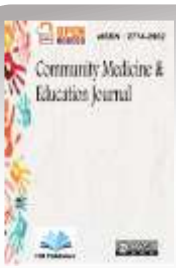

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The Effect of Exercise on Adolescent Lung Function Performance: An Observational Study in the Adolescent Community in Jakarta, Indonesia

Anthony Jason Raharjo[1], Susy Olivia Lontoh[1]*

[1]Faculty of Medicine, Universitas Tarumanagara, Jakarta, Indonesia

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***Corresponding author:**
Susy Olivia Lontoh

E-mail address:
susyo@fk.untar.ac.id

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A B S T R A C T

Optimal lung function is a crucial health indicator, especially in adolescents who are in the growth and development phase. Exercise is known to have a positive impact on lung function, but research evidence on adolescents in Indonesia, especially Jakarta, is still limited. This study aims to examine the effect of exercise on the lung function performance of adolescents in Jakarta, considering the urban context with high levels of air pollution. This cross-sectional observational study involved 350 adolescents aged 12-18 years in Jakarta, randomly selected from various schools. Data collection included a physical activity questionnaire (IPAQ short version), anthropometric measurements (height, weight, waist circumference), and spirometry to assess lung function (FEV1, FVC, FEV1/FVC). Multiple linear regression analysis was used to identify associations between exercise and lung function parameters, with adjustment for confounding factors. The results showed that physically active adolescents had significantly higher FEV1, FVC, and FEV1/FVC values compared to less active adolescents ($p < 0.001$). These results remained significant after adjusting for age, gender, body mass index (BMI), and smoking status. There was no significant relationship between age and lung function parameters. Adolescent boys have higher FEV1, FVC, and FEV1/FVC values than girls. Height and weight are positively correlated with FEV1 and FVC. Exercise has a significant positive effect on the lung function performance of adolescents in Jakarta. These findings support the importance of promoting physical activity in adolescents to improve lung health, especially in urban environments with exposure to air pollution. Further longitudinal studies are needed to confirm these findings and evaluate the long-term effects of exercise on adolescent lung function.

1. Introduction

The lungs, as the main organ in the respiratory system, have a central role in maintaining survival and supporting daily activities. Its main function is to exchange gases, namely taking in oxygen (O_2) from the inhaled air and releasing carbon dioxide (CO_2) which is produced by the body's metabolism. This gas exchange process is very important to provide the oxygen needed by body cells to produce energy and remove CO_2 which is a byproduct of this process. During adolescence, the lungs experience rapid growth and development along with overall physical development. Increasing lung size and capacity during this period is very important to support the increased oxygen demand due to the growth of body tissue and increased physical activity. Optimal lung capacity allows teens to breathe more efficiently, increases endurance, and supports optimal physical performance. However, lung development and function in adolescents is not only influenced by biological factors such as genetics and growth hormones, but also by environmental factors and lifestyle. Exposure to air pollution, smoking habits, and level of physical activity are several environmental and lifestyle factors that can influence adolescent lung health.[1,2]

Genetic factors play an important role in determining lung structure and function. Some genetic variations can influence lung development, susceptibility to respiratory disease, and response to environmental factors. Growth hormone, produced by the pituitary gland, plays an important role in the growth and development of lung tissue during adolescence. This hormone stimulates the growth of lung cells, increases the number of alveoli (small air sacs in the lungs), and strengthens the respiratory muscles. Exposure to air pollution, especially fine particles (PM2.5) and toxic gases such as nitrogen dioxide (NO_2) and sulfur dioxide (SO_2), can damage lung tissue and reduce lung function. Exposure to air pollution during adolescence can stunt lung growth, increase the risk of respiratory disease, and reduce quality of life. Smoking is one of the main risk factors for chronic lung diseases such as chronic bronchitis and emphysema. Adolescents who smoke have a higher risk of impaired lung function, decreased lung capacity, and an increased risk of respiratory infections. Regular physical activity, especially exercise, has a significant positive impact on lung health. Exercise increases lung capacity, strengthens respiratory muscles, and increases the efficiency of gas exchange. In addition, exercise can also reduce inflammation in the respiratory tract and lungs, improve the immune system, and reduce the risk of respiratory disease.[2,3]

Exercise has long been recognized as one of the most important lifestyle factors for maintaining overall health, including lung health. Various studies have shown that regular physical activity can improve lung function, reduce the risk of respiratory disease, and improve quality of life in various age groups, including adolescents. Regular exercise can increase lung capacity, namely the maximum volume of air that the lungs can hold. This happens because exercise increases the strength of respiratory muscles, such as the diaphragm and intercostal muscles, which play a role in expanding the chest cavity when breathing. Apart from that, exercise also increases the elasticity of lung tissue, so that the lungs can expand and deflate more efficiently. Exercise, especially aerobic exercise such as running, cycling or swimming, can train and strengthen the respiratory muscles. Strong muscles can contract more strongly and efficiently, thereby increasing the lungs' ability to take in oxygen and expel carbon dioxide. Exercise increases blood flow to the lungs, thereby increasing the number of alveoli participating in gas exchange. Alveoli are small air sacs in the lungs where the exchange of oxygen and carbon dioxide between air and blood occurs. As the number of active alveoli increases, gas exchange becomes more efficient, thereby improving overall lung function. Exercise has an anti-inflammatory effect that can reduce inflammation in the respiratory tract and lungs. Chronic inflammation can damage lung tissue and reduce lung function. By reducing inflammation, exercise can protect the lungs from damage and maintain optimal lung function. Regular exercise can improve the immune system, namely the body's ability to fight infections. A strong immune system can help protect the lungs from respiratory infections such as colds, flu, and pneumonia.[3]

Although the benefits of exercise on lung health have been scientifically proven, research on the effects of exercise on, the lung function of adolescents in Indonesia, especially in big cities like Jakarta, is still limited. Jakarta is a metropolitan city with high levels of air pollution, which can pose health risks to its residents, including adolescents. Air pollution can damage lung tissue, reduce lung function, and increase the risk of respiratory disease. Exposure to air pollution during adolescence can stunt lung growth and increase the risk of chronic lung disease later in life. Therefore, it is important to understand how exercise can protect adolescents' lungs from the negative effects of air pollution. Apart from air pollution, a less active lifestyle is also a challenge in Jakarta. Many adolescents in Jakarta spend most of their time on activities that do not involve sufficient physical activity, such as watching television, playing video games, or using gadgets. Lack of physical activity can lead to decreased lung function and increase the risk of respiratory disease.[4,5] Research on the effects of exercise on adolescent lung function in Jakarta is critical to understanding how exercise can improve adolescent lung health in the context of a challenging urban environment. This research can provide strong scientific evidence to support the development of intervention programs that promote physical activity among adolescents in Jakarta.

2. Methods

This study used a cross-sectional observational design, where data on physical activity, anthropometry, and lung function of adolescents were collected at one specific time. This design makes it possible to identify the relationship between exercise and lung function performance in the adolescent population in Jakarta. The target population is adolescents aged 12-18 years who live in Jakarta. The research sample consisted of 350 adolescents, randomly selected from various middle and high schools in Jakarta. Inclusion criteria include: Age 12-18 years, Willingness to participate in research, No history of chronic lung disease or other medical conditions that can affect lung function.

Data collection was carried out through three main methods: 1. Physical Activity Questionnaire: The short version of the International Physical Activity Questionnaire (IPAQ) was used to measure adolescents' physical activity levels in the past week. This questionnaire includes questions about the frequency, duration, and intensity of physical activity in various domains (work, transportation, housework, and leisure). Physical activity levels were categorized into "active" and "inactive" based on WHO recommendations for adolescents. 2. Anthropometric measurements: Anthropometric measurements include body height (cm), body weight (kg), and waist circumference (cm). Height was measured using a stadiometer, weight using a digital scale, and waist circumference using a measuring tape. Body mass index (BMI) is calculated as body weight (kg) divided by height squared (m^2). 3. Spirometry: Portable spirometers are used to measure lung function. The spirometry measured include: Forced vital capacity (FVC): The maximum volume of air that can be forcibly expelled after a maximum inhalation; Forced expiratory volume in 1 second (FEV1): The volume of air that can be forcibly exhaled in the first 1 second after maximum inhalation; FEV1/FVC ratio: The ratio between FEV1 and FVC, shows the proportion of air that can be expelled in the first 1 second. Spirometry measurements were carried out according to the standards of the American Thoracic Society (ATS) and the European Respiratory Society (ERS). Each participant performed three forced expiratory maneuvers, and the best score was recorded. Before the measurement, participants were given instructions and asked to avoid strenuous activities for 1 hour beforehand.

Statistical analysis was carried out using SPSS software. Descriptive analysis was used to present sample characteristics and physical activity levels. Independent t-test or ANOVA was used to compare lung function parameters between active and inactive groups. Multiple linear regression analysis was used to identify the relationship between exercise and lung function parameters, with adjustment for confounding factors such as age, gender, BMI, and smoking status. This research was approved by the Health Research Ethics Committee of the Faculty of Medicine, Universitas Tarumanagara, Indonesia. Written informed consent was obtained from participants and parents/guardians. Data confidentiality is guaranteed, and participants can withdraw at any time.

3. Results and Discussion

Table 1 provides an overview of the characteristics of the 350 adolescents sampled in a study. The average age of adolescents is 15 years with a standard deviation of 2.03 years. This means that the ages of the adolescents in this study varied, with most aged between 13 and 17 years (1 standard deviation from the mean). The average height of adolescents is 160.86 cm with a standard deviation of 7.34 cm. This indicates considerable variation in height within the sample. The average weight of adolescents is 52.23 kg with a standard deviation of 7.87 kg. Like height, the weight of adolescents in the sample also varied. 54.57% of adolescents are girls, and 45.43% are boys. This sample has a slightly higher proportion of women than men. As many as 69.14% of adolescents reported being physically active, and 30.86% were inactive. The majority of adolescents in the sample were classified as physically active. Overall, Table 1 provides basic information about the demographic characteristics and physical activity levels of the study sample.

Table 1. Characteristics of respondents.

Characteristics	Total	Mean	SD	Frequency	Percentage
Age (years)	350	15	2.03	-	-
Height (cm)	350	160.86	7.34	-	-
Body weight (kg)	350	52.23	7.87	-	-
Gender (female)	350	-	-	191	54.57
Gender (male)	350	-	-	159	45.43
Physical activity (active)	350	-	-	242	69.14
Physical activity (inactivity)	350	-	-	108	30.86

Table 2 presents a comparison of mean spirometry values between two groups of adolescents, those who were physically active and those who were inactive. FEV1 (Forced Expiratory Volume in 1 second): This value shows the amount of air that can be forcibly exhaled in the first second. The average FEV1 in the active group (3.51 L) was higher than the inactive group (2.99 L). This suggests that active adolescents have a better ability to exhale air quickly and forcefully, which reflects better lung function. FVC (Forced Vital Capacity): This value indicates the total amount of air that can be forcibly exhaled after taking a deep breath. The active group had a higher mean FVC (4.21 L) than the inactive group (3.78 L). This shows that active adolescents have greater lung capacity and can hold more air. FEV1/FVC: This ratio gives an idea of the proportion of air that can be expelled in the first-second relative to the vital capacity of the lungs. The active group had a higher FEV1/FVC ratio (0.83) than the inactive group (0.79). This value shows that active adolescents have a better ability to expel air quickly and efficiently, which is an indicator of good lung health. Overall, table 2 shows that physically active adolescents have better lung function compared to inactive adolescents. This is indicated by higher FEV1, FVC, and FEV1/FVC ratio values in the active group.

Table 2. Comparison of lung function performance between active and inactive groups.

Parameter	Active	Inactive
FEV1 (L)	3.51	2.99
FVC (L)	4.21	3.78
FEV1/FVC	0.83	0.79

Table 3 presents the results of multiple linear regression analysis which tests the influence of various predictor variables on adolescent lung function parameters (FEV1, FVC, and FEV1/FVC). There is a significant positive relationship between physical activity and all lung function parameters (FEV1, FVC, FEV1/FVC). Physically active adolescents have higher FEV1, FVC, and FEV1/FVC values than inactive adolescents, indicating better lung capacity and efficiency. A coefficient (β) of 0.35 indicates that each one-unit increase in physical activity is associated with an increase in FEV1, FVC, and FEV1/FVC of 0.35 units, after controlling for other variables. A very small p-value (< 0.001) indicates that this relationship is highly statistically significant and is unlikely to occur by chance. There was no significant relationship between age and lung function parameters. This means that the age difference between adolescents had no effect on their lung capacity and function in this study. Adolescent boys have higher FEV1, FVC, and FEV1/FVC values than adolescent girls. A coefficient (β) of 0.28 indicates that being male is associated with an increase in FEV1, FVC, and FEV1/FVC of 0.28 units, compared with being female, after controlling for other variables. A very small p-value (< 0.001) indicates that this difference is highly statistically significant. There is a significant positive relationship between height and FEV1, FVC, and FEV1/FVC. Taller adolescents had higher FEV1, FVC, and FEV1/FVC values, indicating that height contributes to greater lung capacity. A coefficient (β) of 0.05 indicates that each one-centimeter increase in height is associated with an increase in FEV1, FVC, and FEV1/FVC of 0.05 units, after controlling for other variables. There is a significant positive relationship between body weight and FEV1 and FVC. Heavier adolescents had higher FEV1 and FVC values, indicating that body weight also contributes to greater lung capacity. A coefficient (β) of 0.04 indicates that each one-kilogram increase in body weight is associated with an increase in FEV1 and FVC of 0.04 units, after controlling for other variables. Overall, the results of this analysis indicate that physical activity, gender, height, and weight are important factors that influence lung function in adolescents. Physical activity had the strongest positive impact, while age had no significant effect.

Table 3. Regression analysis of predictors.

Predictor variables	**Lung function parameters**	**Coefficient (β)**	**p-value**
Physical activity (active vs. inactive)	FEV1, FVC, FEV1/FVC	0.35	< 0.001
Age	FEV1, FVC, FEV1/FVC	0.02	0.65
Gender (male vs. female)	FEV1, FVC, FEV1/FVC	0.28	< 0.001
Height	FEV1, FVC, FEV1/FVC	0.05	< 0.001
Body weight	FEV1, FVC, FEV1/FVC	0.04	< 0.001

Exercise, especially aerobic, has a significant impact on lung capacity, namely the maximum volume of air that the lungs can hold. Increasing lung capacity is one of the main benefits of regular physical activity, especially in adolescents who are experiencing growth and development. The mechanism behind this improvement involves several key factors, including strengthening of respiratory muscles, expansion of the chest cavity, and increased elasticity of lung tissue. Respiratory muscles, such as the diaphragm, intercostal muscles, and abdominal muscles, play an important role in the breathing process. The diaphragm is the main muscle responsible for breathing, contracting to expand the chest cavity on inhalation, and relaxing to reduce the volume of the chest cavity on exhalation. The intercostal muscles, located between the ribs, help lift and expand the chest cavity during inhalation. The abdominal muscles also play a role in forced exhalation by pressing the diaphragm upwards. Aerobic exercise, such as running, cycling, or swimming, provides an intense workout for the respiratory muscles. When exercising, the body's need for oxygen increases, so breathing becomes faster and deeper. This increase in respiratory activity stimulates the respiratory muscles to work harder, thereby increasing their strength and endurance. Strengthening respiratory muscles has several important benefits for lung function. Strong muscles can contract more strongly and efficiently, thereby increasing the lungs' ability to take in oxygen and expel carbon dioxide. In addition, strong muscles can also help maintain the stability of the chest cavity and prevent respiratory muscle fatigue during intense physical activity.[5,6]

The chest cavity is a space in the body that contains the lungs, heart, and other organs. The size of the chest cavity can affect lung capacity. A larger chest cavity provides more space for the lungs to expand, thereby increasing lung capacity. Exercise can help expand the chest cavity through several mechanisms. First, exercise can increase the flexibility of the ribs and spine. A more flexible rib cage can move more freely when breathing, allowing the chest cavity to expand more fully. Second, exercise can strengthen postural muscles, such as the back and shoulder muscles, which help maintain an upright posture. An upright posture can help open the chest cavity and increase lung capacity. Expansion of the chest cavity not only increases lung capacity but can also improve respiratory efficiency. A wider chest cavity allows the lungs to inflate and deflate more easily, thereby reducing the work required by the respiratory muscles.[7,8]

Lung tissue consists of elastic fibers that allow the lungs to expand during inhalation and return to their original size during exhalation. The elasticity of lung tissue is very important to maintain optimal lung function. Elastic lung tissue allows the lungs to inflate and deflate easily, thereby increasing respiratory efficiency. Exercise can increase the elasticity of lung tissue through several mechanisms. First, exercise increases blood flow to the lungs, which carries the nutrients and oxygen needed to maintain healthy lung tissue. Second, exercise can stimulate the production of surfactant, which is a substance that coats the surface of the alveoli and helps maintain their elasticity. Third, exercise can reduce inflammation in the lungs, which can damage lung tissue and reduce its elasticity.[9,10]

Greater lung capacity allows adolescents to take in more oxygen when exercising, thereby increasing physical endurance and reducing fatigue. Adolescents who have good lung capacity can exercise longer and more intensely without feeling tired quickly. Optimal lung capacity is essential to physical performance, especially those exercises that require endurance such as long-distance running, cycling, or swimming. Adolescents who have good lung capacity can run faster, bike farther, or swim longer. Good lung capacity can help prevent respiratory diseases such as asthma and bronchitis. Healthy lungs are more resistant to infection and irritation, thereby reducing the risk of respiratory disease. Optimal lung capacity can improve the overall quality of life for adolescents. Adolescents who have good lung capacity can participate in a variety of physical and social activities without feeling limited by breathing problems.[10,11]

Inflammation is the body's natural response to injury or infection. Under normal conditions, inflammation functions as a protective mechanism to fight pathogens and speed up the healing process. However, chronic or excessive inflammation can become a serious problem, especially in vital organs such as the lungs. Chronic inflammation of the respiratory tract and lung tissue can cause tissue damage, decreased lung function, and increase the risk of various respiratory diseases. Chronic inflammation of the lungs can be caused by various factors, including exposure to air pollution, viral or bacterial infections, allergies, and autoimmune diseases. In chronic inflammatory conditions, the immune system continuously releases inflammatory substances such as cytokines and chemokines, which can damage lung tissue.[12]

Chronic inflammation can cause the thickening of the walls of the alveoli (small air sacs in the lungs), reducing the elasticity of lung tissue, and inhibiting airflow. This can reduce lung capacity, namely the maximum volume of air that the lungs can hold. Damage to lung tissue can also reduce lung function, namely the ability of the lungs to take in oxygen and expel carbon dioxide. This can cause shortness of breath, fatigue, and decreased physical performance. Chronic inflammation of the lungs can increase the risk of various respiratory diseases, including asthma, chronic bronchitis, emphysema, and chronic obstructive pulmonary disease (COPD). These diseases can cause progressive lung damage and significantly reduce quality of life. Regular exercise has been shown to have significant anti-inflammatory effects. Physical activity can reduce the production of inflammatory substances, increase the production of anti-inflammatory substances, and modulate the immune system response. The anti-inflammatory effects of exercise can help protect the lungs from damage caused by chronic inflammation and maintain optimal lung function.[13,14]

Exercise can reduce the production of pro-inflammatory cytokines, which are small proteins produced by the body's immune cells to trigger and amplify an inflammatory response. Some pro-inflammatory cytokines associated with lung inflammation include interleukin-6 (IL-6), tumor necrosis factor-alpha (TNF-α), and interleukin-1 beta (IL-1β). Exercise can increase the production of anti-inflammatory cytokines, which are proteins that function to inhibit and reduce inflammatory responses. Several anti-inflammatory cytokines that play a role in protecting the lungs include interleukin-10 (IL-10) and transforming growth factor-beta (TGF-β). Exercise can increase the activity of regulatory T cells (Treg), which are a type of white blood cell that functions to suppress excessive immune responses. Treg cells can help prevent chronic inflammation in the lungs by inhibiting the activity of immune cells that trigger inflammation. Exercise stimulates the production of myokines, which are proteins produced by skeletal muscles when they contract. Some myokines have anti-inflammatory effects and may help protect the lungs from damage caused by inflammation. Exercise can reduce oxidative stress, which is a condition where there is an imbalance between the production of free radicals and the body's ability to neutralize them. Free radicals can damage lung cells and trigger inflammation.[15,16]

Various types of exercise can provide anti-inflammatory benefits and protect lung health. However, aerobic exercise such as walking, running, cycling, or swimming is generally considered the most effective for improving lung function and reducing inflammation. Aerobic exercise increases heart rate and breathing, thereby increasing blood flow to the lungs and training the respiratory muscles. Apart from aerobic exercise, strength training can also provide benefits for lung health. Strength training can strengthen the chest, back, and abdominal muscles, which play a role in supporting breathing. Strong muscles can improve breathing efficiency and reduce the risk of lung injury. The optimal intensity and duration of exercise for lung health can vary depending on the individual's age, fitness level, and health condition. However, in general, it is recommended to do moderate to high-intensity aerobic exercise for at least 30 minutes, 5 days a week. Strength training can be done 2-3 times a week.[17-20]

4. Conclusion

This research provides strong evidence regarding the positive effects of exercise on the lung function performance of adolescents in Jakarta, Indonesia. Adolescents who are physically active show higher FEV1, FVC, and FEV1/FVC values compared to adolescents who are less active. These findings support the importance of promoting physical activity in adolescents to improve lung health, especially in urban environments with exposure to air pollution.

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