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Impact of moderate and high intensity exercise on lung volumes, lung capacities, and breath holding time

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Abstract

Background: Exercise plays an important role in reducing the rate of decline of pulmonary function. There are very few studies done to compare the effect of intensity of exercise on pulmonary function and these studies included few parameters. **Objective:**This study aimed to evaluate the benefits of moderate- and high- intensity exercise training on pulmonary health and to analyze the correlation between lung volumes, capacities and respiratory muscular strength. **Materials &Method:** This study was conducted on 30 healthy individuals aged of 20 to 40 years. The participants were randomly divided into two groups of 15 each and performed moderate-intensity and high- intensity exercise respectively. Their pulmonary functions were analyzed using a spirometer. The Breath holding time was recorded with a 40 mmHg test. The comparison of parameters between the two groups before and after exercise was performed using paired t-test. A P value less than 0.05 was considered significant. Pearson's correlation coefficient was employed to ascertain the correlation between breath holding time and lung capacities. **Results:** High-intensity exercise training was found to enhance the breath holding time, vital capacity, inspiratory capacity and expiratory capacity more than moderate-intensity exercise. There was a weaker linear positive correlation between breath holding time and lung capacities. **Conclusion:** As high-intensity exercise shows benefits after training sessions three days per week, it can be easily brought into practice in the course of daily life in those finding time a constraint.
Keywords: breath holding time, lung capacities, lung volumes, exercise, moderate-intensity, high-intensity.

Introduction

Physical activity has been recommended by the World Health Organization (WHO) for healthy living. According to the WHO standard, the "Physical

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Activity" is defined as engaging in either 75 minutes of vigorous intensity activity per week or around 150 minutes of moderate-intensity activity per week [1]. Lack of physical activity and occurrence of obesity caused by sedentary life style are the causes for concern globally. A large percentage of India's population is physically inactive, with less than 10% of Indians engaging in physical activity[2]. Most countries in Asia are developing countries, and fewer are underdeveloped. Although the percentage of people below the poverty line varies across developing and

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underdeveloped countries, the addiction to television and cell phones in general in the population is leading to lack of physical activity and to a sedentary life style. Moreover, leisure time activities such as exercising, playing sports, walking, jogging, and visiting forests, gardens, and sites of scenic beauty are all in decline. A physically inactive lifestyle may lead to an increased risk of cardiovascular disorders, hypertension, stroke, diabetes mellitus, depression, and breast cancer [3,4]. The impact of a sedentary lifestyle on the occurrence of non-communicable diseases is similar in countries around the world. Exercise enhances cardiovascular health and also influences muscular bulk and neuromuscular stability. On the other hand, sedentary lifestyle, obesity, frequent eating habits, and environmental pollution are all factors that contribute to compromised lung functions, may lead to cardiorespiratory disorders, and can increase morbidity and mortality rates. Because of people's stressful lifestyles, exercise and fitness have received greater awareness in today's world. Taking time out of a busy schedule is a practical problem, and maintaining exercise practices consistently becomes difficult. Moreover, much research is being conducted to assess the beneficial effects of moderate-intensity/long-duration and high-intensity/short-duration exercises on cardiorespiratory health. Researchers worldwide feel that any exercise regime that is short in duration can be practically adopted in the course of daily life. Some studies have explored the benefits of moderate-intensity and high-intensity exercises on pulmonary functions, and most of them evaluated the parameters forced vital capacity (FVC) and forced expiratory volume(FEV_1) in 1 second. But there is a paucity of studies evaluating vital capacity (VC), inspiratory capacity (IC), expiratory capacity (EC), and breath holding time(BHT) for lung endurance and lung dynamics after moderate- and high-intensity exercise training. VC is the total amount of air exhaled after deep inspiration. IC is the maximum volume of air that can be inhaled into the lung from the point of ending of normal, quiet respiration, and EC is the maximum amount of air that can be exhaled after the completion of resting inspiration. Breath holding time (BHT) reflects the biomechanical efficiency of the lung tissue, thorax cage, and respiratory muscle strength. Bagavad Geetha et al. found that exercise training increases lung volume and capacity and improves BHT. They pointed out that exercise training also increases the efficiency of respiratory muscle strength of the diaphragm and intercostal muscles [5]. BHT is dependent on the sensitivity of the chemoreceptor reflex, mechanoreception (light stretch receptors), descending

cortical respiratory drive, and cognition (volition, emotional state) [6]. Thus, evaluation of BHT not only assesses the respiratory muscle strength but also the sensitivity of the chemoreflex[6,7]. No literature is available yet correlating these lung capacities with the BHT after cardiorespiratory exercise training of moderate and high intensity. We hypothesized that exercise training may influence inspiratory and expiratory capacity, respiratory muscle strength, and breath holding, and is thereby likely to improve respiratory endurance. The changing lung capacities along with BHT reflect respiratory muscle strength. Therefore, we aimed to verify the impact of moderate- and high-intensity exercise training on lung endurance by evaluating VC, IC, EC, and lung dynamics by estimating the tidal volume (TV), inspiratory reserve volume (IRV), and expiratory reserve volume (ERV); we evaluated respiratory muscle strength and chemoreflex sensitivity by BHT. TV is the amount of air inhaled and exhaled during normal breath, IRV represents the air that is forcibly inhaled after normal tidal respiration, and ERV is the volume of air that can be forcibly exhaled after exhalation of normal TV. The novelty of our study is its correlation analysis of lung volume and capacity with BHT following twelve weeks of moderate- and high-intensity cardio respiratory exercise training sessions in the two groups. The exercises recommended for enhancing cardio respiratory endurance include cycling, sprint cycling, running, jogging, swimming, and skating. We decided to conduct training sessions with static cycling for various durations. The goal of our research was to gain further understanding of the physiological basis of the impact of exercise training on breath holding and lung capacity.

Materials and Methods

Participants and Procedure

This study was approved by the Ethics and Research Committee of our institution and was done in accordance with the Helsinki Declaration of 1975, as revised in 2000.The study was conducted in 30 healthy individuals aged 20 to 40 years. Written consent was obtained from the participants after explaining the procedures and the protocol details.The participants were asked to complete the questionnaire to ensure their health and physical activity status. All selected participants were healthy and had no clinical evidence of illness. We included participants who did not engage in any exercise or sports and were leading a normal healthy lifestyle; we excluded smokers, athletes, and those with a history of any systemic disease or muscular disorders. Participants were randomly divided into two groups of 15 each. Participants in

group I performed moderate-intensity continuous exercise at a heart rate of 50-74% of their maximum heart rate for a duration of 40 minutes, 5 days a week. The participants in group II were instructed to perform high-intensity exercise for 8 s by sprint cycling at 75-84% of their maximum heart rate followed by 12 s of low-intensity cycling for a duration of 20 minutes, three times per week, on a bicycle ergometer (Avon Cycles Ltd, Ludhiana, India). These exercise training sessions were conducted for 12 weeks [8]. The training sessions always started with a warm-up period of 5 min followed by the regimen of moderate-intensity or high-intensity exercise. Pulmonary functions were recorded using a computerized spirometer as per the European Respiratory Society/American Thoracic Society Clinical Practice Guidelines [9]. The observed values of VC, TV, IRV, and ERV were noted. The IC was calculated by adding values of TV and IRV, while EC was estimated by adding TV and ERV. For BHT, the participants were instructed to take a deep breath and then blow through the mouthpiece of a mercury manometer until pressure was elevated to 40 mm Hg. The participants were asked to sustain the 40 mm Hg level until they could no longer hold their breath voluntarily [10].

Statistical analysis
The statistical package of Microsoft Excel and SYSTAT 13 was employed for statistical analysis in our study. The results are expressed as mean ± standard deviation (SD). The comparison of parameters between the two groups before and after exercise was performed using a paired t-test. A p- value less than 0.05 was considered significant. Pearson's correlation coefficient was employed to ascertain the correlation between BHT and VC, IC, and EC. We also used a simple linear regression analysis to ascertain whether the observed values of one variable can be used to predict the others.

Results
A total of 30 subjects participated in the study, of whom 20 were male and 10 were female. They were randomly divided into moderate-intensity exercise performer and high-intensity exercise performer groups. As shown in Table 1, the baseline characteristics of the participants in both groups were comparable, with an average age of approximately 37 years, average weight of 65 kg, and average height of 165 cm (Table 1). The subjects in both groups were non-obese (body mass index < 25 kg/m^2) and there was no central obesity (waist-hip ratio <1.0).

Table 1:Baseline characteristics of participants

Variable	Group 1 (Mean ± SD)N = 15	Group 2 (Mean ± SD) N=15
Age (years)	37.2 ± 12.18	36.87± 9.71
Weight (kg)	65.33 ± 14.54	64.73 ± 11.76
Height (cm)	164.4 ± 6.75	166.47 ± 8.12
Body mass index (kg/m^2)	24.18 ± 4.79	24.19 ± 3.31
Waist-hip ratio	0.985 ± 0.238	0.891 ± 0.739

Table 2 shows the changes in pulmonary function after 12 weeks of exercise training in moderate-intensity exercise performers. There was a significant increase in VC, IRV, IC, and BHT after exercise training (P =0.001, 0.014, 0.012, and 0.001, respectively).

Table 2:Comparison of pulmonary functions and breath holding time (BHT) before and after exercise training in group I (moderate-intensity exercisers)

Parameters	Before exercise(Mean ± SD)(N=15)	After exercise(Mean ± SD)(N=15)	P value(paired t-test)
TV	0.36±0.05	0.37±0.05	0.089
VC	2.93±0.70	3.28±0.74[**]	<0.001
IRV	1.58±0.43	1.84±0.56[*]	0.014
ERV	0.98±0.43	1.07±0.51	0.114
EC	1.34±0.42	1.44±0.50	0.10
IC	1.95±0.44	2.20±0.58[*]	0.012
BHT	27.20±2.88	28.67±3.09[**]	<0.001

TV: tidal volume; VC, vital capacity; IRV, inspiratory reserve volume; ERV, expiratory reserve volume; EC, expiratory capacity; IC, inspiratory capacity
*= significant, **= highly significant

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Table 3 shows changes in the pulmonary functions after 12 weeks exercise training in high-intensity exercise performers. There was significant increase in all the pulmonary function parameters after high intensity exercise training (P <0.05).

Table 3: Comparison of pulmonary functions and breath holding time (BHT) before and after exercise training in group II (high-intensity exercise performers)

Parameters	Before exercise(Mean ± SD)(N=15)	After exercise(Mean ± SD)(N=15)	p- value(Paired t-test)
TV(litre)	0.37±0.04	0.39±0.04**	<0.001
VC(litre)	3.22±0.69	3.82±0.76**	<0.001
IRV(litre)	1.82±0.44	2.20±0.50**	<0.001
ERV(litre)	1.04±0.37	1.24±0.40*	0.002
EC(litre)	1.40±0.38	1.63±0.42*	0.001
IC(litre)	2.18±0.45	2.58±0.50**	<0.001
BHT(seconds)	30.93±9.69	35.40±10.95**	<0.001

TV: tidal volume; VC, vital capacity; IRV, inspiratory reserve volume; ERV, expiratory reserve volume; EC, expiratory capacity; IC, inspiratory capacity
*= significant
**= highly significant

As shown in Table 4, the change in TV, VC, and BHT were significantly higher in high-intensity exercise performers than in moderate-intensity exercise performers (P = 0.001, 0.01, and 0.001, respectively). The difference in changes in other parameters was not significant.

Table 4: Comparison of change in pulmonary function between group I (moderate-intensity exercisers) and group II (high-intensity exercisers) post completion of 12 weeks exercise training

Parameters	Change in parameter after exercise Group I(Mean ± SD)(N=15)	Change in parameter after exercise Group II(Mean ± SD)(N=15)	p-value (Unpaired t-test)
TV(litre)	0.01±0.01	0.02±0.01**	<0.001
IRV(litre)	0.25±0.35	0.38±0.08	0.175
IC(litre)	0.72±0.60	0.40±0.08	0.05
VC(litre)	0.35±0.29	0.60±0.21*	0.010
ERV(litre)	0.09±0.21	0.20±0.21	0.173
EC(litre)	0.10±0.22	0.22±0.21	0.113
BHT(seconds)	1.47±0.9	4.47±1.68**	<0.001

TV: tidal volume; IRV, inspiratory reserve volume; IC, inspiratory capacity; VC, vital capacity; ERV, expiratory reserve volume; EC, expiratory capacity
*= significant
**= highly significant

Table 5 show the correlation of BHT with VC, IC, and EC in group I. There was a positive correlation of all three parameters with BHT (Pearson's R correlation was positive), but it was not significant. The correlation of BHT with IC was strongest, whereas that with VC was weakest.

Table 5:Correlation between pulmonary functions and breath holding time (BHT) in moderate-intensity exercisers post-12 weeks training

Parameter(Correlation in between)	Karl-Pearson's correlation coefficient	P value
VC and BHT	0.294	0.287
IC and BHT	0.440	0.101
EC and BHT	0.349	0.203

Note:VC, vital capacity; IC, inspiratory capacity; EC, expiratory capacity

As shown in Table 6, the correlation of BHT with VC and EC was positive in high-intensity exercise performers, while that with IC was negative. None of the correlations in high-intensity exercise performers were significant.

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Table 6: Correlation between pulmonary functions and breath holding time (BHT) in high-intensity exercisers post-12 weeks training

Parameter(Correlation in between)	Karl-Pearson's correlation coefficient	P value
VC and BHT	0.045	0.873
IC and BHT	-0.030	0.917
EC and BHT	0.098	0.730

Note: VC, vital capacity; IC, inspiratory capacity; EC, expiratory capacity

Table 7: Simple linear regression analysis of breath holding time (BHT) with vital capacity, inspiratory capacity, and expiratory capacity on pre-and post-exercise training

Group	Variable		Vital capacity(VC) R^2	Inspiratory capacity(IC) R^2	Expiratory capacity (EC) R^2
Group I High-intensity exercisers	BHT	Pre-exercise training	0.066	0.270	0.002*
		Post-exercise training	0.012	0.096	0.018
Group II Moderate-intensity exercisers	BHT	Pre-exercise training	0.002*	0.007	0.015
		Post-exercise training	0.002*	0.001*	0.01*

* = significant

Discussion

We found that high-intensity exercise for twenty minutes, three times per week, enhanced VC, IC, EC, IRV, ERV, and BHT. This improvement was also found for moderate-intensity exercise of 40 minutes' duration five days per week for all parameters, except that the increase in TV, ERV, and EC in the moderate-intensity exercise group was not statistically significant (Tables 1 and 2). However, the comparison between high-intensity and moderate-intensity exercisers showed that the enhancement in lung function was significantly higher in high-intensity exercisers for TV, IC, VC, and BHT (Table 3). It is clear that the lung capacity of inhalation or exhalation of air is dependent on respiratory muscle strength, apart from airway patency. BHT is also dependent on airway patency and respiratory muscle efficiency. Normal BHT is 45-55 seconds. We observed a positive correlation between BHT and VC, IC, and EC (Tables 4 and 5), though this correlation association was not found to be strong as it was only statistically significant in high-intensity exercise performers, not in the moderate-intensity exercise group. This result indicates that cardiorespiratory exercise training enhances VC, IC, and EC, and thus influences the sensitivity of the chemoreflex and respiratory muscle strength. This enhancement of lung expansion and lung recoil by exercise training and respiratory muscle strength and chemoreflex sensitivity reflects the effect of cardiorespiratory exercises on lung endurance, lung capacity, and BHT. Our findings regarding high-intensity exercise training were consistent with those of Dunham et al. and Nourry et al., who compared the effect of 12 weeks of high - and moderate-intensity exercise on pulmonary functions and found significant improvements in VO_2max (~8-10%) and maximum inspiratory pressure ($P<0.05$) post-exercise training, with values significantly higher for the high-intensity exercise group than for the moderate-intensity exercise group. The improvement in pulmonary function was mainly attributed to the strengthening of respiratory muscles after exercise. The increase in respiratory muscle strength and endurance is greater after high-intensity exercise training [11,12,13]. Exercise also helps to reduce resistance to respiration. Our finding about BHT was in concurrence with that of Bagavad Geetha et al., who reported that breath holding was higher in athletes after deep inspiration, which they attributed to the larger initial lung volumes. Exercise training was also found to facilitate the strength of the respiratory muscles, thereby leading to an increase in lung volume. Physical training improves respiratory efficiency by increasing the strength of the diaphragm and intercostal muscles as well as VC, thus prolonging the BHT [5,7,14]. IC is an indicator of ventilatory response in exercise and shows a positive correlation with peak VO_2 and carbon dioxide retention during exercise [15,16].Moreover, decreased IC reflects critical dynamic mechanical constraints and thus limits further increase in ventilation in diseased conditions. The IC in the right sense exhibits the prevailing

mechanical efficiency of respiratory muscle strength[7,17]. We found an increase in IC and EC after both moderate - and high-intensity exercise, although the results were much higher with high-intensity exercise. But the impact of exercise training on IC has been both modest and inconsistent across studies, and some have suggested that the enhancement of IC during exercise is not necessary to achieve improvements in the intensity and affective domains, especially in patients with chronic obstructive pulmonary disease post exercise training [18]. In our study, we observed increased BHT along with an increase in IC, EC, and VC. Lung volumes are known to alter BHT. Whitelaw et al studied the mechanism by which a larger lung volume decreases the discomfort of breath holding and increases BHT. They analyzed the pressure waves of diaphragm contractions after breaths were held at various lung volumes. They found that expiratory muscle activity was more prominent in fewer individuals and the activity increased through each breath hold. Thus, as observed in our study, the principle of force-length and geometric properties might be the reason for the increased EC with cardiorespiratory exercise training [19]. Thus, both high- and moderate-intensity exercise training will affect the VC, IC, EC, and BHT. The better impact of high-intensity exercise compared with moderate-intensity exercise accords with the findings of Dunham et al. and Nourry et al. This more beneficial effect of high-intensity exercise can be attributed to increased respiratory muscle strength and to the higher level of partial pressure of carbon dioxide (PCO_2) built up during higher-intensity, shorter-duration exercises. The increased PCO_2 via stimulation of chemoreceptors should enhance ventilatory response and ventilatory efficiency. We anticipated a strong correlation between BHT and VC, IC, and EC. Although we noticed a weaker positive correlation by Pearson's correlation coefficient, our analysis on simple linear regression (Table 7) revealed a statistically significant positive correlation between BHT and VC, IC, and EC in high-intensity exercisers and between BHT and EC in moderate-intensity exercisers. This is suggestive of the strength of association between these variables, which could be employed in predictive assumptions for correlating lung volumes with BHT. The non-significant correlation between BHT and VC and IC in moderate-intensity exercisers by simple linear regression analysis limits its predictive applicability in moderate-intensity exercisers; however, this assumption cannot be ruled out without conducting a similar study in a larger sample size population. The limitation of our study was the small sample size employed for exercise training. The reason for this was that our mandate for participants was that they must meticulously adhere to regular exercise training sessions. This smaller sample size might be the reason for the weaker linear association found using Pearson's correlation coefficient. We recommend a larger sample size study in adolescent and adult age groups to explore the beneficial effects of high- and moderate-intensity exercise training on lung capacity, respiratory muscle strength, and cardiorespiratory fitness.

Conclusion

Improvement in VC, IC, EC, and BHT was observed after exercise training sessions in both the moderate-intensity and high-intensity exercise groups. Moreover, practicing high-intensity exercise for twenty minutes, three days a week was found to enhance the VC, IC, EC, and BHT more than moderate intensity exercise of 40 minutes' duration, five days a week, after 12 weeks of training. The positive correlation between BHT and VC, IC, and EC indicates that exercise training is beneficial for cardiopulmonary health and for enhancing respiratory muscle strength. Physical activity can help to prevent diseases and increase quality of life and longevity. High-intensity exercise benefits were observed after three days of training sessions per week, a protocol which can easily be incorporated into daily life [20]. We recommend that a suitable health policy for the promotion of physical activity needs to be implemented globally, considering the potential to decrease the rising trend of non-communicable diseases such as hypertension, obesity, and diabetes worldwide.

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