ORIGINAL ARTICLE

Braz J Cardiovasc Surg 2024;39(2):e20230231
https://doi.org/10.21470/1678-9741-2023-0231

Incremental Ramp Load Protocol to Assess Inspiratory Muscle Endurance in Healthy Individuals: Comparison with Incremental Step Loading Protocol

Guilherme de Souza Areias[1*], PT; Alexandre Fenley[2*], PT; Luan Rodrigues Santiago[1], PT; Alessandra Choqueta de Toledo Arruda[1], PT, PhD; Rodrigo Boemo Jaenisch[3], PT, PhD; Solange Guizilini[4], PT, PhD; Michel Silva Reis[1,2], PT, PhD

[1]Grupo de Pesquisa em Avaliação e Reabilitação Cardiorrespiratória (GECARE)/Faculdade de Fisioterapia, Programa de Pós-Graduação em Educação Física/Escola de Educação Física e Desportos, Universidade Federal do Rio de Janeiro, Rio de Janeiro, Rio de Janeiro, Brazil.
[2]Grupo de Pesquisa em Avaliação e Reabilitação Cardiorrespiratória (GECARE)/Faculdade de Fisioterapia/ Programa de Pós-Graduação em Medicina-Cardiologia/Instituto do Coração Edson Saad, Universidade Federal do Rio de Janeiro, Rio de Janeiro, Rio de Janeiro, Brazil.
[3]Departamento de Fisioterapia e Reabilitação, Programa de Pós-Graduação em Ciências do Movimento e Reabilitação, Universidade Federal de Santa Maria, Santa Maria, Rio Grande do Sul, Brazil.
[4]Programa de Pós-Graduação em Cardiologia, Universidade Federal de São Paulo, São Paulo, São Paulo, Brazil.

*Guilherme de Souza Areias and Alexandre Fenley have contributed equally to this paper.

This study was carried out at the Universidade Federal do Rio de Janeiro, Rio de Janeiro, Rio de Janeiro, Brazil.

ABSTRACT

Introduction: Protocols for obtaining the maximum threshold pressure have been applied with limited precision to evaluate inspiratory muscle endurance. In this sense, new protocols are needed to allow more reliable measurements. The purpose of the present study was to compare a new incremental ramp load protocol for the evaluation of inspiratory muscle endurance with the most used protocol in healthy individuals.
Methods: This was a prospective cross-sectional study carried out in a single center. Ninety-two healthy individuals (43 men [22 ± 3 years] and 49 women [22 ± 3 years]) were randomly allocated to perform: (i) incremental ramp load protocol and (ii) incremental step loading protocol. The sustained pressure threshold (or maximum threshold pressure), maximum threshold pressure/dynamic strength index ratio, time until task failure, as well as difference between the mean heart rate of the last five minutes of baseline and the peak heart rate of the last 30 seconds of each protocol were measured.
Results: Incremental ramp load protocol with small increases in the load and starting from minimum values of strength index was able to evaluate the inspiratory muscle endurance through the maximum threshold pressure of healthy individuals.
Conclusion: The present study suggests that the incremental ramp load protocol is able to measure maximum threshold pressure in a more thorough way, with less progression and greater accuracy in the load stratification compared to the limited incremental step loading protocol and with a safe and expected cardiovascular response in healthy individuals.
Keywords: Exercise Test. Respiratory Muscles. Physical Endurance.

Abbreviations, Acronyms & Symbols			
BMI	= Body mass index	IPAQ	= International Physical Activity Questionnaire
BP	= Blood pressure	IRLP	= Incremental ramp load protocol
CHF	= Chronic heart failure	ISLP	= Incremental step loading protocol
DBP	= Diastolic blood pressure	MIP	= Maximum inspiratory pressure
HR	= Heart rate	PthMax	= Maximum threshold pressure
IME	= Inspiratory muscle endurance	S-Index	= Strength index
IMS	= Inspiratory muscle strength	SBP	= Systolic blood pressure
IMT	= Inspiratory muscle training	SD	= Standard deviation

Correspondence Address:
Michel Silva Reis
https://orcid.org/0000-0002-3817-0529
Grupo de Pesquisa em Avaliação e Reabilitação Cardiorrespiratória (GECARE),
Faculdade de Fisioterapia, Hospital Universitário Clementino Fraga Filho,
Universidade Federal do Rio de Janeiro
Prof. Rodolpho Paulo Rocco St., s/n, 2º andar, Ilha do Fundão, Rio de Janeiro, RJ, Brazil
Zip Code: 21941-913
E-mail: msreis@hucff.ufrj.br

Article received on June 14th, 2023.
Article accepted on August 30th, 2023.

INTRODUCTION

The inspiratory muscle training (IMT) has been applied to improve the capacity of inspiratory muscles to generate maximum force (strength) and to maintain a specific muscular task over time (endurance)[1]. The inspiratory muscle resistance training protocols have been shown to be effective in patients in the cardiovascular postoperative period[1,2] and in those with chronic heart failure (CHF)[1,2], chronic obstructive pulmonary disease[3,4], asthma[5], and chronic kidney disease[6]. The measurement of maximum inspiratory pressure (MIP) had been commonly used as a simple assessment of global inspiratory muscle strength (IMS), however, its physiological benefits to prescribe IMT have been questioned for healthy individuals and athletes who do not present inspiratory muscle weakness. Hill et al.[7] questioned the relevance of MIP for not mimicking an effort commonly obtained in the daily life activities of individuals with or without some respiratory disorder. Therefore, considering that the mechanism involved in the optimization of the IMS of individuals without muscle weakness is related to reduction of the oxygen supply and to the competition for the peripheral blood flow at the peak of the exercise, it is possible to question the relevance of some training protocols for IMS of these individuals. The prescription of IMT should be aimed at improving inspiratory muscle endurance (IME) in order to improve inspiratory muscle tolerance to strenuous exercise and decrease inspiratory muscle metaboreflex[8].

Studies have shown a significant increase of sustained pressure threshold during an incremental test (maximum threshold pressure [PthMax]) using MIP as the basis of IMT[9,10]. However, IME evaluation protocols are used only for post-intervention analysis[7,9,11]. This allows to envisage the benefits of IMT protocol based on the previous IME evaluation and by using the PthMax as an IMT prescription parameter and not as a variable to just control the training effects. Given the potential of the PthMax, a good protocol to obtain loads is necessary. The protocol for evaluating IME through PthMax is based on a progressive increase of the load in percentage platforms and has been shown to be an important and widely used tool[6,10,12,13]. However, the increase of loads on percentage platforms of stratification occurs every 10%, the threshold of failure during the test does not reflect, accurately, the exact values with which the individual would not support a certain ventilatory overload. Another factor is the threshold of the percentage of the test in which the individual fails. Since PthMax is only established when the subject performs more than half the time/incursions in the corresponding percentage platform, this implies the possibility of underestimating the IME of these individuals. A high initial load, around 50-60% of MIP, is another factor limiting the test for individuals with low endurance capacity.

PthMax is therefore a measure with enormous diagnostic and exercise prescription potential and is being underestimated, mainly due to a limited stratification protocol, which makes the test inappropriate for individuals with low IME. In this context, the objective of the present study was to compare a new tool for the evaluation of IME, with small load increases and starting at lower values of the dynamic strength index (S-Index), with the most used protocol within the method of pressure threshold loading.

METHODS

Study Design and Participants

This prospective cross-sectional study was conducted at laboratory of Grupo de Pesquisa em Avaliação e Reabilitação Cardiorrespiratória (GECARE), Faculdade de Fisioterapia, Universidade Federal do Rio de Janeiro. Participants were consecutively recruited between February 2018 and June 2020. This study was guided by the Strengthening the Reporting of Observational Studies in Epidemiology (or STROBE) statement[14].

One hundred and one healthy individuals according to clinical evaluation of both sexes, aged between 18 and 40 years, were recruited from a university population. The volunteers were submitted to a detailed evaluation, in which the personal data, anthropometrics, and vital signs were collected. The anamnesis and physical examination were performed in order to investigate the history of previous diseases, as well as lifestyle and food habits. The individuals were stratified into very active, active, irregularly active, and inactive by the short form of the International Physical Activity Questionnaire (IPAQ)[15]. Individuals who were unable to perform the IMS protocol, participants with a history of smoking or illicit drugs consumption, and those with cardiovascular (such as systemic arterial hypertension, CHF, electrical conduction disorder, among others), respiratory (obstructive and restrictive diseases), muscular (myopathy), neurological, metabolic (diabetes mellitus) and immunological diseases were excluded. This sample size was justified by a priori power analysis in G*power using a target effect size of f = 0.25, alpha of 0.05, and power of 0.80, which determined that 36 subjects were required for participation; the additional recruitment accounted for the possibility of dropouts. This project was approved by the Ethical Committee of Hospital Clementino Fraga Filho, Universidade Federal do Rio de Janeiro (CAAE 43656115.8.0000.5257). All volunteers signed an informed consent form to participate in this research.

Experimental Protocols

A prospective cross-sectional, blind, and randomized study was undertaken to compare an incremental ramp load protocol (IRLP) and an incremental step loading protocol (ISLP) (control condition). The individuals were submitted to the S-Index measurement by using an inspiratory linear charge resistor (Power Breathe, IMT Technologies Ltd, Birmingham, United Kingdom). After S-index measurement, individuals were randomly allocated to the incremental load protocols: (i) ISLP (control condition) and (ii) IRLP with a minimum recovery time of 15 minutes in between. For the comparison of the protocols, three variables were analyzed: (i) PthMax, characterized as the peak load reached during the incremental tests — it reflects a physical measure (cmH_2O) representative of its maximum IME capacity —; (ii) PthMax/S-Index ratio, characterized as the ratio between the IME and the pressure peak in isolated maneuver — this relationship is able to show if the individuals have a very low or low IME, because it normalizes the peak resistance with the data of the peak of pressure obtained, providing data in percentage —; (iii) total time (s), duration time of the individual in each protocol until task failure.

The same linear inspiratory resistor (Power Breathe, IMT Technologies Ltd., Birmingham, United Kingdom) was used to perform the protocols, and individuals received the same instructions from the S-Index evaluation for optimal test performance. Blood pressure was measured at the beginning and end of each incremental protocol.

Dynamic Strength Index Measurement

The S-Index was determined after maximal inspiratory effort, from the residual volume to the total lung capacity, against a mouthpiece duly coupled to the volunteer. The S-Index values were those observed at the peak pressure generated by the pressure × time plot observed through BreatheLink Software 1.1. The S-Index was measured with a 30-second interval between maneuvers, being considered the highest value found in three reproducible maneuvers (difference < 10%)[16]. A short period of training was performed until the individual was familiar with the functioning of the device[17,18]. Individuals were instructed to use a nasal clip and to not perform compensatory head and trunk movements during the maneuver. We also performed a previous correlation and concordance analyze between serial S-Index and MIP measurements with a sample of 45 individuals with a strong and significant correlation (r = 0.74 and P<0.0001) and good agreement[16].

Incremental Step Loading Protocol

The initial load was 60% of the S-Index, with 10% added every minute without interruptions between overloads. The maximum possible load to be reached was 90% of the S-Index or until interruption by failure, observed by the non-opening of the inspiratory valve by the individuals (Figure 1). The respiratory rate was controlled by verbal command[19] of the same researcher during the test, being induced to 15 cycles per minute (inspiration:expiration ratio = 1:3). It was considered as the peak load, that the individual can perform at least seven full raids or 30 seconds on that percentage platform. Since the test aims at reaching failure, characterized by the inability to overcome the burden imposed during three consecutive inspirations[20], there was no pause period between each percentage platform.

Incremental Ramp Load Protocol

The initial load of this protocol is based on the lowest value provided by the device (3 cmH_20) and, in the sequence, incremental increases of 2% (less load progression according to the technical limitation of the resistive load S-Index at each ventilatory incursion until reaching 100% of the S-Index or failure interruption, characterized by the inability of the volunteer to overcome the load imposed during three consecutive inspirations) (Figure 1). The respiratory rate was controlled by the verbal command of the researcher during the test, being induced to 15 cycles per minute (inspiration:expiration ratio = 1:3).

Cardiovascular Stress

Sixteen randomized individuals were selected to infer cardiovascular stress from each IME assessment protocol. Heart rate (HR) was collected, beat-to-beat, through the Polar® V800 cardio frequency meter[21] during rest (10 minutes) and during ISLP and IRLP protocols. The difference between the mean HR of the last five minutes of baseline and the peak HR of the last 30 seconds of each protocol was considered for analysis. Additionally, systolic and diastolic blood pressures (SBP and DBP, respectively) were assessed before and after ISLP and IRLP protocols.

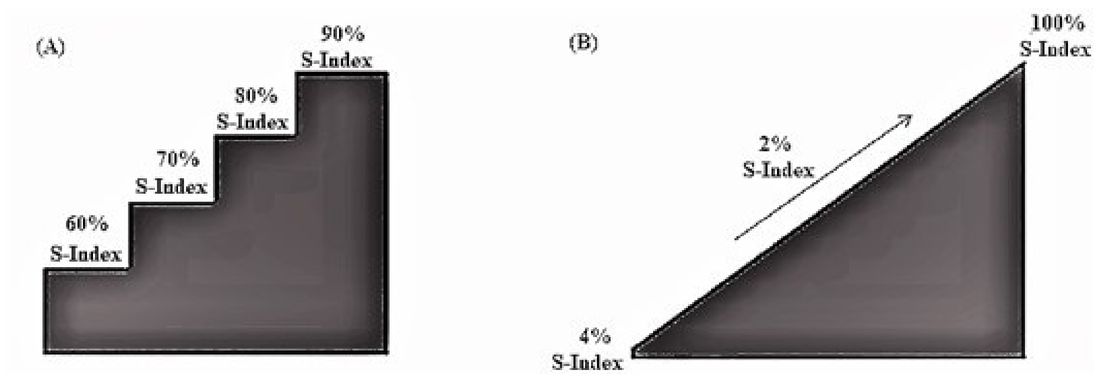

Fig. 1 - *Illustration of the protocols for obtaining the sustained pressure threshold during an incremental test (maximum threshold pressure): (A) incremental step loading protocol; (B) incremental ramp load protocol. Values are expressed as a percentage of the dynamic strength index (S-Index).*

Data Analysis

For statistical analysis, Sigmaplot Software 12.0 was used, and the volunteers were divided by sex. Initially, the Shapiro-Wilk and Levene tests were applied to evaluate normality and homogeneity, respectively. The PthMax/S-Index, PthMax, total time and HR Delta data were analyzed using the paired *t*-test. The Pearson correlation was then applied to evaluate the association between the protocols. The Bland-Altman analysis with a 95% confidence interval was adopted to evaluate the agreement of the PthMax between the protocols. Data were presented as mean and standard deviation with an established level of significance of $P<0.05$.

RESULTS

One hundred and one young and eutrophic individuals were screened. Nine individuals were excluded for failing to perform S-Index. Male subjects presented a higher level of physical activity by IPAQ when compared to female subjects. None of the individuals had inspiratory muscle weakness, as shown in Table 1.
Regarding the variables in men, the PthMax/S-Index (66.74 ± 7.78 and 67.86 ± 13.29 cmH_2O) and the PthMax (109.02 ± 19.68 and 111.25 ± 23.95 cmH_2O) showed no statistical difference between ISLP and IRLP, respectively. However, total time (94.04 ± 54.63 and 138.79 ± 27.52 seconds) presented a significant difference between ISLP and IRLP ($P<0.05$) (Figure 2). Regarding the variables in women, the PthMax/S-Index (66.53 ± 8.30 and 64.73 ± 17.81 cmH_2O) and PthMax (74.65 ± 17.20 and 73.92 ± 27.39 cmH_2O) showed no statistical difference between ISLP and IRLP, respectively. The total time, as in men, also presented statistical difference between ISLP and IRLP (94.53 ± 56.56 and 132.73 ± 35.55 seconds) ($P<0.05$) (Figure 2). Data from the Pearson analysis demonstrated a strong and significant correlation for the PthMax variable between ISLP and IRLP ($r = 0.78$, $P<0.001$ and $r = 0.82$, $P<0.001$, for men and women, respectively) (Figure 3). In addition, the Bland-Altman test was performed, revealing good agreement, and confirming the strong correlations of PthMax (Figure 3). Regarding the analysis of the HR and blood pressure delta, no

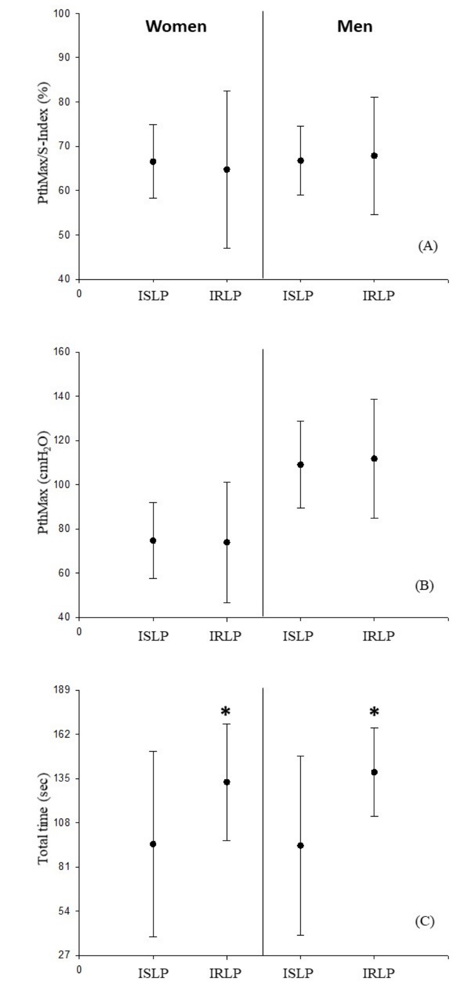

Fig. 2 - *Comparison of incremental step loading protocol (ISLP) and incremental ramp load protocol (IRLP) by sex. (A) Sustained pressure threshold ratio during an incremental test (maximum threshold pressure [PthMax])/dynamic strength index (S-Index); (B) PthMax; (C) total time. *t-test paired with P<0.05 when comparing protocols.*

Table 1. Demographics, anthropometric data, level of physical activity, and inspiratory muscle strength of the volunteers studied.

	Women	Men
n = 92	n = 49	n = 43
Age (years)	22 ± 3	22 ± 3
Body mass (kg)	57.50 ± 9.53	76.63 ± 12.82
Height (m)	1.63 ± 0.06	1.77 ± 0.08
BMI (kg/m²)	21.80 ± 3.60	24.50 ± 3.34
IPAQ, very active (%)	24.48	46.51
IPAQ, active (%)	40.82	39.53
IPAQ, irregularly active (%)	26.54	13.96
IPAQ, inactive (%)	8.16	0
S-Index (cmH_2O)	111.55 ± 18.33	162.95 ± 24.15

Data are expressed as mean ± standard deviation or percentages
BMI=body mass index; IPAQ=International Physical Activity Questionnaire; S-Index=strength index

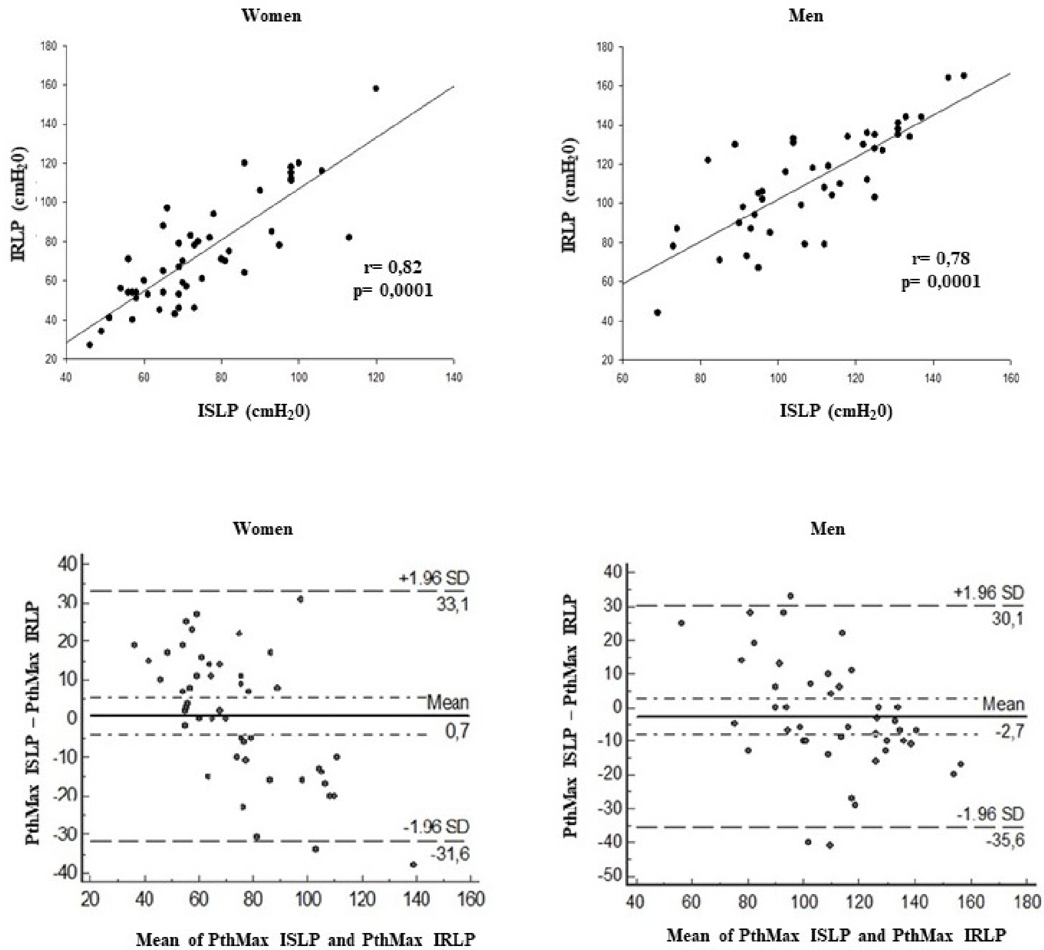

Fig. 3 - *Pearson correlation and Bland-Altman agreement between incremental step loading protocol (ISLP) and incremental ramp load protocol (IRLP) for women and men. PthMax=maximum threshold pressure; SD=standard deviation.*

statistical difference was observed between the protocols, which shows that even with longer total ventilatory time in the IRLP, both have similar cardiovascular stress (Figure 4).

DISCUSSION

The main findings of our study showed that the new protocol, with small increases in the load and starting from minimum values of S-Index, was able to evaluate IME through the PthMax of healthy individuals. IRLP also showed a longer total time until reaching PthMax compared to ISLP, despite both protocols presented similar cardiovascular stress. To our knowledge, this is the first study to propose a protocol in ramp conformation to evaluate IME through PthMax, making the IRLP an extremely relevant tool with greater accuracy in the stratification of the load obtained during incremental resistance tests.

In our study, IMS assessment was done through the S-Index, which is a dynamic measurement of the inspiratory muscles. In a previous study, we found that the values of S-Index are not the same as those of MIP. However, the two methods of IMS assessment had a strong and significant correlation ($r = 0.74$ and $P<0.0001$), as well as good concordance evidenced by the Bland-Altman analysis[16]. The rational application of S-Index, for IMS dynamic evaluation, refers to standardization of muscle contraction pattern adequate to support the dynamic endurance protocols, in contrast to protocols used in previous studies that based the resistance evaluation in a static force measurement (MIP) to support the ISLP[6,10,12].

The ISLP has been a widely used tool to stratify the PthMax of individuals aiming to evaluate the impact of different IMT protocols on post-intervention IME[6,7,9,11]. However, the ISLP presents limitations that urges to the conception of a new strategy. The ISLP's first limitation is the stratification in percentages per 10%,

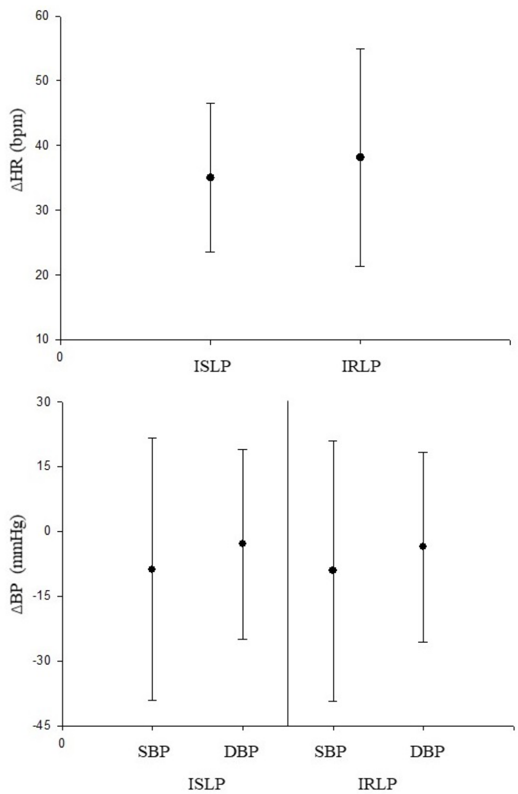

Fig. 4 - *Delta of heart rate (HR), systolic blood pressure (SBP), and diastolic blood pressure (DBP) of 16 volunteers (males and females) evaluated by the incremental step loading protocol (ISLP) and the incremental ramp load protocol (IRLP) and analyzed by the paired t-test. BP=blood pressure.*

which may represent a wide range of stratification for fatigue. This is a limitation for stratification of the maximum tolerated load during the evaluation, either to analyze intervention effects or to measure PthMax for serial training. This may explain the fact that authors who apply ISLP do so only to try to evidence an improvement in IME even basing their IMT protocols on the MIP maneuver[6,9,10]. In contrast, in the IRLP, the increment occurs every 2% of the maximum value obtained in the previous force test. We have extremely detailed values of load stratification, not only allowing precision in the post-intervention evaluation, but also as a possible variable when prescribing the appropriate load for the IMT.

The second limitation is to evaluate individuals with low resistance through ISLP. Since it begins with loads of 50-60% of the maximum pressure value obtained in the IMS test by varying the load every 1-3 minutes[9,12], it may restrict the good evaluation capacity, as the individuals do not remain in the test for a minimum time necessary for the stratification of PthMax. This ISLP's limitation can be observed by the high standard deviation observed in the time variable of our study which demonstrates the selectivity of the test to individuals with higher levels of IME. Alternatively, in the IRLP, the increase of loads starts from minimum values, which allows its application to individuals who present all degrees of IME.

In the present study, healthy individuals required a longer total time to obtain PthMax performing IRLP with similar cardiovascular stress and safety of ISLP. However, further studies of these protocols are necessary in other populations, protocols with serial inspirations against high resistances that can determine impacts on the cardiovascular system of special populations. Scharf et al.[22] demonstrated that in individuals with coronary artery disease or previously infarcted submitted to multiple inspirations against occluded airway, a left ventricular wall akinesia could occur, which impairs ejection fraction and increases SBP and DBP. Sampol et al.[23] showed that high intrathoracic negative pressures increase the sympathetic activity and overload of the intrathoracic structures, which can lead to increased aortic transmural pressure and dilation, as well as posterior dissection, clinically evidenced in individuals with obstructive sleep apnea and Marfan syndrome. Taking this into account, we suggest that future studies evaluate whether IRLP could be more adequate to cardiovascular patients since it has a slow progression and a shorter total charge time allowing better adaptation to the imposed overload. Another relevant aspect of the IRLP was the report of the great majority of individuals in qualifying it as a "less unpleasant" tool. From this, it is possible to suppose that neuroadaptive factors, correlated to the small increment, allowed the individuals to be better adapted to the progression of the loads.

Limitations

A limitation of our study was not to have inserted a tool that checked a subjective response on the adaptation to each protocol, being made by simple asking the volunteers after each test.

CONCLUSION

In conclusion, our study suggests that IRLP is able to measure PthMax in a more thorough way, with less progression and greater accuracy in the load stratification compared to the limited ISLP and with a safe and expected cardiovascular response in healthy individuals.

ACKNOWLEDGMENTS

The authors would like to thank the staff of the Grupo de Pesquisa em Avaliação e Reabilitação Cardiorrpiratória (GECARE) and funding agencies for financial support to the laboratory.

Financial support: This study was funded by the Conselho Nacional de Desenvolvimento Científico e Tecnológico and Fundação Carlos Chagas Filho de Amparo à Pesquisa do Estado do Rio de Janeiro.

No conflict of interest.

Author's Roles & Responsibilities

GSA	Substantial contributions to the conception or design of the work; or the acquisition, analysis, or interpretation of data for the work; drafting the work or revising it critically for important intellectual content; agreement to be accountable for all aspects of the work in ensuring that questions related to the accuracy or integrity of any part of the work are appropriately investigated and resolved; final approval of the version to be published
AF	Substantial contributions to the conception or design of the work; or the acquisition, analysis, or interpretation of data for the work; drafting the work or revising it critically for important intellectual content; agreement to be accountable for all aspects of the work in ensuring that questions related to the accuracy or integrity of any part of the work are appropriately investigated and resolved; final approval of the version to be published
LRS	Drafting the work or revising it critically for important intellectual content; final approval of the version to be published
ACTA	Drafting the work or revising it critically for important intellectual content; final approval of the version to be published
RBJ	Drafting the work or revising it critically for important intellectual content; final approval of the version to be published
SG	Drafting the work or revising it critically for important intellectual content; final approval of the version to be published
MSR	Substantial contributions to the conception or design of the work; or the acquisition, analysis, or interpretation of data for the work; drafting the work or revising it critically for important intellectual content; agreement to be accountable for all aspects of the work in ensuring that questions related to the accuracy or integrity of any part of the work are appropriately investigated and resolved; final approval of the version to be published

REFERENCES

1. Laoutaris I, Dritsas A, Brown MD, Manginas A, Alivizatos PA, Cokkinos DV. Inspiratory muscle training using an incremental endurance test alleviates dyspnea and improves functional status in patients with chronic heart failure. Eur J Cardiovasc Prev Rehabil. 2004;11(6):489-96. doi:10.1097/01.hjr.0000152242.51327.63.
2. Lin SJ, McElfresh J, Hall B, Bloom R, Farrell K. Inspiratory muscle training in patients with heart failure: a systematic review. Cardiopulm Phys Ther J. 2012;23(3):29-36.
3. Lisboa C, Villafranca C, Leiva A, Cruz E, Pertuzé J, Borzone G. Inspiratory muscle training in chronic airflow limitation: effect on exercise performance. Eur Respir J. 1997;10(3):537-42.
4. Ramirez-Sarmiento A, Orozco-Levi M, Guell R, Barreiro E, Hernandez N, Mota S, et al. Inspiratory muscle training in patients with chronic obstructive pulmonary disease: structural adaptation and physiologic outcomes. Am J Respir Crit Care Med. 2002;166(11):1491-7. doi:10.1164/rccm.200202-075OC.
5. Sampaio LMM, Jamami M, Pires VA, Borghi-Silva A, Costa D. Força muscular respiratória em pacientes asmáticos submetidos ao treinamento muscular respiratório e treinamento físico. Rev Fisioter Univ São Paulo. 2002;9(2):43-8. doi:10.1590/fpusp.v9i2.78554
6. de Medeiros AIC, Fuzari HKB, Rattesa C, Brandão DC, de Melo Marinho PÉ. Inspiratory muscle training improves respiratory muscle strength, functional capacity and quality of life in patients with chronic kidney disease: a systematic review. J Physiother. 2017;63(2):76-83. doi:10.1016/j.jphys.2017.02.016.
7. Hill K, Jenkins SC, Philippe DL, Shepherd KL, Hillman DR, Eastwood PR. Comparison of incremental and constant load tests of inspiratory muscle endurance in COPD. Eur Respir J. 2007;30(3):479-86. doi:10.1183/09031936.00095406.
8. Ribeiro JP, Chiappa GR, Callegaro CC. The contribution of inspiratory muscles function to exercise limitation in heart failure: pathophysiological mechanisms. Rev Bras Fisioter. 2012;16(4):261-7. doi:10.1590/s1413-35552012005000034.
9. Dall'Ago P, Chiappa GR, Guths H, Stein R, Ribeiro JP. Inspiratory muscle training in patients with heart failure and inspiratory muscle weakness: a randomized trial. J Am Coll Cardiol. 2006;47(4):757-63. doi:10.1016/j.jacc.2005.09.052.
10. Winkelmann ER, Chiappa GR, Lima CO, Viecili PR, Stein R, Ribeiro JP. Addition of inspiratory muscle training to aerobic training improves cardiorespiratory responses to exercise in patients with heart failure and inspiratory muscle weakness. Am Heart J. 2009;158(5):768.e1-7. doi:10.1016/j.ahj.2009.09.005.
11. Eastwood PR, Hillman DR, Morton AR, Finucane KE. The effects of learning on the ventilatory responses to inspiratory threshold loading. Am J Respir Crit Care Med. 1998;158(4):1190-6. doi:10.1164/ajrccm.158.4.9803108.
12. Neves LM, Karsten M, Neves VR, Beltrame T, Borghi-Silva A, Catai AM. Relationship between inspiratory muscle capacity and peak exercise tolerance in patients post-myocardial infarction. Heart Lung. 2012;41(2):137-45. doi:10.1016/j.hrtlng.2011.07.010.
13. Neves LM, Karsten M, Neves VR, Beltrame T, Borghi-Silva A, Catai AM. Respiratory muscle endurance is limited by lower ventilatory efficiency in post-myocardial infarction patients. Braz J Phys Ther. 2014;18(1):1-8. doi:10.1590/s1413-35552012005000134.
14. von Elm E, Altman DG, Egger M, Pocock SJ, Gøtzsche PC, Vandenbroucke JP, et al. The strengthening the reporting of observational studies in epidemiology (STROBE) statement: guidelines for reporting observational studies. J Clin Epidemiol. 2008;61(4):344-9. doi:10.1016/j.jclinepi.2007.11.008.
15. Matsudo S, Araujo T, Matsudo V, Andrade D, Andrade E, Oliveira LC, et al. Questionário internacional de atividade física (IPAQ): estudo de validade e reprodutibilidade no Brasil. Rev Bras Ativ Fis Saúde. 2001;6(2):5-18. doi:10.12820/rbafs.v.6n2p5-18. Portuguese.
16. Areias GS, Santiago LR, Teixeira DS, Reis MS. Concurrent validity of the static and dynamic measures of inspiratory muscle strength: comparison between maximal inspiratory pressure and s-index. Braz J Cardiovasc Surg. 2020;35(4):459-64. doi:10.21470/1678-9741-2019-0269.
17. 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. doi:10.1159/000050458.
18. Lomax M, McConnell AK. Influence of prior activity (warm-up) and inspiratory muscle training upon between- and within-day reliability of maximal inspiratory pressure measurement. Respiration. 2009;78(2):197-202. doi:10.1159/000211229.
19. Neder JA, Andreoni S, Lerario MC, Nery LE. Reference values for lung function tests. II. Maximal respiratory pressures and voluntary ventilation. Braz J Med Biol Res. 1999;32(6):719-27. doi:10.1590/s0100-879x1999000600007.
20. Archiza B, Simões RP, Mendes RG, Fregonezi GA, Catai AM, Borghi-Silva A. Acute effects of different inspiratory resistive loading on heart rate variability in healthy elderly patients. Braz J Phys Ther. 2013;17(4):401-8. doi:10.1590/S1413-35552012005000100.
21. Giles D, Draper N, Neil W. Validity of the Polar V800 heart rate monitor to measure RR intervals at rest. Eur J Appl Physiol. 2016;116(3):563-71. doi:10.1007/s00421-015-3303-9.
22. Scharf SM, Woods BO, Brown R, Parisi A, Miller MM, Tow DE. Effects of the mueller maneuver on global and regional left ventricular function in angina pectoris with or without previous myocardial infarction. Am J Cardiol. 1987;59(15):1305-9. doi:10.1016/0002-9149(87)90909-x.
23. Sampol G, Romero O, Salas A, Tovar JL, Lloberes P, Sagalés T, et al. Obstructive sleep apnea and thoracic aorta dissection. Am J Respir Crit Care Med. 2003;168(12):1528-31. doi:10.1164/rccm.200304-566OC.