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Human Kinetics
ORIGINAL INVESTIGATION

Moderate- and High-Intensity Inspiratory Muscle Training Equally Improves Inspiratory Muscle Strength and Endurance—A Double-Blind Randomized Controlled Trial

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Background and Objective: Inspiratory muscle training (IMT) produced outstanding results in the physical performance of active subjects; however, little is known about the best training intensity for this population. The objective was to investigate the impact of an IMT of high intensity, using the critical inspiratory pressure (CIP), on inspiratory muscle strength (IMS), inspiratory muscle endurance (IME), peak power, and oxygen uptake of recreational cyclists; and to compare these results with moderate-intensity IMT (60% of maximal inspiratory pressure [MIP]). ***Methods:*** Thirty apparently healthy male recreational cyclists, 20–40 years old, underwent 11 weeks of IMT (3 times per week; 55 min per session). Participants were randomized into 3 groups: sham group (6 cmH_2O; n = 8); 60% MIP (MIP60; n = 10) and CIP (n = 12). All participants performed the IMS test and incremental IME test at the first, fifth, ninth, and 13th weeks of the experimental protocol. Cardiopulmonary exercise testing was performed on an electromagnetic braking cycle ergometer pre-IMT and post-IMT. Data were analyzed using a 2-way repeated measures ANOVA (group and period factors). ***Results:*** IMS increased in CIP and MIP60 groups at the ninth and 13th weeks compared with the sham group ($P < .001$; $\beta = 0.99$). Regarding IME, there was an interaction between the CIP and MIP60 groups in all periods, except in the initial evaluation ($P < .001$; $\beta = 1.00$). Peak power (in watts) increased after IMT in CIP and MIP60 groups ($P = .01$; $\beta = 0.67$). Absolute oxygen uptake did not increase after IMT ($P = .49$; $\beta = 0.05$). Relative oxygen uptake to lean mass values did not change significantly ($P = .48$; $\beta = 0.05$). ***Conclusion:*** High-intensity IMT is beneficial on IMS, IME, and peak power, but does not provide additional gain to moderate intensity in recreational cyclists.

Keywords: breathing exercises, physical endurance, respiratory muscles, oxygen consumption

Inspiratory muscle training (IMT) has been used as a complementary tool to improve the physical performance,[1–4] which can be evaluated by maximal or peak oxygen uptake (VO_2peak) and peak power (peak work) during cardiopulmonary exercise testing (CPET) in healthy subjects, athletes, and nonathletes.[5] Studies have shown that peripheral and respiratory muscle fatigue can induce an early interruption of physical exercise. The fatigue leads to neural and cardiovascular changes, such as increased sympathetic nervous activity, heart rate, and mean arterial pressure; changes in respiratory patterns; and also blood flow redistribution between the exercise limbs and respiratory muscle, known as inspiratory muscle metaboreflex.[1–4] The IMT induces the delay in activating this mechanism, decreasing the onset of peripheral muscle fatigue and the sensation of dyspnea, thus improving physical performance.[1–4] However, despite the outstanding results of IMT, little is known about the prescription of this type of training, the best parameters, and their responses in the respiratory system in healthy subjects.[6]

In addition, respiratory muscles stand out from other muscles of the body because of their endurance; however, the most common IMT prescription only uses inspiratory muscle strength (IMS) indexes, such as percentages of maximal inspiratory pressure (MIP). Therefore, a load prescription considering both inspiratory muscle endurance (IME) and IMS can lead to additional gains compared with those generated by a prescription based only on IMS. Considering this, the idea emerged of using the concept of critical power (CP) to define the resistance for performing IMT, thus creating critical inspiratory pressure (CIP).[7] The CP method is defined as the highest work rate at which a steady state is attainable for pulmonary oxygen output, arterial blood acid–base status (hydrogen ions [H^+], lactate [L^-], and bicarbonate), and intramuscular phosphates (phosphocreatine and inorganic phosphate).[8,9] Thus, CP is the highest sustainable work rate without progressive contributions from anaerobic metabolism[10,11] and is thus an important parameter in defining tolerance to high-intensity exercise.[12]

This concept has already been used to evaluate and determine the training load for different sports, such as cycling,[13] running,[14] rowing,[15] table tennis,[16] among others. In addition, the CP model has already been applied to heart rate[13] and ventilatory responses,[17] whereby CP values observed for the cardiac and respiratory systems (~90% of maximal load) were larger than those observed for the locomotor system (~80% of maximal load) due to the great homeostatic function of these systems.[18] Using the CP method, satisfactory results were obtained for the improvement of physical performance in several studied populations.[13–16] However, to the best of our knowledge, there are no studies that applied this concept to the respiratory system in order to determine the training load for IMT.

We hypothesized that the IMT performed with CIP load would lead to better responses such as an increase in IMS, IME, and physical performance (peak power and VO_2peak) compared with training with the traditional load (60% MIP) and the sham group

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(SHAM) in recreational cyclists. The main purpose of this study was to investigate the effect of CIP in IMT for the improvement of IMS, IME, and physical performance. The second objective is to compare CIP with 60% MIP responses.

Methods

Classification of the Study

This study used an experimental, randomized, controlled, and double-blinded design. The research participants and researcher, who performed the statistical analysis, were blinded. The methodological design was based on the CONSORT guidelines,[19] and the full description of the protocol was described in Rehder-Santos et al.[7]

Ethical Aspects and Study Planning

This project was approved by the Human Research Ethics Committee at the Federal University of São Carlos (No. 1.558.731) and registered in the ClinicalTrials.gov (No. NCT02984189). Written informed consent was obtained from all subjects.

The experimental protocol was performed at the Cardiovascular Physical Therapy Laboratory at the Physical Exercise Research Nucleus in the Department of Physical Therapy and the clinical ergometric tests at the Health School Unit, both located at Federal University of São Carlos.

Participants

The G*Power software (version 3.1.3; Heinrich-Heine-Universität Düsseldorf, Düsseldorf, Germany) was used to calculate the sample size for this study. The mean effect size value ($f = 0.25$, according to COHEN[20]) was used for the 2-way mixed analysis of variance test, values of 0.05 for the type I probability error (α) and .80 for the type II probability error (power or β). Therefore, in order to ensure these preestablished conditions, at least 30 subjects should participate in this study.

Thirty recreational male cyclists, aged between 20 and 40 years, apparently healthy, who had been practicing cycling for at least 6 consecutive months and at least 150 minutes per week (classified as active by the American College of Sports Medicine[5]) were evaluated. In addition, the noninclusion criteria were as follows: present abnormalities in the human systems that make the proposed tests impossible, obese (body mass index >30 kg/m^2), drinkers, users of illicit drugs or medications, diabetics, hypertensive, smokers, and participants who performed any type of IMT over the last 12 months. The following were excluded: participants with electrocardiogram malignant alterations, in rest and/or during the clinical exercise test, and former smokers with at least 1 year of interruption and respiratory muscle weakness (MIP and maximal expiratory pressure <60% predicted[21]).

In this study, group randomization was performed by stratified randomization[22] and blocks (Supplementary Material 1 [available online]). After the initial evaluations, the participants were paired considering individuals with the same aerobic functional classification[23] and age range (20–30 and 31–40 y), forming blocks. Afterward, using brown envelopes, participants within each block were randomized into 3 groups: SHAM (n = 8), 60% MIP (MIP60; n = 10), and CIP (n = 12).

Experimental Protocol

The protocol was performed over 13 weeks. At the first, fifth, ninth, and 13th weeks, the participants were submitted to the following evaluations: IMS and incremental IME. The pulmonary function test and CPET were performed only in the first and 13th weeks of the study. The IMT lasted 11 weeks and during the reevaluation weeks, the participants continued to carry out the training. In addition, before the beginning of the experimental protocol, all participants were familiarized with all the maneuvers and tests performed, thus avoiding the learning effect in the data collected in this study.

Respiratory Muscle Strength

The evaluation of respiratory muscle strength was performed with the participant at rest in a sitting position, using a digital manovacuometer (MVD-300; GlobalMed, Porto Alegre, Brazil) and a nasal clip, according to the Brazilian guidelines for measuring maximal static respiratory pressures.[24] This measure was always carried out by the same researcher. The MIP was determined after maximal inspiratory effort, from the residual volume. The maximal expiratory pressure was determined after maximal expiratory effort, from the total lung capacity. These maneuvers were performed against a tube with an occluded distal end and a 2-mm hole mouthpiece was used. The values of the maximal respiratory pressures were obtained in the first second after the peak pressure. At least 3 maneuvers were performed, with a 30 second interval between each maneuver, obtaining the highest reproducible values (difference < 10%) found in at least 3 maneuvers and considering the maximal respiratory pressure value as the highest value. Normal values were proposed by Neder et al[25] for the Brazilian population.

Cardiopulmonary Exercise Testing

The CPET was used to assess the aerobic power of the participants (VO_2peak).[26] The ramp-type protocol was performed on an electromagnetic braking cycle ergometer (CORIVAL V3; Lode BV, Groningen, The Netherlands) and consisted of a 6-minute rest, 3-minute free-load warm-up, and a gradual increase in load until the exercise was stopped, followed by 6-minute active recovery and 1-minute passive recovery. The power increments (ranging from 25 to 45 W/min) were calculated for each participant using the formula described by Wasserman et al[27] and adapted according to the evaluator's experience, preventing the increment from being underestimated.

Participants were instructed to maintain a cadence between 60 and 80 revolutions per minute throughout the protocol and the test lasted from 8 to 12 minutes.[26] The ventilatory and metabolic variables were obtained, breath-by-breath, through a metabolic cart (ULTIMA MedGraphics—St Paul, MN/VMAX Encore 29 System—CareFusion, Yorba Linda, CA) and processed using specific software. The highest value of VO_2 obtained in the last 30 seconds of the CPET was considered the VO_2peak.[26]

Pulmonary Function Test

The pulmonary function test was performed according to the international standard[28] and consisted of slow and forced vital capacity tests and maximal voluntary ventilation. The test was performed using a flow module coupled with a metabolic cart (ULTIMA MedGraphics). The variables analyzed were forced vital capacity (FVC) tests, forced expiratory volume in 1 second (FEV_1), relationship between FEV_1 and FVC (FEV_1/FVC), inspiratory capacity, expiratory reserve volume, and maximal voluntary ventilation. The predicted values were calculated according to Pereira.[29]

Incremental Inspiratory Muscle Endurance Test

An incremental protocol using loads from 50% to 100% MIP was performed, with 10% MIP added every 3 minutes. The participant received a verbal stimulus to maintain the respiratory rate at 12 breaths per minute, and the test continued until reaching 100% MIP. If the participant generated an air flow capable of triggering the equipment more than once in this load, the MIP measurement was redone and the test repeated. The following test termination criteria were considered: failure to maintain the stipulated load at 12 breaths per minute for at least 1 minute, failure to maintain respiratory effort indicated by the participant (Borg/category ratio $10 \geq 7$),[30] and the participant's request for interruption. The highest percentage of MIP that the participant maintained for at least 1 minute (maximal threshold pressure—PTh_{MAX}) was considered as the IME measurement.[7]

Inspiratory Muscle Training

The IMT lasted for 11 weeks, with a weekly frequency of 3 sessions. Each session had a 1-hour duration, and consisted of a 5-minute warm-up, where each participant performed a constant loading protocol with 50% of their training load, and 3 sets of 15 minutes of breaths, with 1-minute interval between sets. Training loads were adjusted at the fifth and ninth training weeks.

The loads used in the training were determined: for the CIP group, as the value of the CIP calculated as $CIP = (0.97 \times PTh_{MAX}) - 6.957$[7]; for the MIP60 group, the resistance representing 60% MIP; and for the SHAM group, using the resistance of 6 cmH_2O. All groups performed the IMT using a linear load respiratory device (POWERBreathe, Ironman K5; HaB Ltd, Warwickshire, United Kingdom).

Participants were instructed to maintain diaphragmatic breathing and the respiratory rate of 12 breaths per minute for the entire duration of the training protocol. The respiratory rate was controlled using a recorded verbal command, ensuring that all participants received the same stimulus. During the 11 weeks of training, participants were instructed to not change their daily activities, physical training, and eating habits.

Every day, before and after the training protocol, the arterial pressure and health status were checked while the heart rate was monitored, recorded, and stored throughout all the training sessions using a Polar RS 800 CX (Polar Electro, Kempele, Finland). In addition, to monitor the activities performed, participants completed a physical activity record on a weekly basis. The same weekly and total training volume, controlled over 11 weeks, was ensured to all participants throughout this study.

Participants who did not complete the 3 weekly training sessions and/or the 33 total training sessions, or that changed their physical activity, or those who began to use medication of continuous use were excluded.

Statistical Analysis

All statistical analyses were performed using the SigmaPlot software (version 11.0; Systat Software, Inc, San Jose, CA). The level of significance was set at $P < .05$. Data with normal distribution were presented according to the mean (SD); and those with nonnormal distribution, according to median (interquartile range). Data were checked for normality using the Shapiro–Wilk test and homogeneity using the Levene test. A comparative analysis of the 3 evaluated groups was performed using the 1-way ANOVA and post hoc Tukey or Kruskal-Wallis test and post hoc Dunn concerning the following data: age, anthropometric evaluation, body composition analysis, baseline RMS (MIP and maximal expiratory pressure), and CPET (VO_2peak) and pulmonary function test index.

To analyze the comparison between the 3 groups, the following factors were considered: group and period (first [period 1], fifth [period 2], ninth [period 3], and 13th [period 4] weeks of the protocol) in the variables of the IMS (MIP), IME (PTh_{MAX}), and CPET (peak power and VO_2), 2-way repeated measures ANOVA and post hoc Tukey test.

Results

Subjects Studied

The flowchart of the study is presented in Figure 1. A single participant had rib pain during the training with the CIP load. He was excluded and referred to a professional for medical treatment. No lesion or clinical alteration was identified. All groups were similar in body composition, RMS, and aerobic functional capacity at the beginning of the protocol (Table 1). Pulmonary function showed no differences between groups before or after training, except for percentage predicted expiratory reserve volume, which was higher in MIP60 compared with the SHAM. However, despite the statistical difference, all groups were within the range of normality. Thus, only the pretraining results of pulmonary function were presented, as according to a recent meta-analysis review these variables do not change after IMT in athletes.[3]

IMS and Endurance

The training induced changes in IMS, assessed by means of MIP in both groups. The MIP60 presented higher values compared with the SHAM ($P = .037$; $\beta = 0.488$). In relation to the training period, there was an increase in MIP overtime ($P < .001$; $\beta = 1.000$). There was a group × time interaction showing that MIP60 improved IMS compared with the SHAM from the fifth until the 13th week of training; and both MIP60 and CIP showed an improvement compared with the SHAM from the ninth until the 13th week of training ($P < .001$; $\beta = 0.993$) (Figure 2).

Regarding IME, CIP and MIP60 also showed an improvement compared with the SHAM ($P = .002$; $\beta = 0.915$). There was an increase in PTh_{MAX} until the ninth week ($P < .001$; $\beta = 1.000$). There was an interaction between factors showing that MIP60 and CIP improved compared with the SHAM from the fifth until the 13th week of training ($P < .001$; $\beta = 1.000$) (Figure 2).

Considering that the MIP60 group had an initial MIP value higher than the other groups, in Supplementary Material 2 (available online) we present the analysis of MIP and PTh_{MAX} in relative percentage values (data acquired in the fifth, ninth, and 13th weeks of the experimental protocol subtracted from the value of the initial evaluation). Despite the fact that at the end of 11 weeks the CIP group had an improvement in relation to the first week, higher than the other groups for MIP (increased of CIP = 40% [18%]; MIP60 = 28% [11%]; SHAM = 14% [8%]), and PTH_{MAX} (increase of confidence interval $P = 51\%$ [13%]; MIP60 = 42% [13%]; SHAM = 13% [18%]), there was no statistical difference between CIP and MIP60 for these variables.

Inspiratory Muscle Training

Regarding the progression of the training loads, the SHAM trained during the 11 weeks using the load of 6 cmH_2O; the MIP60 trained

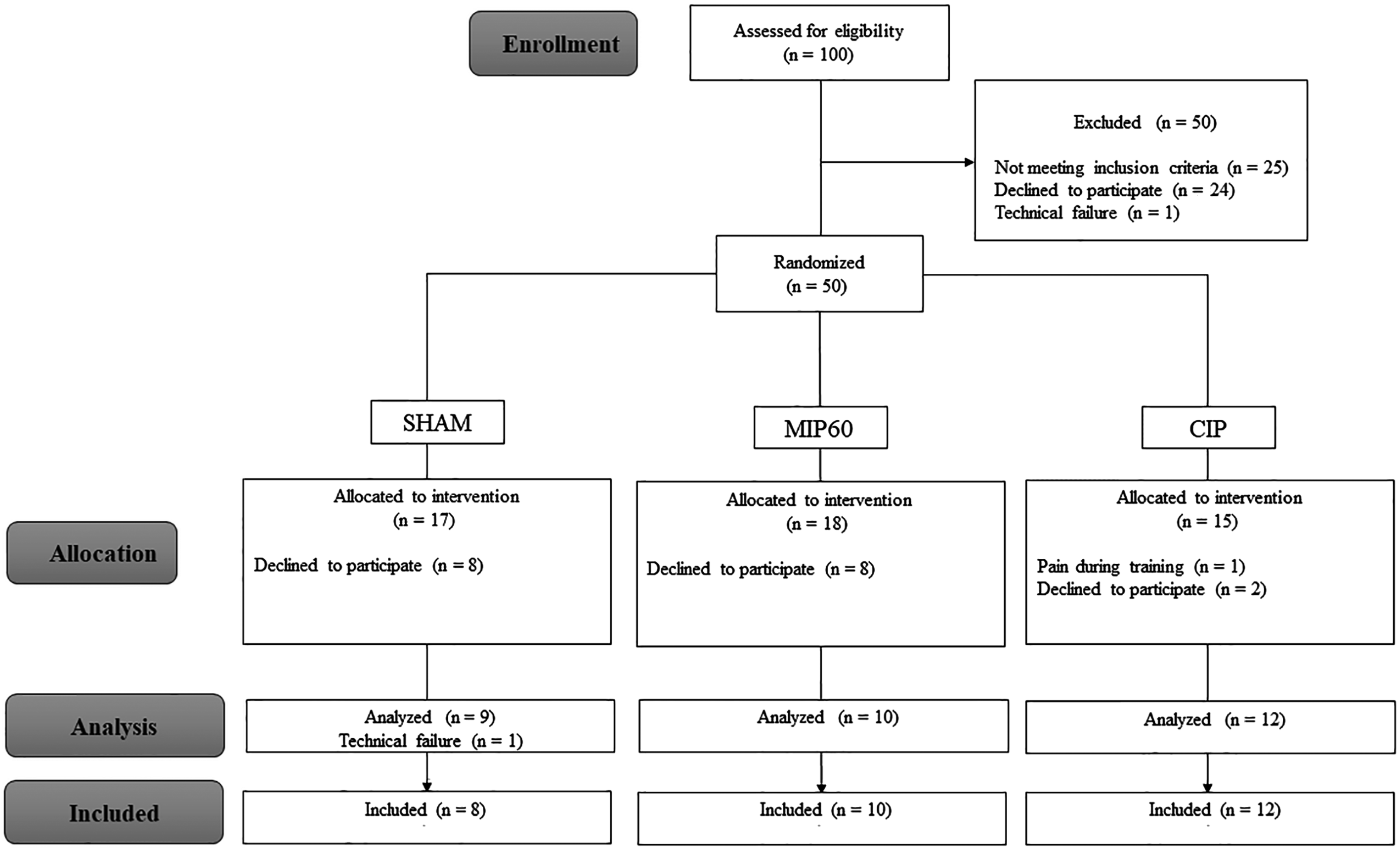

Figure 1 — Flowchart of the study. CIP indicates critical inspiratory pressure; MIP60, 60% of maximal inspiratory pressure; SHAM, sham group.

from the second to the fifth week using an average of 94 (15) cmH_2O, from the sixth to the ninth week using an average of 110 (15) cmH_2O, and from the 10th to the 12th week using an average of 116 (17) cmH_2O; CIP trained from the second to the fifth week with an average of 111 (15) cmH_2O, from the sixth to the ninth week with an average of 139 (17) cmH_2O and from the 10th to the 12th week with an average of 162 (17) cmH_2O. There was a significant difference between the training loads of the 3 groups ($P < .001$) and the training period ($P < .001$). A significant interaction effect was observed between the groups and period ($P < .001$), showing that load IMT improved in the CIP and MIP60 in all periods of training (Figure 3).

Peak Power and Oxygen Uptake

Peak power (in watts) increased after training in CIP and MIP60 groups ($P = .01$; $\beta = 0.67$). Absolute VO_2peak showed no increase after training ($P = .061$; $\beta = 0.35$), with no significant differences between groups ($P = .14$; $\beta = 0.21$). VO_2peak corrected by lean mass showed no difference between the groups ($P = .16$; $\beta = 0.19$) or between the training periods ($P = .14$; $\beta = 0.18$) (Figure 4).

In the qualitative analysis in Figure 4, it was observed that in all groups there were participants who did and did not respond to the applied training. The SHAM presented 3 (37.5%) respondents and 5 (62.5%) nonrespondents. The MIP60 presented 8 (80%) respondents and 2 (20%) nonrespondents. The CIP presented 9 (75%) respondents and 3 (25%) nonrespondents.

Discussion

The IMT using a high-intensity (CIP) improved endurance and strength of the inspiratory muscles, as well as peak power, in recreational cyclists. Despite these findings, no significant differences between the CIP and MIP60 were found. The results of this research provide the creation of a new hypothesis regarding the best load to perform the IMT in recreational cyclists, as the higher training load did not generate better results for the performance of the evaluated population. It can be suggested that there is an ideal load, at which it is possible to obtain the best result of the training performed and that loads above it do not generate additional adaptations capable of optimizing the functioning of the systems involved, such as metabolic, cardiovascular, and respiratory systems, in order to achieve higher performance during an incremental exercise test.

Inspiratory Muscle Strength

The literature suggests that the increase in IMS is due to 2 factors: morphological and neural.[3] Regarding the morphological factors, the main one is the increase in diaphragmatic thickness, which was observed in several studies, both in healthy[31,32] and in cardiorespiratory diseased individuals.[33] The neural changes suggest that IMT can attenuate the fatigue of accessory muscles of inspiration[3] and an improvement in neuromuscular activation and synchronism. Segizbaeva et al[34] showed that 3 weeks of IMT was sufficient to attenuate fatigue in scalene, sternocleidomastoid, and parasternal

Table 1 Characterization of Participants and Baseline Data

Characteristics	SHAM (n = 8)	MIP60 (n = 10)	CIP (n = 12)	*P* value
Age, y	32 (35–25)	35 (38–24)	30 (38–25)	.66
Anthropometric data				
Body mass total, kg	77 (84–65)	77 (82–68)	77 (88–65)	.74
Stature, m	1.78 (0.04)	1.76 (0.06)	1.76 (0.05)	.54
BMI, kg/m^2	23.64 (3.64)	24.06 (1.92)	24.74 (3.48)	.73
% of fat	21.75 (5.42)	20.69 (3.38)	21.86 (4.56)	.81
Respiratory muscle strength				
MIP, cmH_2O	149 (12)	158 (25)	146 (14)	.32
% predicted	130 (7)	127 (11)	132 (10)	.61
MEP,[a] cmH_2O	160 (39)	161 (20)	178 (40)	.30
% predicted[a]	118 (23)	119 (21)	131 (28)	.42
Inspiratory muscle endurance				
PTh_{MAX}, cmH_2O	118 (9)	119 (16)	121 (16)	.94
Aerobic functional capacity				
VO_2peak, mL/kg/min	57.48 (6.43)	63.44 (8.93)	65.27 (12.23)	.23
Pulmonary function				
FEV_1/FVC, L	5.61 (1.06)	5.86 (0.77)	5.62 (0.65)	.73
% predicted	107 (117–88)	115 (120–106)	109 (114–102)	.34
FEV_1, L	4.59 (5.78–3.69)	4.76 (5.18–4.21)	4.70 (5.06–3.94)	.95
% predicted	105.68 (23.61)	107.92 (14.86)	103.29 (11.74)	.80
FVC	83.29 (4.54)	79.20 (5.61)	81.42 (7.86)	.44
% predicted	97.29 (4.81)	93.38 (7.70)	95.15 (9.10)	.60
SVC, L	5.51 (0.78)	5.71 (1.15)	5.58 (0.67)	.90
% predicted	100 (108–92)	109 (118–104)	103 (109–97)	.11
IC, L	3.67 (0.66)	3.61 (0.64)	3.46 (0.63)	.77
% predicted	84 (107–82)	89 (96–81)	78 (105–75)	.53
ERV, L	1.97 (2.19–1.49)	2.42 (2.71–2.11)	2.32 (2.59–1.69)	.07
% predicted	93.38 (20.13)	143.08 (32.98)	116.63 (35.58)	.01
MVV, L/s	205.00 (38.17)	203.20 (36.48)	191.50 (36.63)	.67
% predicted	114.11 (16.46)	117.03 (24.48)	108.87 (19.59)	.65

Abbreviations: ANOVA, analysis of variance; BMI, body mass index; CIP, inspiratory critical pressure group; ERV, expiratory reserve volume; FEV_1, forced expiratory volume in 1 second; FEV_1/FVC, relationship between forced expiratory volume in 1 second and forced vital capacity; FVC, forced vital capacity; IC, inspiratory capacity; MEP, maximal expiratory pressure; MIP, maximal inspiratory pressure; MIP60, 60% MIP group; MVV, maximum voluntary ventilation; PTh_{MAX}, maximal threshold pressure; SHAM, sham group; SVC, slow vital capacity; VO_2peak, peak oxygen uptake corrected by lean mass. Note: SigmaPlot 11.0 software. One-way ANOVA and post hoc Tukey or Kruskal-Wallis test and post hoc Dunn. Values are expressed as the mean (SD) or median (Quartile 3–Quartile 1). $P < .05$ was established.
[a]There were 4 missing pieces of data in the MEP analyses (MEP and percent predicted); 3 in MIP60 and 1 in CIP.

muscles during incremental exercise, to increase MIP and improve maximal work performance. Moreover, Hellyer et al[35] showed increased electromyographic activity in the diaphragm and sternocleidomastoid muscles when performing IMT concurrently with cycling, compared with performing IMT alone.

The results of this study corroborate with the results of the recent systematic review by Karsten et al[3] that investigated the effects of IMT using linear training methods, such as in this study, in different sports modalities. The training loads used were 50% to 80% MIP, and regardless of the intensity of training, an increase in RMS was observed. In addition, aerobic sports showed a better result when compared with other types of sports.[3]

According to our findings, moderate (MIP60) and high (CIP) intensities increased IMS. Although no statistical difference was observed between CIP and MIP60 groups, the CIP had a greater increase in MIP compared with MIP60, after 11 weeks of training (Supplementary Material 2 [available online]). Despite the evidence that CIP can additionally contribute to improve IMS and endurance, further studies with a larger sample size should be carried out to prove this hypothesis.

Inspiratory Muscle Endurance

According to the systematic review by Sales et al,[4] IMT improves RME in athletes and nonathletes, using different loads between 30% and 50% MIP; furthermore, percentages of other variables were also related to IME such as sustained MIP (40%–80%) and maximal voluntary ventilation (50%–85%). It is worth pointing out that the best results were obtained with loads derived from an RME test, which can be attributed to the specificity of the evaluation and training objective.

The findings of this study showed that MIP60 and CIP intensities of IMT improved the IME of recreational cyclists, assessed using the incremental IME test and represented by the

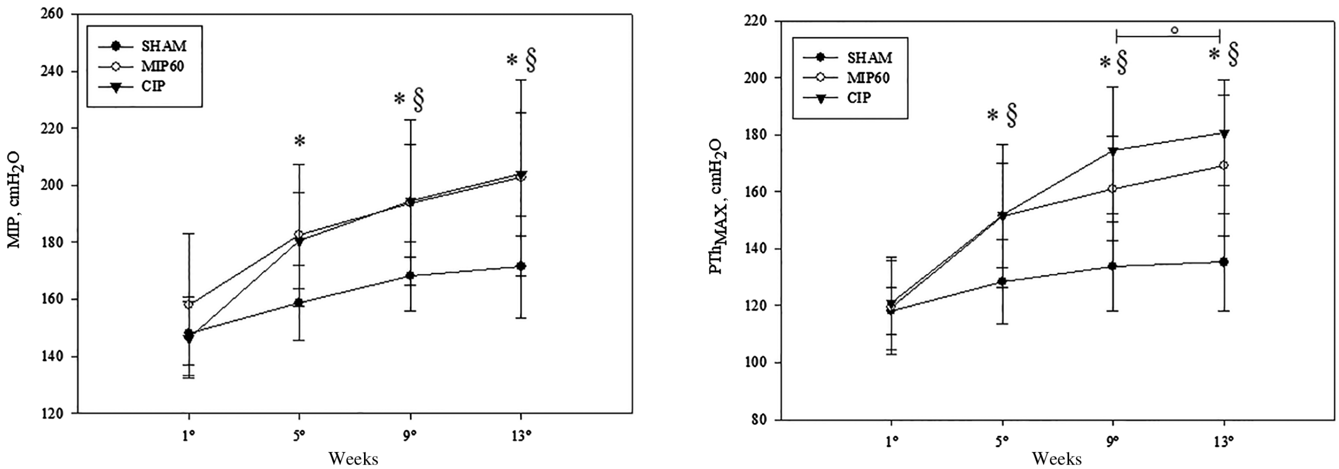

Figure 2 — Effect of CIP on inspiratory muscle strength and endurance. CIP indicates critical inspiratory pressure; MIP60, 60% of maximal inspiratory pressure; PTh_{MAX}, maximal threshold pressure; SHAM, sham group. §CIP versus SHAM. *MIP60 versus SHAM. °No difference between the ninth and 13th weeks.

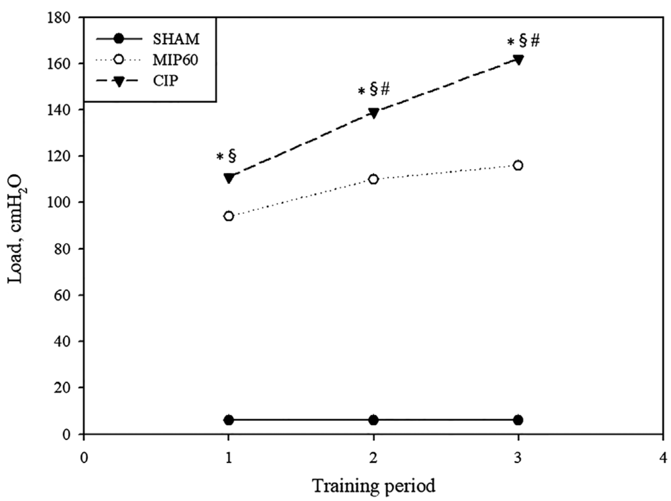

Figure 3 — Progression of the training loads. CIP indicates critical inspiratory pressure; MIP60, 60% of maximal inspiratory pressure; SHAM, sham group. §CIP versus SHAM. *MIP60 versus SHAM. #CIP versus MIP60.

PTh_{MAX}. We believed that using a load (CIP), which considers both strength and IME characteristics, would bring complementary results in contrast to those prescribed based only on strength testing. This hypothesis was not confirmed by our findings.

The CIP intensity in healthy young people corresponds to approximately 80% MIP and 90% PTh_{MAX}. Thus, the values of the critical power observed for the cardiac and respiratory systems are larger than those observed for the locomotor system due to the great homeostatic function of these systems.[18] This factor may be related to the lack of difference for IME findings, CIP compared with 60% MIP, as both loads have predominantly strength characteristics.

Based on the findings using the training loads of this study, a comparison with other lower loads, as shown in Sales et al,[4] would bring complementary information in order to verify the best load to improve IME.

Peak Power and Oxygen Uptake

Several systematic reviews[2–4,36] present the benefits of IMT for practitioners of various sports. Among the articles in these reviews, few studies achieved changes in maximal oxygen uptake.[2–4,36] Evaluating 6 clinical studies that investigated the effect of IMT on oxygen consumption, Karsten et al[3] concluded that IMT using linear workload devices was not effective in changing this parameter. When separately evaluating 7 clinical studies that investigated only cycling athletes, HajGhanbari et al[2] showed consistent trends that favor IMT in the results obtained concerning sports performance, endurance time limit, and oxygen uptake. They suggest that the demands placed on the respiratory muscles during IMT, especially in studies that used normocapnic hyperpnea, seem similar to those required during competitive cycling. Thus, they suggest that studies that performed a more aggressive training progression could obtain better benefits with IMT. Another mechanism capable of improving performance after IMT is the delay in activating the inspiratory muscle metaboreflex, as detailed in the introduction and highly discussed in articles with IMT.[2–4,36] These are the mechanisms that supported our hypothesis that the CIP load could stand out in improving the maximum oxygen consumption in this population, which was not confirmed in this study. However, maximal oxygen uptake is not the single determinant of endurance exercise performance; other factors such as endurance of the limbs and respiratory muscles can play a major role.[2–4,36] These factors are controlled by several mechanisms and body reflexes, where the inspiratory muscle metaboreflex is the most studied when it comes to IMT.[2–4,36]

These same reviews, which point out the lack of studies reporting changes in maximal oxygen uptake after IMT, also reveal that this type of training improved factors considered limiting of physical exercise, due to the delay of the metaboreflex, as peripheral and respiratory muscle fatigue, resulting in sports performance enhancement.[2–4,36] In addition, we emphasize the need for new studies to evaluate other exercise limiting factors, such as expiratory flow limitation during exercise.[37] In this study, it was observed that even without the change in VO_2peak, there was an increase in peak power (in watts). Joyner et al[38] reported that the increase in peak power may be related to an improvement in the efficiency of the cardiovascular, respiratory, and musculoskeletal systems to maintain

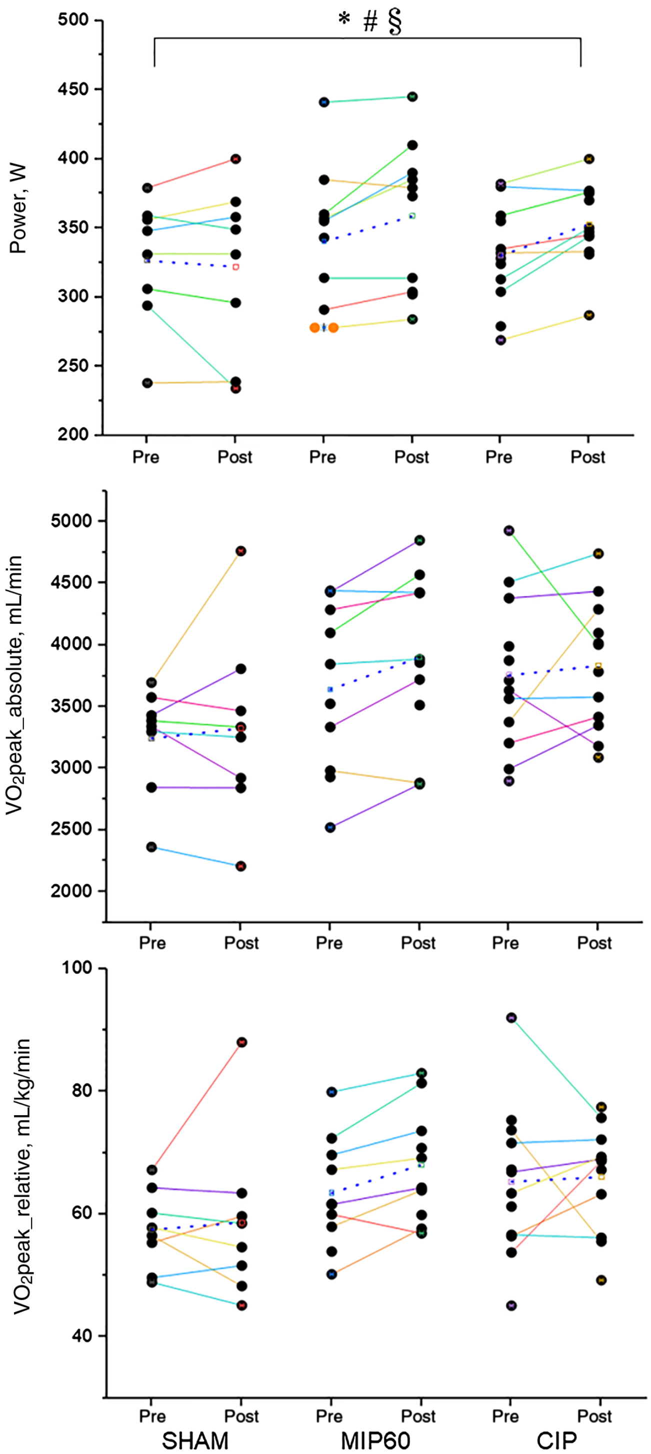

Figure 4 — Effect of critical inspiratory pressure on peak oxygen uptake and peak power. CIP indicates critical inspiratory pressure; MIP60, 60% of maximal inspiratory pressure; SHAM, sham group; VO_2peak_relative, peak oxygen uptake corrected by lean mass. §CIP versus SHAM. *MIP60 versus SHAM. #Post versus Pre.

physical activity. Thus, the body is able to increase its exercise capacity without increasing its metabolic demand, that is, the maximal oxygen uptake.

Snell and Mitchell[39] showed that only maximal ability to deliver oxygen to the tissues of the body establishes the upper limit of endurance performance, but is not able to predict sports performance. Thus, in order to achieve the best sports performance, other factors need to be developed, such as peripheral adaptation, through specific training, which leads to a better sports technique. In addition, other factors can also interfere with physical performance, such as genetic, motivational, and psychological factors.[38]

Limitation

The limitation of this study is the load restriction presented by the software of the equipment used, as it has the highest resistance value of 200 cmH_2O, which limited evaluating some participants.

Practical Applications

Knowledge on the effects of different IMT intensities is essential for an evidence-based choice of the best training protocol for each population and goal. Thus, the results of this research provided a better understanding of the effects of different intensities of IMT for recreational cyclists, for the improvement of IMS and IME.

Karsten et al[3] affirm that the IMT protocols used for applications in athletes were developed and studied initially with the aim of treating cardiorespiratory patients. Therefore, this study is the first step toward developing specific IMT protocols for amateur athletes. We showed that using the CIP load improves IMS and IME. However, despite the good CIP results for the population studied, it was not able to present additional results to those presented by moderate-intensity training (60% MIP). Thus, future studies should design a protocol that studies the effect of IMT on the physical performance b considering a larger number of loads and training groups.

Conclusion

The CIP and 60% MIP induced similar responses, improving the IMS, IME, and physical performance by an increase in peak power. Thus, high-intensity IMT was beneficial, but did not provide additional gain to moderate intensity in recreational cyclists.

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