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The effect of high-intensity interval training on pulmonary function tests in older adults with heart and pulmonary diseases: A randomized trial

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A B S T R A C T

In the coming years, the aging population is expected to increase significantly. As people age, their respiratory system undergoes structural and physiological changes, making it difficult to define "normal" limits and distinguish between disease and normal aging. This study aimed to investigate the impact of these changes on individuals over 60 years old, both healthy and those with heart or pulmonary diseases, and to examine the effects of high-intensity interval training (HIIT) on them. We used a spirometer to assess respiratory muscle activity daily, measuring Forced Vital Capacity (FVC), Forced Expiratory Volume in one second (FEV_1), the FEV_1/FVC ratio, and Maximal Voluntary Ventilation (MVV) during three weeks of HIIT in 200 participants over 60 years old. The results showed significant improvements in FEV_1, MVV, and the FEV_1/FVC ratio after HIIT, suggesting that HIIT positively impacts pulmonary function. Additionally, there was a positive association between MVV and FEV_1, and an improvement in FVC was observed. Our findings indicate that HIIT enhances pulmonary function tests and strengthens respiratory muscles in both healthy individuals and patients over 60 years old.

1. Introduction

The aging population is expected to increase significantly in the coming years, with a particular focus on those aged 60 and above. This demographic shift highlights the importance of understanding the effects of aging on various organ systems, including the respiratory system (Aakerøy et al., 2021; Hilde et al., 2013). As individuals age, the respiratory system undergoes structural and physiological changes, leading to a wide variation in physiological measures among older adults. This makes it challenging to establish "normal" limits to differentiate between disease and normal aging (Park and Han, 2017; Shadmehri et al., 2021).

According to the Framingham Heart Study (Andersson et al., 2019), which included 30,000 people over the age of 50, 40% of individuals at age 50 had lost 40% of their total lung capacity (TLC). By age 80, most people had lost 60% of their lung capacity. The main respiratory measures are forced vital capacity (FVC), forced expiratory volume in one second (FEV_1), and maximum volume ventilation (MVV). These measures, which are used to assess lung function and diagnose respiratory conditions, decline with age. This decline is linked to a higher risk of chronic obstructive pulmonary disease (COPD) (Campbell Jenkins et al., 2014; Radovanović et al., 2009).

However, high-intensity interval training (HIIT) has been shown to have positive effects on pulmonary function in older healthy and non-healthy individuals. Prolonged aerobic training is thought to improve aerobic capacity and have a positive effect on pulmonary function. A study showed that eight weeks of HIIT could improve pulmonary function in non-athlete women. The mechanism of such training is that aerobic training improves the strength and endurance of the respiratory muscles, and frequent stretching of the lungs due to airway smooth muscle associated with aerobic training also reduces airway resistance (Burge et al., 2020; Sharma and Goodwin, 2006). Despite the positive effects of HIIT on pulmonary function, there is a lack of data on the

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benefits of physical exercise, including HIIT, in older individuals, both healthy and non-healthy. Specifically, there is a dearth of prior research on the impact of HIIT on pulmonary function tests. It remains uncertain whether HIIT exerts beneficial or detrimental effects on pulmonary function tests in this population (Camilli et al., 1987; Enright et al., 1993).

Therefore, the present study aims to investigate the effects of a 3-week HIIT exercise program on pulmonary function in older individuals aged 60 and above, both healthy and non-healthy, and to compare the impact of HIIT and aerobic training on the respiratory volumes in older people.

This research can help explain the clinical presentation of older individuals, atypical diagnostic findings, and the potential for increased susceptibility to respiratory diseases. Furthermore, these changes may account for the varying response of older adults to existing pulmonary disease treatments.

2. Methods

A total of 200 male individuals were recruited for this study. The ages of the subjects ranged from 61 to 88 years. After a thorough explanation of the experiment, each participant provided informed consent. To ensure that the subjects were a good fit for our study and did not have any serious conditions, we asked them to complete questionnaires regarding their medical histories. The inclusion criteria were as follows:

- > 60 years old.
- Meeting health criteria according to study protocol
- Collaborative
- Nonsmokers

Pre- and post-test assessments were used to measure how the parameters changed. These assessments, known as comparative cross-sectional data, are commonly used to evaluate intervention effectiveness. In this study, 200 males were chosen randomly using a simple random sampling (SRS) technique. The participants were older individuals, either healthy or with heart or pulmonary disease.

For three weeks, daily pre- and post-exercise measurements of respiratory indices were taken, and their averages were analyzed. Participants were instructed to maintain their usual exercise routines and not take any dietary supplements.

Participants performed HIIT, which involved various high-intensity exercises, such as treadmill running or rebounding for 90 seconds, followed by a 60-second recovery period, repeated for six cycles. The workout duration increased by 5 minutes each week, reaching 25 minutes in the third week. The weekly average values were used for analysis. Workouts were conducted daily for three weeks (Dockery et al., 1985).

FVC, FEV_1, FEV_1/FVC, and MVV were measured using a spirometer from SCHILLER Switzerland called the SPIROVIT SP-1G2. The participants were instructed to maintain an upright posture throughout the examination, and a nasal clip was applied to their nostrils to prevent any air from escaping. A mouthpiece was inserted into the participant's mouth, and they were instructed to keep their lips sealed around it (Rawashdeh and Alnawaiseh, 2018a; 2018b).

Procedure for FVC: The participants were instructed to take a deep breath and hold it for fewer than 1 second at TLC. They were later asked to breathe out as quickly and totally as possible, forcing out all the air from their lungs. This maneuver is commonly used in spirometry tests to measure FVC and FEV_1 and FEV_1/FVC (Rawashdeh and Alnawaiseh, 2018a; 2018b).

MVV procedure: The individuals were seated and instructed to wear a nose clasp. They were directed to exhale quickly and totally intended for twelve seconds following taking at least three resting tidal breathing through a tight closure around the mouthpiece (Rawashdeh and Alnawaiseh, 2018a; 2018b).

The data is presented as the average and standard deviation. Statistical analyses were accomplished by operating SPSS software edition 16, involving a paired t-test to compare prior and following-test results. The changes in pulmonary parameters between high-intensity activities for three weeks were compared using repeated-measures analysis. The Friedman test was employed on the way to contrast the average FEV_1/FVC ratio earlier and after training over a three-week period, and the Spearman correlation coefficient was utilized to evaluate the correlations between MVV, FVC, and FEV_1.

3. Results

Table 1 shows the average anthropometric characteristics of the 200 individuals. The average age was 75.00 ± 12.00 years, the average height was 173.80 ± 6.61 cm, and the average weight was 80.00 ± 12.20 kg.

Table 1: Mean and standard deviation of anthropometric characteristics of the study participant

Characteristic	Mean	Standard deviation
Age (years)	65.00	12.00
Height (cm)	173.80	6.61
Weight (kg)	80.00	12.20

Table 2 shows the standard spirometry data and predicted results for the 200 individuals. The average predicted values were: mean FVC 4.69 ± 0.61 L, mean FEV_1 3.16 ± 0.66 L, and average maximum voluntary ventilation (MVV) 150.14 ± 33.44 L.

Table 3 shows the standard spirometry values for FVC, FEV_1, and MVV before and after training at different intensities. The pre-training mean FVC was 3.88 ± 0.71 L, and the mean FEV_1 was 2.00 ± 0.77 L. After training for 15, 20, and 25 minutes, the post-training mean FVC increased to 3.99 ± 0.56 L, 4.00 ±

0.70 L, and 4.66 ± 0.40 L, respectively. The post-training mean FEV_1 after 15, 20, and 25 minutes was 2.73 ± 0.62 L, 3.00 ± 0.49 L, and 3.10 ± 0.53 L, respectively. The pre-training mean MVV was 122.47 ± 32.97 L, while the post-training mean MVV after 15, 20, and 25 minutes was 139.26 ± 30.21 L, 140.54 ± 53.18 L, and 144.95 ± 31.34 L, respectively. These findings show a clear trend in respiratory parameters, indicating potential improvements in lung function in response to the training at different intensities.

Table 2: Predicted standard spirometry values

Parameter	Mean	Standard deviation
PRED FVC (L)	4.69	.61
PRED FEV_1 (L)	3.16	.66
PRED MVV (L)	150.14	33.44

Table 3: Standard spirometry data (Mean ± standard deviation) of FVC, FEV_1, and MVV before and after training at varying intensities (L)

Parameter	Mean	Standard deviation
Pre exercise FVC	3.88	.71
15 min post exercise FVC	3.99	.56
20 min post exercise FVC	4.00	.70
25 min post exercise FVC	4.66	.40
Pre exercise FEV1	2.00	.77
15 min post exercise FEV_1	2.73	.62
20 min post exercise FEV_1	3.00	.49
25 min post exercise FEV_1	3.10	.53
Pre exercise MVV	122.47	32.97
15 min post exercise MVV	139.26	30.21
20 min post exercise MVV	140.54	53.18
25 min post exercise MVV	144.95	31.34

Table 4 presents the results of the Friedman test applied to contrast the predicted FEV_1/FVC% ratios prior to and following training at various intensities. The findings revealed that the prior-training FEV_1/FVC ratio was lower than the following-training means, indicating an improvement in lung function. This trend is evident in the data and suggests that exercise at varying intensities may have a positive impact on respiratory function. According to the Friedman test, the mean prior-training FEV_1/FVC ratio was significantly lower than the mean following-training ratio, with P=0.000.

Table 4: Friedman test of predicted FEV_1/FVC ratio pre and post-training at varying intensities

Ranks	
	Mean rank
Ratio: FEV_1/FVC before	70.00
Ratio: FEV-15/FVC-15	75.40
Ratio: FEV-20/FVC-20	85.70
Ratio: FEV-25/FVC-25	90.00
P-value	.0000**

**: Significant at p<.01

Table 5 displays the results of the paired t-test used to compare the prior and following-exercise FEV_1, MVV, and FVC means. The results showed that the prior-training means for all three parameters were significantly less than the following-training means of $p < 0.001$. These findings suggest that exercise at varying intensities may have a positive impact on respiratory function, as evidenced by the improvements in these key respiratory parameters.

Table 5: Presents the results of the paired t-test used to compare the prior and after exercise averages of FEV_1, MVV, and FVC

Variable	Prior-training	Following-training	P-value
FVC (L)	3.88±0.71	4.22±0.30	<.001**
FEV (L)	2.00±0.77	2.94±0.34	<.001**
MVV	122.47±32.97	141.58±21.53	<.001**

**: Significant at p<.01

Table 6 shows that the prior-training average for FEV_1, MVV, and FVC were significantly higher than the prior-training average of p<0.001. This indicates that training at varying intensities may have a positive impact on respiratory function, as evidenced by the improvements in these key respiratory parameters.

Table 6: The analysis of variance (ANOVA) was conducted to compare lung function prior and following exercise at varying intensities

FVC (L)	3.88	3.99	4.00	4.66	<.001**
FEV (L)	2.00	2.73	3.00	3.10	<.001**
MVV	122.47	139.26	140.54	144.95	<.001**

**: Significant at p<.01

Table 7 displays the results of the correlation analysis between post-exercise improvements in FEV_1 and FVC with MVV. The findings revealed a significant and positive correlation between the post-exercise enhancements in FEV_1 and FVC with MVV improvement. This suggests that exercise at different intensities may have a positive impact on respiratory function, as evidenced by the improvements in these key respiratory parameters.

The results of Table 8 indicate that individuals with reported heart and pulmonary diseases had lower values of lung function indices compared to healthy individuals. However, the study also found significant improvement of FEV_1/FVC% P value< 0.001 in both normal and reported disease individuals. Moreover, the predicted FEV_1/FVC% did not indicate any COPD after exercise. This suggests that HIIT had a beneficial effect not only on normal elderly individuals but also on those with heart and pulmonary diseases.

4. Discussion

All the results of the present study provide strong evidence of significant improvement in the airway and respiratory muscles after HIIT, as supported by improvements in all spirometric parameters, including FEV_1, FVC, and MVV.

However, the most important finding of this study, which was not observed in previous studies, was the strong correlation between FVC and MVV. This may be because the intensive exercise in this study not only improved the airways but also increased the compliance of the alveoli and respiratory muscles.

Table 7: Associations of MVV changes with FVC and FEV_1 improvements before and after exercise

		Before	
		FVC	FEV
MVV	Rho	.140	.038
	P-value	.239	.751
		After	
		FVC	FEV
MVV	Rho	-.104**	-.307**
	P-value	.008**	.009**

**: Significant at p<.01

Table 9 shows that lung function tests decline significantly with age p<0.001, but the ratio of $FEV_1/FVC\%$ significantly increased P<0.001 after exercise for all age groups. This suggests that exercise can improve lung function indices in elderly people of any age group.

As previously demonstrated in our studies, improvements in MVV following exercise may be linked to enhanced respiratory muscle growth as a result of physical training. High-intensity aerobic exercise has been found to have several positive effects on pulmonary function. Research has shown that it can lead to an increase in VO2 max and the activation of inactive alveoli (Rawashdeh and Alnawaiseh, 2018a; 2018b). Additionally, the repeated stimulation of inspiration and expiration during high-intensity aerobic exercise has been linked to improvements in alveolar compliance, resulting in higher FVC. Furthermore, the effect of this type of exercise on the FEV_1/FVC ratio has been shown to enhance respiratory and trunk muscles, as well as rib cage movement, which is advantageous for overall pulmonary function (Lee et al., 2016; Medbø and Melbye, 2007).

Table 8: Spirometric results in 200 men by reported diseases, and for the healthy

Total	N	After exercise FEV_1% predicted mean	After exercise FVC% predicted mean	Before exercise FEV_1/FVC% mean	After exercise FEV_1/FVC % mean
Myocardial infarction	20	81	88	67	75
Cerebral stroke	10	80	86	70	80
Angina	10	81	88	69	80
Asthma	30	80	82	65	75
Chronic bronchitis	10	81	82	68	80
Normal	120	89	88	85	90

Table 9: Spirometric results in 200 men by age group

Total	N	After FEV_1% predicted mean	After FVC% predicted mean	Before exercise FEV_1/FVC% mean	After exercise FEV_1/FVC% mean
61–65	80	84.90	88.20	90.40	95.03
65–69	40	84.70	85.80	80.50	85.34
70–74	30	84.00	83.80	67.40	83.00
75–79	20	83.10	81.30	66.40	80.66
80+	30	75.00	80.00	65.00	75.00

The significant increase in FVC may also be related to an increase in vascular wall strength and the number of blood vessels in the muscle, which pump large volumes of blood and enhance muscular activity (Song and Kim, 2016; Yeun et al., 2013).

As a result, the improvements in MVV and FVC in this study revealed that three weeks of daily intense exercise produced greater TLC. More regular and consistent exercise results in improved benefits. This implies that even if a person is older, intense exercise may help them rebuild their TLC.

Our result shows that the frequency of FEV_1/FVC < 70% increased with age, which can be attributed to the normal aging process and the increasing prevalence of COPD. Age-related reductions in lung function can be explained by structural changes in the airways, including senile emphysema, which is the loss of supportive tissue in the peripheral airways. Additionally, the loss of muscular tissue and reduced physical endurance associated with normal aging can contribute to a decline in lung function (Enright et al., 1994; Janssens et al., 1999).

The heart and pulmonary diseases were associated with reduced spirometric values, including the FEV_1/FVC ratio. However, HIIT has been shown to improve lung function indices in older people, including the FEV_1/FVC ratio, and can help relieve COPD and other morbidities that influence lung function, as shown in our study.

Many people become "high chest breathers," meaning they use only the upper half of their lungs to breathe, and the main reason for this is not using the abdominal muscles to breathe. The body uses abdominal muscles during breathing, and failure to do so can lead to a significant reduction in the amount of oxygen that reaches the lungs, making individuals more susceptible to chronic fatigue syndrome (McClaran et al., 1995).

According to the Framingham study, by 50 years of age, a person loses 40% of their lung capacity, and by the age of 80 years, they lose 60%; the main reason for this loss of capacity is not using the abdominal muscles in breathing, leading to the use of only the upper half of the lungs only. Therefore, it is essential to perform intense exercise daily to strengthen the abdominal muscles and use them for breathing to obtain an adequate amount of oxygen (Mittman et al., 1965; Peterson et al., 1981).

The impact of HIIT compared to aerobic exercises is clear and significant in improving all spirometric values, with improvements before and after training reaching up to 90% or more, as shown in Table 3. This is a much higher improvement rate compared to aerobic exercises, which have shown improvements ranging from 25% to 75% in our previous research (Rawashdeh and Alnawaiseh, 2018a; 2018b). This confirms the importance of HIIT in enhancing respiratory endurance, improving respiratory mechanics, and reducing airway resistance. Individuals who participate in HIIT can enjoy better respiratory function and lung efficiency compared to those who engage in aerobic exercises.

This indicates that the short interval exercise and rest periods in HIIT have a greater effect on improving respiratory endurance than aerobic exercise. Therefore, we believe that understanding how these factors improve lung function helps improve HIIT protocols for different age groups, especially for healthy or non-healthy old people.

HIIT is a significant factor that a person should be aware of in terms of overall health and decreasing serious chronic diseases such as heart and pulmonary diseases, as demonstrated in our study.

5. Conclusion

The findings of this study provide robust evidence supporting the beneficial impact of HIIT on pulmonary function in older adults, including those with heart and pulmonary diseases. Our data demonstrate significant improvements in key spirometric parameters—FVC, FEV_1, Maximal Voluntary Ventilation (MVV), and the FEV_1/FVC ratio—following a structured three-week HIIT program. These improvements indicate enhanced respiratory muscle strength, increased lung capacity, and overall better pulmonary function.

The study reveals a strong positive correlation between improvements in FVC and MVV, suggesting that intensive exercise enhances the compliance of alveoli and respiratory muscles. This aligns with previous research indicating that high-intensity aerobic exercise can activate inactive alveoli, increase VO2 max, and improve overall lung function by strengthening the respiratory and trunk muscles. The significant increase in FVC can also be attributed to enhanced vascular wall strength and an increased number of blood vessels in the muscles, which together improve muscular activity and overall pulmonary efficiency.

The improvements observed in this study are particularly notable because they suggest that regular and intense exercise can help older adults rebuild TLC, regardless of age. This is critical given the natural decline in lung function with aging, as evidenced by the increase in the frequency of $FEV_1/FVC<70\%$ among older individuals. The findings underscore the potential of HIIT to mitigate age-related reductions in lung function and combat conditions like COPD.

Moreover, the study highlights the superiority of HIIT over traditional aerobic exercises in enhancing respiratory endurance and reducing airway resistance. The data show that HIIT yields higher improvement rates in spirometric values compared to aerobic exercises, indicating its greater efficacy in improving respiratory mechanics and lung function.

Importantly, the study also demonstrates that HIIT benefits not only healthy older adults but also those with heart and pulmonary diseases. This suggests that HIIT can be an effective intervention for improving pulmonary function and reducing the impact of chronic diseases in older populations.

In conclusion, the results of this study highlight the significant positive effects of HIIT on pulmonary function in older adults. The substantial improvements in FVC, FEV_1, MVV, and FEV_1/FVC ratios suggest that HIIT is a vital exercise regimen for enhancing respiratory health and overall physical well-being in this demographic. These findings advocate for the incorporation of HIIT into regular fitness routines for older adults to promote better lung function and mitigate the effects of aging and chronic diseases on the respiratory system. Further research is recommended to explore the long-term benefits of HIIT and its application across diverse populations with varying health conditions.

Compliance with ethical standards

Ethical considerations

This study was approved by the Ethics Committee of Mutah School of Medicine, Al-Karak, Jordan (approval number: 1112023). Informed consent was obtained from all participants, and confidentiality was maintained.

Conflict of interest

The author(s) declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

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