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## ORIGINAL ARTICLE

### Alternative therapy for respiratory muscle training using breath stacking

#### *Terapia alternativa para o treinamento dos músculos respiratórios utilizando o breath stacking*

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## Abstract

**Objective:** To evaluate the effectiveness of the breath-stacking technique as a method of ventilatory muscle training. **Methods:** Thirty-eight healthy youngsters were included in the study. The maximum respiratory pressures were evaluated in cmH<sub>2</sub>O by a digital manovacuometer. The breath-stacking system (face mask attached to a T-tube with a unidirectional inspiratory valve) was used as an overload method in a 4-week 12-session ventilatory muscle training program. **Results:** Both maximal inspiratory and expiratory pressures increased significantly after ventilatory muscle training for all. Positive peak pressure also increased significantly at the end of the program. **Conclusion:** Breath-

stacking generates sufficient overload to ventilatory muscles to consistently increase maximal respiratory pressures when used in a ventilatory muscle training protocol. The technique was well tolerated, although it needs to be tested in clinical situations involving muscle weakness and other organic dysfunctions.

**Keywords:** breathing exercises; maximal respiratory pressures; ventilatory muscles; respiratory mechanics; inspiratory capacity; physical therapy techniques.

## Resumo

*Objetivo:* Avaliar a efetividade da técnica de breath-stacking como método de treinamento dos músculos ventilatórios. *Métodos:* Trinta e oito jovens saudáveis foram incluídos no estudo. A pressão respiratória máxima foi avaliada em cmH<sub>2</sub>O em um manovacuômetro digital. O sistema de breath-stacking (máscara facial conectada a um tubo T acoplado a uma válvula unidirecional inspiratória) foi o método utilizado para gerar a sobrecarga ao longo de 12 sessões do programa de treinamento da muscular (4 sessões/semana). *Resultados:* Ambas pressões inspiratórias e expiratórias máximas aumentaram significativamente após o treino dos músculos ventilatórios. O pico de pressão positiva aumentou significativamente ao final do programa. *Conclusão:* O breath-stacking gera sobrecarga suficiente para os músculos ventilatórios promovendo aumento consistente das pressões respiratórias máximas quando utilizado em um protocolo de treino da musculatura ventilatória. A técnica foi bem tolerada, mas permanece a necessidade de testes em situações clínicas que envolvam fraqueza muscular e outras disfunções orgânicas.

**Palavras-chave:** exercícios respiratórios; pressão respiratória máxima; músculos ventilatórios; mecânica respiratória; capacidade inspiratória; modalidades de fisioterapia.

## Introduction

The respiratory muscles are responsible for mobilizing a satisfactory air volume into the lungs at a large range of metabolic rates. To move the ribcage during inspiratory and expiratory cycles, all resistive forces must be overcome by these muscles. Respiratory muscle strength is fundamental to ventilatory pump particularly when some restrictive, obstructive or both disorders are present [1-4].

Two meta-analyses have demonstrated the beneficial impact of respiratory muscle training (RMT) in healthy sedentary [5] and athletic [6] populations. Moreover, patients with low functional capacity have also demonstrated substantial increase in inspiratory performance [7,8]. Recently, inspiratory muscle training (IMT) has been used to prevent

pulmonary complications in post operative stages [9-11]. IMT seems to be beneficial to several clinical conditions [12-17], reinforcing the central role of inspiratory muscle strength on physical performance [18] and rehabilitation programs [7,8].

Respiratory muscle adaptations have been described in the literature through diverse training arrangements and overload techniques [19,20]. Some protocols deliver overload only to inspiratory muscles while others focus on inspiratory and expiratory training (RMT). In the literature, descriptions of muscle overload level, training program structure and equipment employed are highly diverse [5-8,17-20].

Breath-stacking (BS) is a breathing technique used to induce higher alveolar ventilation through pulmonary expansion [21] and is particularly helpful for poorly collaborative patients. Due to using a unidirectional valve (expiratory occlusion) [22], the BS incites a clinical situation that may correspond to dynamic hyperventilation. This occurs following repetitive sequential inspirations that promote considerable air retention, conducting the patient's tolerance to their limit for pulmonary hyperinflation [23]. When performing the maneuver repeatedly, lung volume expansion and subsequent peripheral air distribution are incited [21-23]. However, as the volume of air trapped increases with sequential inhalation, it is assumed that the muscle overload progresses in parallel with hyperinflation. The additional muscle effort imposed by changes in ventilatory mechanics (due to hyperinflation) may act as an overload stimulus and provide the respiratory muscles with functional adaptations. This effect has not yet been fully described. Therefore, the main objective of this study was to evaluate the efficacy of BS intervention as an alternative respiratory therapy on respiratory muscle training in healthy young individuals.

## Methods

In this preclinical single-arm study, young healthy and non-athlete volunteers participated in a training program to investigate the viability, safety, and potential therapeutic use of the Breath-Stacking technique as a respiratory muscle training. Thirty-eight individuals (18-24 years old) were included in the study. Considering the high standard deviations between the maximal inspiratory pressure (MIP) and maximal expiratory pressure (MEP) in this population (MIP = 17.3 cmH<sub>2</sub>O) [24,25] and the expected increase of one standard deviation after the ventilatory muscle training (VMT) program, the sample size calculation resulted into 26 subjects; however, 40 individuals were recruited in order to balance for possible dropouts. Participants reporting claustrophobia, tympanic membrane rupture, MIP and MEP exceeding the normal range,

and those who were competitive athletes, wind instrumentalists, and singers were excluded.

### *Procedures*

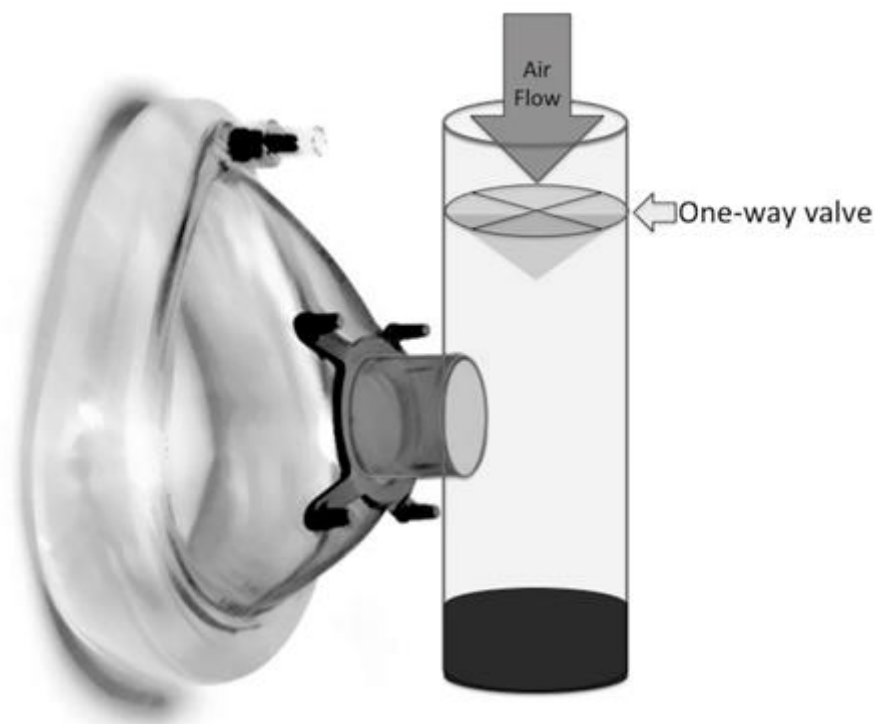
After being informed about the study procedures, eligible individuals signed a consent form and underwent an educational session regarding the assessment tests and methods of respiratory muscle strength training. An experienced independent researcher assessed both MIP and MEP (72 hours following the educational session).

### *Assessment of ventilatory muscle strength*

MIP and MEP were measured and recorded on a digital manovacuometer (MVD 300® model, Sao Paulo, Brazil). MIP was measured by performing a maximum inspiration, while MEP was measured by performing a maximum expiration according to the Pulmonary Function Test Guidelines [26].

### *Respiratory muscle training*

RMT was conducted using a silicone facemask attached to a T-tube, which was connected to a one-way inspiratory valve (Figure 1). Participants were instructed to remain seated with their elbows resting on a table and hands holding the mask firmly against their face to minimize air leakage. Training sessions were conducted three times a week, over a period of four weeks (twelve sessions in total). In every training session, three sets of RMT (three-minute long each) were performed, with two recovery intervals (three minutes each) between sets (15 minutes in total). In the second set of each session, the BS system was coupled to the manovacuometer to monitor the positive pressure peak (PPP) generated at the tolerance limit (maximum pulmonary expansion).



**Fig. 1** - Respiratory muscle training device for breathing-staking protocols

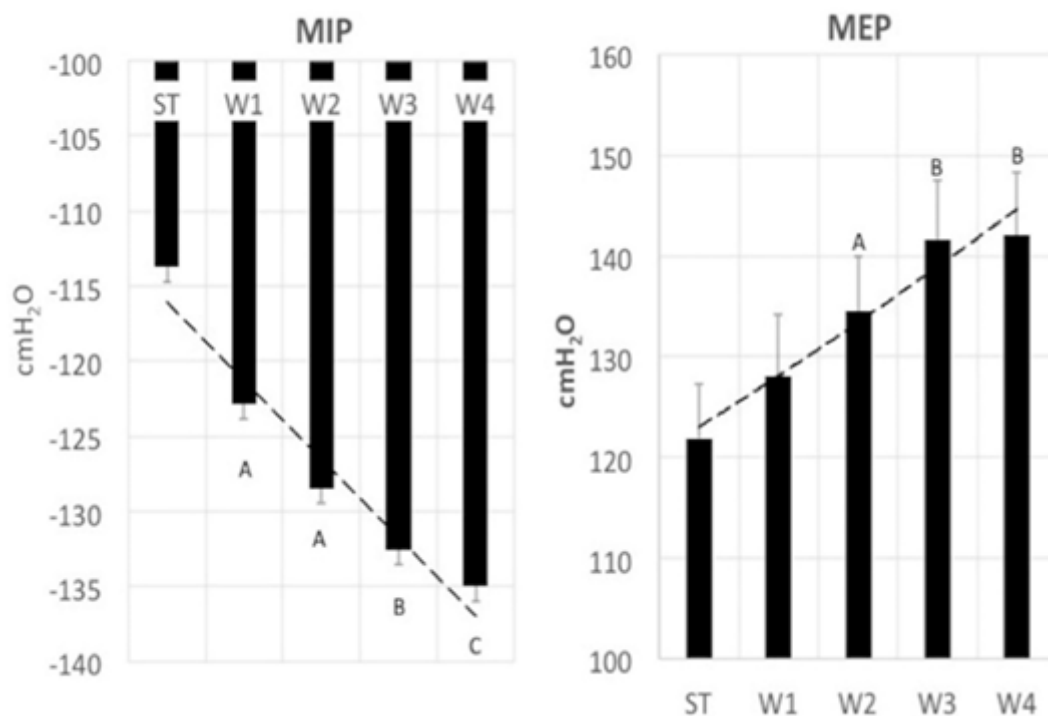
Participants were instructed to fractionate inspiration in at least three parts. In the interval between each inhalation, air should be maximally forced into the mask (with the expiratory valve occluded) generating successive PPP. After each expiration attempt, a new inspiratory cycle should be started successively until the hyperinflation tolerance limit was reached. This limit was defined as a drastic decrease or absence of inspiratory flow. After that, the mask was removed to allow pulmonary emptying and the start of a new repetition. MIP and MEP were reevaluated at the end of each week and reports of discomfort and/or difficulties to properly perform exercises were constantly recorded. To continue in the study, adherence to the program should be full. Any absence was later recovered; therefore, no exclusion due to lack of adherence occurred.

### *Statistical analysis*

Data are expressed as absolute (mean, standard deviation, standard error) and relative values (percentage variation between pre and post-test). The effect of RMT on MIP and MEP was analyzed through Student's t-test (paired) and repeated measure analysis of variance for time and sex factors were performed. Tukey's test was used for multiple comparisons, and effect size was assessed by Cohen's d coefficient for dependent t-test, as preconized by Lenhard W and Lenhard A [27]. A significance level of 5% ( $p < 0.05$ ) and an observed power of 80% ( $OP > 80\%$ ) were assumed.

## Results

Forty healthy young individuals (Table I) were invited to participate, although one declined due to time restriction and another one quit the program due to intolerance to the BS RMT protocol (ear pain provoked during PPP). The remaining 38 participants (26 females) completed the study. As expected, MIP and MEP were significantly higher in males (MIP:  $f = 84.60$  and  $p = 0.0001$ ; MEP:  $f = 71.28$  and  $p = 0.0001$ ). There was a significant increase in respiratory muscle strength (Figure 2) but no interaction between time and sex was found (MIP:  $p = 1.0$ ; MEP:  $p = 0.7$ ). This indicated that functional adaptations induced by muscle overload occurred regardless of sexual characteristics (Figure 3). The relative increase in muscle strength was equivalent between males and females (approximately 4% higher in men for both MIP and MEP) (Table I). On the other hand, the effect of time on strength increment was significant (MIP:  $p = 0.002$ ; MEP:  $p = 0.02$ ) and progressive throughout the program.



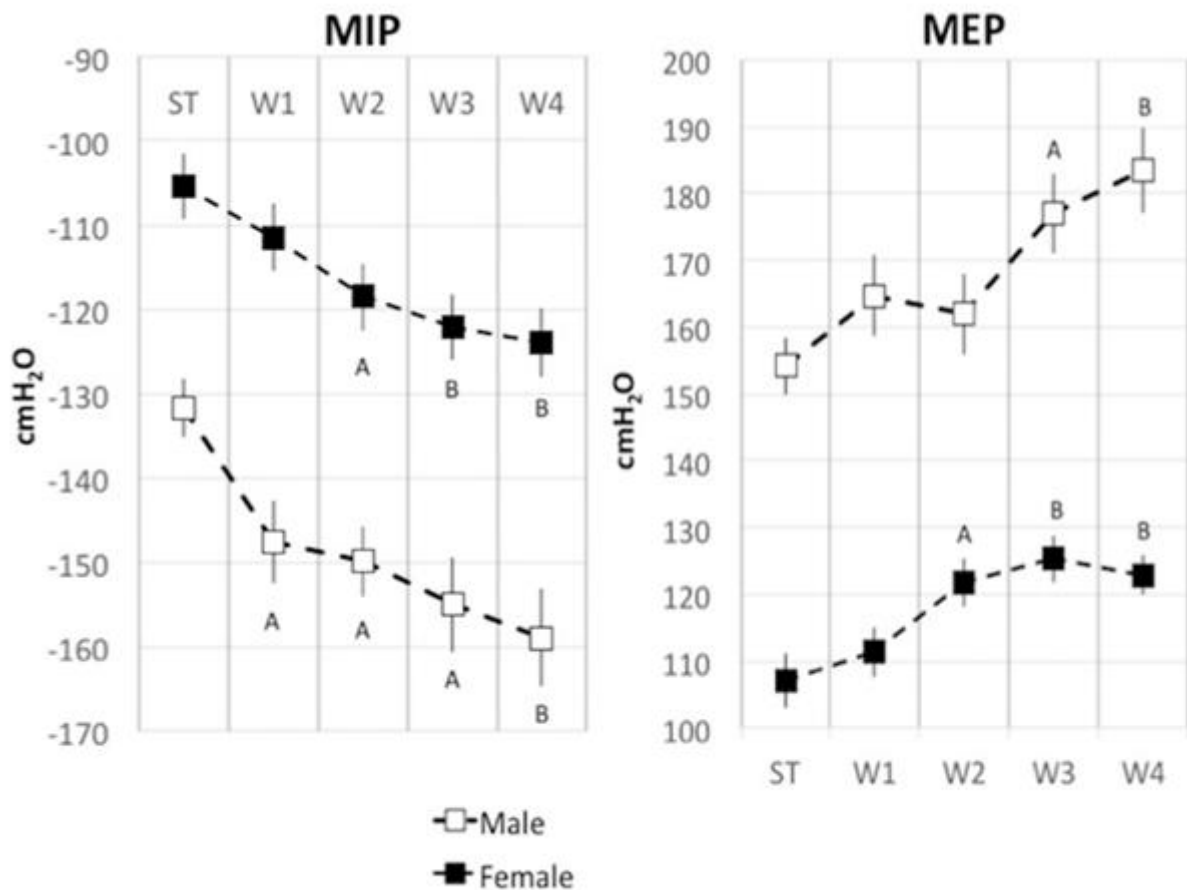
ST = start training; W = week; A = significant difference when compared to the ST; B = significant difference when compare to the A; C = significant difference when compared to the B. Data represent average and standard error; the effects of respiratory muscle training were available by repeated measure analysis of variance

**Fig. 2** - Maximal inspiratory pressure (MIP) and maximal expiratory pressure (MEP) development during the respiratory muscle training program

**Table I - Increase in muscle strength in the respiratory muscle training program**

Physical characteristics (n = 38)	N (%) or average $\pm$ SD
Age (years)	21.8 $\pm$ 1.8
Male	12 (31)
Female	26 (69)
Self-considered as little physically active	23 (57)
Self-considered as physically active	16 (43)
Self-considered as high performance athlete	0 (0)
<b>Male</b>	
MIP (cmH <sub>2</sub> O)	-131.7 $\pm$ 21.3
Predicted value (%)	95.4
MEP (cmH <sub>2</sub> O)	154.1 $\pm$ 26.3
Predicted value (%)	104.1
<b>Female</b>	
MIP (cmH <sub>2</sub> O)	-105.5 $\pm$ 26.3
Predicted value (%)	108.7
MEP (cmH <sub>2</sub> O)	107.0 $\pm$ 24.9
Predicted value (%)	103.8

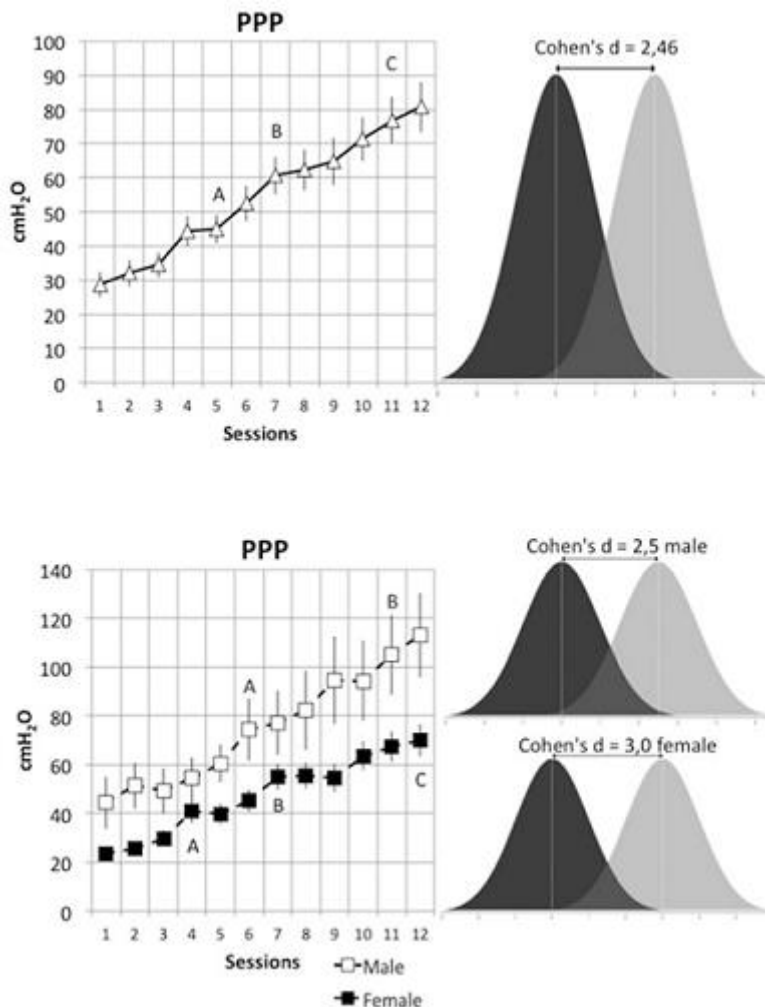
MIP = maximal inspiratory pressure; MEP = maximal expiratory pressure



ST = start training; W = week; A = significant difference when compared to the ST; B = significant difference when compare to the A. Data represent average and standard error; the effects of respiratory muscle training were available by repeated measure analysis of variance

**Fig. 3 - Maximal inspiratory pressure (MIP) and maximal expiratory pressure (MEP) development during the respiratory muscle training program**

PPP also increased linearly and progressively until the end of the RMT (Figure 4). In the fifth session, PPP significantly exceeded the values recorded on the first day of training ( $p < 0.05$ ). In the seventh session, PPP reached values higher than the fifth session and the values of the eleventh session were even higher when compared to the seventh session. The pattern of PPP increment was comparable between sexes while no interaction between sex and time was found ( $p = 0.98$ ).



ST = start training; W = week; A = significant difference when compared to the ST; B = significant difference when compare to the A; C = significant difference when compare to the B Data represent average and standard error; the effects of respiratory muscle training were available by repeated measure analysis of variance, effect size estimate for Cohen's d test

**Fig. 4 - Positive pressure peak (PPP) development during the respiratory muscle training program**

Considering baseline values as normality pattern, it could be assumed that baseline values represent data from a control group of healthy young individuals. Thus, it was possible to rearrange the data to perform effect size calculation (Cohen's d) and the number needed to treat (NNT). It was observed that the effect size was relatively large for MIP and MEP, but larger for PPP (Table II). At the end of training, it was possible to



expect increases in MIP, MEP and PPP of 76%, 73% and 281% in healthy young individuals, respectively, regardless of sex. The NNT suggested that one therapeutic success could be achieved for each 4.1 (MIP), 4.9 (MEP) and 1.3 (PPP) healthy youngers treated (respectively).

**Table II – Differences before and after training**

Efficiency of the BS as a RMT	Before	After	Δ%	p	Cohen's d	NNT
<b>All</b>						
MIP	-113.7 ± 26	-135.0 ± 33	19	0.001	0.73	4.1
MEP	121.9 ± 33	142.0 ± 29	17	0.001	0.66	4.9
<b>Male</b>						
MIP	-131.7 ± 21*	-158.9 ± 35*	21	0.009	0.98	2.7
MEP	154.1 ± 26*	183.5 ± 39*	19	0.008	0.93	3.0
<b>Female</b>						
MIP	-105.5 ± 23	-123.9 ± 25	17	0.001	0.80	3.5
MEP	107.0 ± 24	122.8 ± 18	15	0.001	0.76	4.0
<b>PPP</b>						
All	28.7 ± 13	80.7 ± 29	281	0.001	2.46	1.3
Male	44.3 ± 18*	113.0 ± 35	255	0.005	2.58	1.3
Female	23.5 ± 9.1	70.5 ± 20	300	0.001	3.09	1.3

MIP = maximal inspiratory pressure; MEP = maximal expiratory pressure, PPP = positive pressure peak, \* = p < 0.0001 when compared with female

## Discussion

This study has been the first so far to evaluate the effectiveness of Breath Stacking as a therapeutic method of respiratory muscle training in young and healthy individuals. The results were consistent and demonstrated that adaptations occurred regardless of sex. Even with slight differences between sexes, the expectation of enhancing the performance of the respiratory muscles is quite high for this population. In general, the changes started from the second week of training and kept on progressing towards the end of the twelfth session. Since healthy individuals have shown to improve their respiratory muscle strength, it may be assumed that those presenting reduced respiratory muscle strength will benefit from more significant improvements.

Based on the results, the use of BS as proposed in this study can be classified as a respiratory muscle training due to the significant increases in the performance of the ventilatory (both inspiratory and expiratory) muscle groups. Although the Breath Stacking technique has been originally used as a therapeutic resource to promote increased lung volume [21-23], this study showed that muscle overload generated by the artificial dynamic hyperventilation is sufficient to induce gains in ventilatory strength performance - even in the absence of mechanical or pathological airflow resistance during inspiration processes. When comparing the relative increase in maximum pressures (MIP ~ 19% and MEP ~ 17%), it is reasonable to assume that BS imposes an equivalent overload to both inspiratory and expiratory muscles.

Measurement of positive pressure peak (PPP) during the isovolumetric expiration phase allowed to monitor the degree of effort produced by the expiratory muscles throughout the program. In the first session, PPP corresponded to 26% of basal MEP. Interestingly, the relative increase in PPP (281%) at the end of the program was substantially higher than the relative increase in MPE (17%). This indicates that participants began to develop higher muscle capacity (56% of the post training MEP), which may represent the effect of learning in improving the performance of the technique.

When analyzed separately by sex, PPP reached 61% and 57% of MEP (male and female, respectively). This muscle requirement is very close to the highest muscle overload values recommended in the literature, which generally do not exceed 60% of the maximum pressure for expiratory muscle training [6-11]. Regarding expiratory overload, BS can be considered an effective expiratory muscle training technique since the achieved overload rate is substantially high. RMT using BS protocol may also be useful for pulmonary expansion therapy or atelectasis reversion due to the significant increase in PPP achieved at the end of training. However, this mechanism must be studied through new trials recruiting patients with pulmonary disorders.

Considering the size of the effect obtained after training, our findings strongly support the therapeutic potential that this technique offers as an RMT modality. It is also important to consider the relevant influence of motivation for physical training since in this method the degree of muscle demand is influenced by each individual determination. Thus, the applicability of BS as RMT in clinical situations has yet to be evaluated. Another important aspect to consider is related to the degree of strength increase that is intended to be obtained with training. In athletes, for instance, equipment that uses airflow resistance (springs) generates very high workloads, and, consequently, greater training potential. In fact, BS is a much more feasible technique for treating clinical dysfunctions than for high performance training, although similar gains to ours were reported in healthy young people (17%) [19]. Nonetheless, flow resistors achieve much greater gains [28] than those found with BS, especially over MIP, reinforcing the recommendation that high-performance physical training should prioritize more robust overloading techniques as a first option.

The results show statistical importance and bring light to a new alternative therapy for RMT since BS has been studied and applied for other purposes other than the one proposed and proved by the results in this study. The size effect found is relatively large for MIP, MEP and PPP regardless of sex. Moreover, the small number needed to treat (NNT) demonstrates this therapy must be explored in new trials, with other populations and specific pathologies (NNT: MIP = 4.1; MEP = 4.9; PPP = 1.3).

Finally, the upward behavior of respiratory muscle strength (inspiratory and expiratory) performance observed throughout the proposed training period (4 weeks) suggests that the physiological adaptations promoted by BS may reach values higher than those observed in this study, since there was no accommodation (plateau pattern) in the MIP and MEP curves. Therefore, the maximum potential of BS as RMT has not been found yet, and our data support the hypothesis that the apex of functional development of ventilatory muscles should occur over a 4-week training period.

## Conclusion

In conclusion, BS can be a feasible choice for RMT aiming at the recovery of muscle strength. However, exposure to training periods longer than 12 sessions will be required to elucidate the physiological peak of ventilatory muscle adaptation when overloaded by this technique. In addition, BS must be tested under different clinical conditions of ventilatory muscle weakness to unravel the likelihood of success of this therapeutic resource for rehabilitation of ventilatory muscles functions. The BS protocol as a RMT may also be useful for pulmonary expansion therapy, due to the significant increase in PPP achieved at the end of training, but clinical trials with different lung disorders should be conducted to further confirm our findings.

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### Conflict of interest

The authors declare they have no conflict of interest.

### Founding Source

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### Ethical approval

The study design was approved by a local Research Ethics Committees of Porto Alegre, RS, Brazil (AN: 07/03874).

### Authors' contributions

Statistical analysis, presentation and discussion of results and writing the paper: Macagnan FE; Providing extra methodological help, writing assistance and proof reading the article: Martha BA, Lourenzon IM, Pedroni AS, Kessler A

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