies performed on terrestrial sports athletes, inspiratory muscle training (IMT) may improve athletes’ performance. However, evidence of its effects in elite swimmers is lacking. Therefore, we aimed to assess the effect of 12-week IMT on swimming performance, inspiratory muscle strength, lung function, and perceived breathlessness in elite swimmers.

**Methods:** Elite swimmers from the main FC Porto swimming team (in competitive training for a minimum period of 3 years) were invited to participate and were randomly allocated into intervention or control groups. The intervention group performed 30 inspiratory efforts, twice a day, 5 times a week, against a pressure threshold load equivalent to 50% of maximal inspiratory pressure, whereas the control group performed inspiratory efforts at the same frequency but against a 15% load. Swimming performance was assessed through time trials, converted into points according to International Swimming Federation Points Table. Outcomes were evaluated before and following the 12-week study period.

**Results:** A total of 32 participants (22 girls) were included. The median age was 15 and 14 years old for the intervention (n = 17) and control (n = 12) groups, respectively. No differences were found in swimming performance (P = .914), inspiratory muscle strength (P = .914), forced vital capacity (P = .262), forced expiratory volume in 1st second (P = .265), peak expiratory flow (P = .270), and perceived breathlessness (P = .568) between groups after 12 weeks of intervention.

**Conclusion:** Twelve weeks of IMT had no effect on swimming performance, lung function, and perceived breathlessness in elite swimmers. These results may be related to swimming-specific factors and/or an applied load insufficient to achieve training overload that could induce further improvements.

**Keywords:** breathlessness, inspiratory muscle strength, inspiratory muscle training, lung function, swimming performance

Introduction

Respiratory system’s efficiency restricts the body’s capacity to perform exercise, due to increased work of breathing, leading to respiratory muscle fatigue and perceived breathlessness.\(^1\)\(^,\)\(^2\) This seems particularly important in elite swimmers, as swimming demands the ability to regulate breathing patterns at volumes and flow rates that are higher than in other sports.\(^3\) Indeed, data suggest swimming to be an extraordinarily demanding sport for the inspiratory muscles; submersion in water forces swimmers to expand chest wall against a higher pressure and to increase inspiratory muscle contraction velocity and tidal volume, which could lead to muscle fatigue.\(^3\) Fatiguing respiratory muscles can affect exercise performance through the respiratory muscle metaboreflex.\(^4\)

Evidence shown that elite level swimmers have an increased risk for exercise-induced respiratory symptoms.\(^5\) Elite competitive swimmers are particularly affected by airway disorders that are probably linked with the combination of a sustained high ventilation and provocative training environment.\(^6\) This may increase susceptibility for exercise-induced bronchoconstriction even in the absence of asthma. Research shows that inspiratory muscle training (IMT) may be used to overcome these limitations and improve athletes’ performance and respiratory efficiency.\(^1\)\(^,\)\(^2\)\(^,\)\(^7\) Several physiological effects have been associated with the improvement in performance, including diaphragm hypertrophy, increased nitric oxide levels in the airways, muscle fiber-type switching, improved
neural control and economy of the respiratory muscles, delayed onset of the metaboreflex effect, decrease in perceived breathlessness, and an improvement in pulmonary function. Most of these findings were from studies performed in competitive athletes mostly from terrestrial sports. Indeed, there is limited knowledge regarding the effect of IMT in swimmer’s performance. Few studies have assessed the impact of IMT on elite swimmers’ performance, providing limited data and no consistent results.

In this study, we hypothesized that IMT could increase swimming performance and mechanical efficiency of the respiratory muscles, secondary to improved respiratory muscles strength and lung function, and decreased perceived breathlessness. Therefore, we aimed to assess the effect of a 12-week IMT on swimming performance, inspiratory muscle strength, lung function, and perceived breathlessness in elite swimmers.

**Methods**

**Study design**

We conducted a randomized controlled trial evaluating IMT in elite swimmers. Elite swimmers were randomized to an intervention or control groups by sealed opaque envelopes in random block sizes of 4 and 6. The researcher responsible for the random allocation was not involved in the evaluation or intervention procedures. Investigators who assessed the outcomes were also blind to the participants’ allocation order.

The annual training calendar of the team includes a total of 48 weeks. Athletes reported training an average of 16 hours per week. In addition to general swimming exercise training program, during the 12-week study period, the intervention group received an additional IMT program described to the athletes as “respiratory muscle training” at high intensity [50% of maximal inspiratory pressure (MIP)], whereas the control group received an IMT intervention at a low training intensity (15% of MIP). Athletes were aware of the existence of 2 different groups.

Before starting the intervention, all participants underwent 2 guiding sessions to become familiar with IMT procedure. Performance trials made in these sessions were not used in data collection analysis. Outcomes were evaluated before and after the 12-week study period.

The trial was registered in clinicaltrials.gov NCT03062735.

**Participants**

Elite swimmers from the main FC Porto swimming team were invited to participate (n = 41). All engaged in competitive training for a minimum period of 3 years and were aged between 13 and 25 years. Those with diagnosed pulmonary disease, cardiac disease, musculoskeletal disease (n = 1), cognitive disorders, or already in a regular respiratory muscle training program were excluded.

Participants (n = 32) were allocated to intervention (n = 17) or control group (n = 15). Three participants in the control group dropped out because they gave up from competitive swimming (Fig. 1).

The study was approved by Ethics Committee of Faculty of Medicine, University of Porto and was conducted according to the Declaration of Helsinki, and informed consent was obtained from athletes or their caregivers. Sociodemographic and anthropometric data were collected using a structured questionnaire.

**Intervention**

Investigation was conducted during the competitive season, between March and June 2017, in an indoor Olympic-sized pool (50m long, 25m wide 1.57 m deep), during 12 weeks. During the intervention, participants were asked to keep their training and regular diet.

**Regular swim training.** Coaches providing this intervention were blind to group allocation. Regular swimming training included dry land training and swimming pool training. The first consisted in strengthening and stretching of the peripheral musculature and was performed 3 times per week during 50 minutes, whereas swimming sessions were performed between 8 and 9 times per week, averaging 6000m per session. Each session consisted of warm up, in which athletes swam 2000 to 2400m, followed by anaerobic 200 to 1200m and aerobic 2400 to 3000 m series. Sessions were finalized with a low intensity 1200 to 2000m swimming. Regular swimming training had a similar work intensity and training protocol for all participants.

**Inspiratory muscle training.** IMT was performed using POWERbreathe Plus PB-2002 (POWERbreathe, HaB International Ltd, Southam, UK) pressure threshold device. Participants were instructed to perform 2 cycles of 30 inspiratory efforts each, 5 days/wk, during 12 weeks before swimming training, in a standing position. They were instructed to initiate every breath from residual volume in a powerful manner and not to perform both cycles of inspiratory efforts consecutively.

Athletes in the intervention and control groups performed IMT against a pressure threshold load equivalent to 50% and 15% of MIP, respectively. Participants in intervention group were instructed to periodically increase the load that allowed only 30 inspiratory maneuvers to be completed. The control group were instructed to maintained their initial inspiratory load for the whole intervention.

In order to assess compliance, participants were asked to make a daily record of the frequency and volume training. The record consisted of a table with the number of days per week they performed IMT and the inspiratory maneuvers performed per day (maximal of 60) during the study period.

**Outcome measurements**

**Primary outcome**

**Swimming performance.** Swimming performance was assessed through the time taken to complete 200m time trial (TT). Each TT simulated a true moment of competition, to introduce competitiveness and induce a maximal effort. TT were converted into points according to the International Swimming Federation (FINA) Points Table. Points (P) were calculated using a cubic curve, as follows \( P = 1000 \times \frac{B}{T} \) with \( T \) being the swim time and \( B \) the base time, both in seconds. The FINA Points Table allowed for comparisons of results among different events and athletes.

**Secondary outcomes**

**Inspiratory muscle strength.** Inspiratory muscle strength was assessed in a noninvasive way, using MIP. Measurements were performed from residual volume using a hand held electronic pressure transducer (MicroRPM; Micromedical, Kent, UK) presenting in units of cmH2O. Participants were asked to produce a maximal inspiratory effort as quickly as possible and to repeat the maneuver, at least 5 times. Attempts were continued until a good reproducibility was achieved from the 3 best
Figure 1. Study flow chart. IMT = inspiratory muscle training; MIP = maximal inspiratory pressure.
measurements (within 10 cmH2O difference among measurements). The highest MIP value was recorded.3,20 Participants received visual feedback of pressure achieved during each attempt to maximize inspiratory effort.

**Lung function.** Spirometry was performed using a MasterScreen Vntus iOS interfaced with a personal computer system according to American Thoracic Society Spirometry standards.21

Participants were asked to inhale completely after 3 to 4 cycles of tidal breathing, and to exhale with maximum force until no more air was left. All maneuvers were performed using a mouth piece and a nose clip. Throughout the procedure, loud verbal encouragement was given to optimize expiratory and inspiratory maneuvers. The procedure was monitored for compliance by a researcher.

**Perceived breathlessness.** Perceived breathlessness was assessed using the Modified Borg Scale (MBS)—a vertical scale ranging from 0 to 10 in which numbers match verbal expressions of increasing intensity. Participants were asked to quantify their perceived breathlessness by selecting the number with matching words that best described their sensation of breathlessness after TT.22

**Statistical analysis**

Baseline characteristics were compared using unpaired samples t test or Mann-Whitney U test for numeric variables. Data are expressed as median and interquartile range or mean and standard deviation (SD), as appropriate, and in discrete variables as count and percentage. Changes within groups were compared using paired samples t test and differences between groups were compared by analysis of covariance with baseline value as covariate.

Significance was set at P < .05. Data were analyzed using SPSS (Statistical Package for Social Sciences) version 25.0 for Windows.

**Results**

**Baseline characteristics**

The median age was 15 and 14 years old for the intervention and control groups, respectively (Table 1). No significant differences were found between groups for baseline features (Table 1).

**Swimming performance**

After the 12-week period, the intervention and control groups registered an increase in FINA points, with mean difference changes of 30 (confidence interval: −12, 60) and 19 (confidence interval: 12, 27), respectively. However, the training protocol failed to show significant differences between groups (P = .271) on swimming performance (Fig. 2A; Table 2).

**Inspiratory muscle strength**

No significant differences (P = .914) were found between groups after intervention in inspiratory muscle strength (Fig. 2B; Table 2).

Within both groups, IMT resulted in an improvement in MIP values with mean difference changes of 19.6 (P < .001) and 17.9 (P = .036) in intervention and control groups, respectively (Fig. 2B; Table 2).

| Table 1 | Baseline characteristics and comparison accordingly to group allocation |
|---------|---------------------------------------------------------------------|
|         | Intervention (n = 17) | Control (n = 15) | P     |
| Female (n/%) | 11 (64.7) | 11 (73.3) | .288‡ |
| Age (yr) median [IQR] | 15 [14;16] | 14 [13;16] | .145† |
| Height (cm) | 171 (9) | 164 (11) | .051‡ |
| Weight (kg) | 60.9 (9.3) | 56.7 (11.6) | .262‡ |
| FINA points | 485 (71) | 429 (88) | .060† |
| MIP (cmH2O) | 73.4 (23.9) | 79.8 (29.9) | .419† |
| FVC (L) | 5.1 (0.9) | 4.3 (1.2) | .205† |
| FEV1 (L) | 4.4 (0.8) | 3.7 (0.9) | .077† |
| PEF (L/s) | 8.5 (1.9) | 7.2 (1.7) | .056† |
| Borg scale | 3 (2) | 4 (2) | .076† |

Data are presented as mean (standard deviation) except otherwise specified.

FEV1 = forced expiratory volume in 1st second; FINA points = International Swimming Federation Points; FVC = forced vital capacity; IQR = interquartile range; MIP = maximal inspiratory pressure; PEF = peak expiratory flow.

† Independent samples Mann-Whitney U test.

‡ Independent samples t test.

**Lung function**

No significant differences were found between groups after the 12 weeks of IMT for forced vital capacity (FVC; P = .262), forced expiratory volume in 1st second (FEV1; P = .265) and peak expiratory flow (P = .270) (Fig. 2C–E; Table 2). We found a modest increase in FVC and FEV1 for the intervention group, with mean difference changes of 0.1L, reaching significance (P = .011) for FVC but not for FEV1 (P = .061) (Fig. 2C, D; Table 2).

**Perceived breathlessness**

The employed training protocol had no effect on perceived breathlessness (Fig. 2F; Table 2). A difference was, however, found for the control group (P = .009) following the intervention. On average, the control group reported a 5 (SD: 2) on MBS and then a 4 (SD: 2). No differences (P = .145) were found for the intervention group. After the 12-week study period, MBS value was on average 3 (SD: 2) similar to the baseline value (Fig. 2F; Table 2).

**Compliance**

No significant differences were found for adherence to training protocol (P = .335) on the intervention and control group. Of the 60 recommended days of 2 cycles of 30 inspiratory efforts each, athletes from the intervention and control group performed on average 18 (SD: 3) and 17 (SD: 2), respectively (Fig. 3A). Both groups were most compliant during the first week. The intervention group performed on average 233 (SD: 30) inspiratory efforts per week (Fig. 3B).

**Discussion**

IMT has been suggested to improve performance in a wide range of sports, due to its ergogenic improvement inducing abilities.1,2 However, our study did not demonstrate significant difference on the improvements in swimming performance, inspiratory muscle strength, or lung function, or even on the perceived breathlessness.

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decrease between the intervention and control groups, after the 12-week training period.

This was a small-scale trial (sample size of 29 swimmers), which may limit finding significant differences between groups following the intervention period and generalizing results to the clinical practice. Considering the inclusion criteria and specificity of our population, the intervention cannot be generalized to other specific populations, namely recreational athletes or athletes suffering from diseases.

Athletes’ compliance to IMT protocol was also a limitation. In our study, participants were required to daily record the frequency and volume training. Nevertheless, this task was dependent on participants’ good will, not being supervised. The intervention and control groups performed the IMT on average 18 (SD: 3) and 17 (SD: 3), respectively, out of the 60 recommended days, revealing a low adherence to IMT sessions. However, participants from both groups performed on average >150 efforts per week, out the recommended 300. The exception was in the 2 last weeks, which coincided with a time of greater number of competitions. This event characterized by high levels of fatigue may explain the conditioned ability and motivation to perform the IMT.

Before starting the IMT protocol, all participants were instructed about the PowerBreathe technique. After this first

Figure 2. Effect of training protocol on (A) swimming performance, (B) inspiratory muscle strength, (C) forced vital capacity (FVC), (D) forced expiratory volume in 1st second (FEV1), (E) peak expiratory flow (PEF), (F) perceived breathlessness: pre- and postcomparison. Data are presented as mean [standard deviation (SD)]. FINA points = International Swimming Federation Points; MIP = maximal inspiratory pressure.
demonstration participants, however, performed IMT by themselves, without being supervised. The lack of understanding of the instructions initially done and the lack of adaptation to the device could have influenced the IMT performance and, consequently, the main outcomes results.

To our knowledge, this is the first randomized controlled trial evaluating the effect of a specific IMT with one of the largest sample size (29 elite swimmers), and training period reported (12 weeks of intervention).

Inspiratory muscles can be trained, just like peripheral musculature, to increase strength or muscle shortening. In our study, training was performed through inspiratory pressure threshold loading. IMT is one of the most cited types of intervention, being reported as the technique that induces the highest activation of the inspiratory muscles.7 IMT has been suggested to enhance athletes’ performance.1,2 Several mechanisms have been proposed to explain the physiological adaptations induced by IMT: (a) an increase in aerobic metabolism and oxygen delivery may improve aerobic capacity of the respiratory muscles, resulting in a delayed onset of the fatigue and mitigate competitive blood flow between respiratory and peripheral muscles, leading to the reduction of the respiratory metaboreflex23; (b) hypertrophy of the diaphragm and an increase in type I fibers24; (c) decrease in perceived breathlessness25; (d) improved neural control and economy of respiratory muscles with a reduction in work of breathing8; and (e) the improvement in pulmonary function. Despite these physiological adaptations being similar to our results, some studies showed no differences in exercise performance and pulmonary function measured after adding IMT to regular swimming.2 Swimming is a very demanding sport with regard to lung function and work of respiratory muscles. It requires a higher tidal volume and shortening of inspiratory muscles at a high speed. During a regular swimming training, athletes face the increased hydrostatic pressure during submersion and the high flow rates experienced during inspiration.3 These swimming-specific factors have been described as inducing IMT.1,3,10 Trained swimmers may be near plateau with concerns to their respiratory muscle function, which may diminish the possibility of further gains. Therefore, adding IMT to regular swimming training seems to lack a beneficial effect.

The applied IMT protocol may have induced an overload that was incapable of inducing further improvements beyond swimming training. Indeed, training intensity may be insufficient to achieve significant adaptations to respiratory musculature and improvements in lung function, perceived breathlessness, and exercise performance. This seems to be particularly important in swimmers, as evidence shown that elite swimmers had lesser improvements in their exercise performance compared to other sports.3

### Table 2

|                          | Intervention group (n=17) | Control group (n=12) | Intervention vs control |
|--------------------------|--------------------------|----------------------|-------------------------|
|                          | Preintervention | Postintervention | Change (CI) | P* | Preintervention | Postintervention | Change (CI) | P* |
| FINA points              | 485 (71)         | 516 (73)           | 30 (-0.60) | .053 | 418 (83)         | 437 (85)           | 19 (12.27) | <.001 |
| MIP (cmH2O)              | 73.4 (23.9)      | 93.0 (25.2)        | 19.6 (11.1,28.1) | <.001 | 81.2 (30.4)      | 99.1 (27.9)        | 17.9 (14.3,34.5) | .036 |
| FVC (L)                  | 5.0 (0.9)        | 5.1 (0.9)          | 0.1 (0.0,1) | .011 | 4.3 (1.2)        | 4.3 (1.1)          | 0.0 (-0.1,0.2) | .525 |
| FEV1 (L)                 | 4.4 (0.8)        | 4.5 (0.8)          | 0.1 (-0.0,0.2) | .061 | 3.7 (1.0)        | 3.7 (0.9)          | 0.0 (-0.2,0.3) | .876 |
| PEF (L/s)                | 8.4 (1.9)        | 8.3 (1.9)          | -0.1 (-0.6,0.4) | .705 | 7.3 (1.9)        | 6.9 (1.8)          | -0.4 (-1.3,0.5) | .347 |
| Borg Scale               | 3 (2)            | 3 (2)              | 0 (-1,0)    | .145 | 5 (2)            | 4 (2)              | -1 (-2,-0) | .009 |

Data are presented as mean [standard deviation (SD)] or mean differences (CI 95%).

CI = confidence interval; FINA = International Swimming Federation Points; MIP = maximal inspiratory pressure; FVC = forced vital capacity; FEV1 = forced expiratory volume in 1st second; PEF = peak expiratory flow.

*Paired samples t test.
†Analysis of covariance, baseline value as covariate.

Figure 3. A, Number of days in which subjects completed 2 cycles of 30 inspiratory efforts each. B, Inspiratory efforts performed by trial week. Data are presented as mean [standard deviation (SD)]. MIP=maximal inspiratory pressure.
A possible alternative may be to explore different and more aggressive training protocols, starting with a higher intensity that would ensure training overload and with a larger sample size, to investigate whether the load training influences the muscular recruitment pattern or have an additive improvement effect. Moreover, a more personalized assessment of swimmers may be necessary to define more specific and individualized training protocols, allowing a greater improvement on swimmers’ performance.

Furthermore, athletes at the intervention group may have included IMT responders and nonresponders. Sport performance is optimized on an individual basis. Although most participants were highly trained in swimming, considerable individual differences remain for performance, potentially due to physiological or psychological factors. Consequently, there may be a subgroup that responds favorably to IMT and another in which it does not affect performance. The mix of responders and nonresponders within a small sample could easily influence the effect size of the study.

In our research, IMT had no effect on swimming performance over the 12-week training period. This result is not corroborated by previous studies in club level trained swimmers in which IMT enhanced performance ($P = .02$). Nevertheless, our findings are consistent with those observed in competitive swimmers after the 12-week IMT ($P = .08$).

A significant improvement ($P < .001$) was reached for the control group. This difference may be explained by a lower initial average values of FINA-points in the control group athletes (418 vs 485), which may have allowed for greater progression. Less trained athletes benefit most from the combination of IMT and swim training.

Results obtained in MIP values are similar to previous studies in which IMT participants had a greater improvement in MIP values than controls ($P < .001$), in all sports except swimming. Opposing results were reported by a previous study that showed a significant increase ($P < .01$) in MIP values after a 6-week IMT. As previous discussion, swimming training alone has been shown to increase MIP, showing no gains after addition of IMT.

No significant differences were found in respiratory measures FVC, FEV1, and peak expiratory flow ($P = .262, .265, .270$, respectively) between groups over the 12-week study period, as shown by the majority of the previous studies. Our results differ from a study with basketball players that showed an increase in pulmonary function after 4 weeks of IMT.

Respiratory system’s maturation and, therefore, the ability to generate volumes and capacities is growth dependent. In our study, no age differences were observed between groups; however, the median ages were 15 and 14 years for intervention and control group, respectively. Participants are adolescents and their pulmonary maturation may be incomplete.

Our research shows no differences in perceived breathlessness between intervention and control groups, following the study period, which may explained by the lack of differences in inspiratory muscle strength and lung function between groups. Opposing results are reported by other studies. Perceived breathlessness may be diminished because of desensitization to load and greater strength of the inspiratory muscle such that ventilation requires a lower proportion of maximum inspiratory strength. Trained inspiratory muscles, through their improved aerobic metabolism and oxygen delivery, may contribute onset delay of inspiratory muscle fatigue. In addition, the reduction in perceived breathlessness may be explained by the improvement in lung function.

Compared to intervention group, the control group had a significant decrease in perceived breathlessness after the 12-week study period. Control group started with an average value of 5 on MBS, meaning “severe breathlessness” and reached an average value of 4, meaning “somewhat severe,” following training. Intervention group started and finished with an average value of 3, meaning “moderate.” This result may be explained by the fact that the control group started with a higher average value, allowing for greater progression.

### Practical applications

The evidence presented in our study supports that, in elite swimmers, swimming exercise alone strengthens inspiratory muscles in a similar manner to IMT, as no improvements were observed when IMT was added to swimming training.

Swimmers who perform a high volume of swimming training are likely to get no additional benefit from complementary training with IMT. Alternatively, the IMT regimen can be started with a higher training load, being periodically increased to induce inspiratory muscle adaptation and, consequently, improve swimmers’ performance.

Challenge now focuses on a personalized assessment of swimmers to explore more specific and targeted respiratory muscle training loading protocols; at what time and for how long they should be performed, ensuring a sufficient training overload. Knowing these training specificities allied to the understanding of the mechanisms underlying the ergogenic effects of IMT will help coaches to determine whether and how to incorporate IMT into athletes’ training regimen.

Our study also suggests that an aggressive progression of IMT intensity, to ensure a training overload, may be essential to achieve optimal benefit and greatest improvements on swimmers’ performance.

### Conclusion

Twelve weeks of IMT had no significant effects on swimmers’ performance, inspiratory muscle strength, lung function, and perceived breathlessness of elite swimmers. After a randomized training protocol, no differences were found in measured outcomes between the intervention and control groups.

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### Conflicts of interest

Authors declare no conflicts of interest.
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