New Approaches in Exercise Physiology (NAEP)
Vol. 6, No.12, December 2024
www.nass.atu.ac.ir
DOI: 10.22054/nass.2025.88149.1185

ATU PRESS

Original Research
Received: August 13, 2025 Accepted: September 28, 2025

Anthropometric Predictors of Acute Ventilatory Responses to Maximal Field Exercise in Adolescents

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How to Cite: Beiramy, M, & Yaghoob Nezhad, F. (2024). Anthropometric Predictors of Acute Ventilatory Responses to Maximal Field Exercise in Adolescents, *Journal of New Approaches in Exercise Physiology*, 6(12), 38-58.
DOI: 10.22054/nass.2025.88149.1185

Abstract

Purpose: The acute ventilatory response to exercise in adolescents is a critical indicator of cardiorespiratory fitness, yet the predictive power of basic anthropometric measures for this response, particularly in field-based settings, is not fully established. This study aimed to investigate the relationship between anthropometric variables (height, weight, BMI) and acute ventilatory responses both at rest and immediately following a maximal one-mile (1600m) field run in healthy adolescent boys. **Method:** In a pre-test/post-test experimental design, 80 healthy adolescent boys (mean age: 14.65 ± 1.22 years, height: 168.20 ± 9.72, body mass index: 19.54 ± 2.80) were selected via cluster sampling. Anthropometric data (height, weight, BMI) and estimated VO_2max were recorded. Pulmonary function variables (FVC, FEV_1, VC, TV, MVV) were measured via spirometry at rest and immediately after a maximal one-mile run. Stepwise multiple regression analysis was used to predict ventilatory responses from anthropometric and physiological variables. **Results:** Height, weight, and BMI were all significant predictors of pulmonary function (FVC, FEV_1, VC) in both pre- and post-test conditions ($p < 0.05$). Height emerged as the strongest single predictor. A slight but consistent decrease in mean FVC, FEV_1, and VC values was observed post-exercise. VO_2max was a weaker predictor compared to anthropometric measures. **Conclusion:** Basic anthropometric characteristics, most notably height, are strong and consistent predictors of pulmonary function in adolescent boys, both at rest and following acute strenuous exercise. These findings highlight the importance of using individual morphometric characteristics for accurately assessing and interpreting exercise-induced ventilatory responses in youth populations. Field-based testing provides a valid practical method for such evaluations.

Keywords: Exercise, Adolescents, Anthropometry, Pulmonary Ventilation.

Introduction

The respiratory system undergoes a complex process of growth and maturation from conception through full adulthood, progressing through several distinct developmental stages. During physical activity, children exhibit increased ventilatory demands, which are met by elevating minute ventilation through higher respiratory rates and tidal volumes (A. Fasihi, Siyahkohiyan, Jafarnezhadgero, Fasihi, & Sheikhalizade, 2021). Understanding ventilatory responses to exercise in children requires consideration of both changes in body size—such as height and weight—and the maturation of organ function, which is influenced more by biological age and developmental stage than by size alone (Krchegani & Savari, 2025). Assessing acute ventilatory responses during exercise benefits from measuring multiple lung volumes and capacities, providing a comprehensive evaluation of respiratory system function in the developing child (L. Fasihi, Tartibian, & Eslami, 2021). Recognizing the factors that influence these ventilatory responses enhances our understanding of respiratory physiology and informs the design of appropriate training and rehabilitation programs. Among these factors, body size and age are particularly significant (Jokar, Behpoor, Fasihi, Fasihi, & Ebrahimi Torkamani, 2021). Lung volumes and capacities tend to correlate more strongly with stature than chronological age, often changing proportionally with height during childhood and adolescence. Additionally, lung function parameters vary according to sex, ethnicity, and anthropometric characteristics (Quanjer et al., 2012; Stocks & Quanjer, 2013). Previous studies have demonstrated significant correlations between pulmonary function and physical characteristics. For example, Chatterjee et al. (2018) found that tidal volume (TV), forced vital capacity (FVC), vital capacity (VC), forced expiratory time (FET), and maximal voluntary ventilation (MVV) were all significantly associated with weight, height, arm and chest circumference, and age in Indian twin children. Similarly, Zorrio and Gandu (2019) reported that vital capacity indices in Malawian children were strongly dependent on body size and age. Torres et al. (2020) also observed positive relationships between pulmonary function and anthropometric measures. Despite these insights, there remains a paucity of research focusing on acute ventilatory responses to high-intensity aerobic exercise across different age groups and body sizes, particularly in Iranian populations. Most existing studies have been conducted in controlled laboratory settings using equipment such as cycle ergometers, treadmills, or stair climbers, with fewer investigations employing field-based exercise tests (Mercier et al., 2021; Wang et al., 2022). Mercier and colleagues found that tidal volume increased with age and anthropometric variables in boys aged 10.5 to 15.5 years; however, when adjusting for lean body mass, the age-related increase in tidal volume was not significant, suggesting that lean mass is a key determinant of ventilatory adaptation during exercise. Wang et al. (2022) further reported that obese children exhibited lower tidal volumes during exercise compared to their lean counterparts. The influence of body size and developmental stage on physiological responses to exercise remains a critical area of study in pediatric exercise science. Concurrently, the rising prevalence of pediatric pulmonary conditions, such as bronchial asthma, underscores the need for updated normative lung function data to better predict lung volumes and capacities in children and adolescents (Global Initiative for Asthma, 2023). Moreover, secular trends in growth have altered average height and body composition over recent decades, contributing to variability in lung function reference values (Quanjer et al., 2012). Given ongoing debates regarding the relative impact of various anthropometric factors on ventilatory responses, this study aims to clarify which body measurements most strongly correlate with lung volumes and capacities in adolescent boys following a field-based intense aerobic exercise test. Specifically, we seek to identify reliable predictors of respiratory function among height, weight, and body mass index (BMI). The primary objective is to measure pulmonary function parameters in healthy 13- to 16-year-old boys post-exercise to establish normative spirometric values and explore their relationships with anthropometric variables.

Methods

Study Design and Participants

This experimental study employed a pre-test/post-test design to investigate acute ventilatory responses to severe aerobic field exercise in healthy adolescent boys. A cluster sampling method was used to select 80 adolescent boys aged 13-16 years from boys' schools in Miandoab City, Iran. From this initial pool, 20 subjects were selected for each age group. All participants were assessed for health status using the Physical Activity Readiness Questionnaire (PAR-Q), and informed consent forms were collected prior to participation. The study was conducted in accordance with ethical principles.

Anthropometric and Physiological Measurements

Body height was measured to the nearest 0.1 cm using a stadiometer (seca), and body weight was measured to the nearest 0.1 kg using a digital scale (seca) with participants wearing minimal clothing. Body Mass Index (BMI) was calculated as weight (kg) divided by height squared (m^2). Resting heart rate was measured using a Polar heart rate monitor. Maximal oxygen consumption (VO_2max) was estimated using the following equation, based on the time taken to run one mile (1600m), age, sex, and BMI (Heyward, V. H., & Gibson, A. L., 2014; Tartibian B., & Khorshidi M., 2005):

VO_2max (mL/kg/min) = $(0.21\times(\text{age}\times\text{sex})) - (0.84 \times \text{BMI}) - (8.41 \times T) + (0.34 \times T^2) + 108.94$

Sex: [where male=1].

Exercise Protocol

The aerobic activity program included a 1600-meter (Cureton, KJ. Protocol) run. The subjects ran a mile at their maximum speed. The time to cover the mile was measured and calculated to the nearest hundredth of a second, and aerobic capacity was estimated based on the time to cover the mile, age, sex, and body mass index. The test's reliability coefficient was R = 0.72, and the standard error of its estimate was estimated to be 4.8 mL/kg/min (Tartibian B., & Khorshidi M., 2005). Respiratory variables were measured using a standard method before and immediately after the running program.

Pulmonary Function Testing

Measurement of Respiratory Variables Then, subjects were asked to refrain from taking stimulants and medications for at least 6 hours before measuring respiratory factors. Lung volumes and capacities were measured at baseline and according to the instructions of a pulmonologist after three repetitions and selection of the best maneuver (Miller MR., et al., 2005). On the day of the 1600-meter run program, pulmonary tests were performed immediately after the completion of the field activity. Ventilation variables were measured using a spirometer (Spirometer Dotospir mod. 120 C, Spain) according to American Thoracic Society (ATS)/European Respiratory Society (ERS, 2012) guidelines (Graham, B. L., et al., 2019) as follows: first, the spirometer was adjusted according to the Asian population, then the test characteristics (age, height, weight and sex) were recorded in the device's memory and a clip or noseband was placed on the subject's nose to close the air outlet through the nose, then the subject placed his or her mouth on the edge of a disinfected plastic tube connected to the spirometer and blew into the rubber tube according to the type of breathing maneuver. Pulmonary tests were divided into three parts: In the first part (FVC), the subject took a deep breath that completely filled the lungs with air, followed by a strong and rapid exhalation. In this maneuver, the FVC curve was obtained. Through this curve, the factors FVC, 1FEV, %, FEF25-75% 1, FE can be measured. In the second part (VC), the subject takes a full breath and then makes a gradual deep exhalation to empty all the air in the lungs up to the residual volume. By performing this test, basic lung volumes and capacities such as TV, VC, IRV, and ERV can be obtained. In the third part for the test (MVV), the subject inhales and exhales rapidly for 10 to 15 seconds and the

MVV curve is obtained within one minute. Thus, pulmonary factors including MVV (liter/minute), VC (liter), TV (liter), 1FEV (liter), and FVC (liter) were estimated (Miller MR., et al Miller MR., 2005).

Statistical Analysis

Descriptive statistics (mean ± standard deviation) were used to summarize the data. To predict acute ventilatory responses based on height, weight, and BMI, a stepwise multiple regression analysis was employed. All statistical analyses were performed using SPSS version 26, and the significance level was set at $p < 0.05$.

Results

The anthropometric and physiological characteristics of the participants are presented in Table 1.

Table 1. Anthropometric and physiological characteristics of the students (13-16 years)

Variables	Mean + SD
Age (years)	14.65 ± 1.22
Height (cm)	168.20 ± 9.72
Weight (kg)	55.65 ± 11.21
BMI (kg/m^2)	19.54 ± 2.80
VO_2max (mL/kg/min)	35.29 ± 4.80

Heart Rate $_{Resting}$ (beat.min)	82.35±7.81

VO_2max: maximal oxygen uptake; SD: standard deviation; BMI: body mass index.

The results of the multiple regression analysis demonstrated that the anthropometric variables (height, weight, and BMI) were significant predictors of pulmonary function variables (FVC, FEV_1, VC) both before and after the Cureton protocol ($p < 0.05$). Height was consistently the strongest predictor (Tables 2, Table 3, and Table 4).

Table 2: FEV1 prediction based on anthropometric and physiological variables ((n=80).

Variable	ß	S.E	Beta	t	p < 0.05
Weight (kg) **Pre-Exe** **Post-Exe**	0.034 0.0.37	0.007 0.009	0.470 0.425	4.708 4.14	0.001 0.001
Height (cm) **Pre-Exe** **Post-Exe**	0.038 0.042	0.008 0.010	0.450 0.413	4.450 4.005	0.001 0.001
BMI (kg/m²) **Pre-Exe** **Post-Exe**	0.031 0.038	0.038 0.032	0.310 0.266	2.879 2.435	0.005 0.017

VO_2max: maximal oxygen uptake; S.E: standard errors; BMI: body mass index; ß: regression coefficients; Beta: beta weights; t: t-values; p <: p-values; Pre-Exe: before exercise; Post Exe: immediately after exercise.

Table 3: FVC prediction based on anthropometric and physiological variables (n=80).

Variable	ß	S.E	Beta	t	p < 0.05
Weight (kg)					
Pre-Exe	0.033	0.007	0.472	4.732	0.001
Post-Exe	0.037	0.007	0.500	5.093	0.001
Height (cm)					
Pre-Exe	0.037	0.008	0.453	4.486	0.001
Post-Exe	0.044	0.008	0.506	5.186	0.001
BMI (kg/m²)					
Pre-Exe	0.086	0.030	0.306	2.841	0.006
Post-Exe	0.090	0.032	0.302	2.795	0.007

VO_2max: maximal oxygen uptake; S.E: standard errors; BMI: body mass index; ß: regression coefficients; Beta: beta weights; t: t-values; p <: p-values; Pre-Exe: before exercise; Post Exe: immediately after exercise.

Table 4: VC prediction based on anthropometric and physiological variables (n=80)

Variable	ß	S.E	Beta	t	p < 0.05

Weight (kg) **Pre-Exe** **Post-Exe**	0.053 0.039	0.013 0.009	0.424 0.446	4.138 4.400	0.001 0.001
Height (cm) **Pre-Exe** **Post-Exe**	0.082 0.054	0.013 0.010	0.573 0.532	6.180 5.553	0.001 0.001
BMI (kg/m²) **Pre-Exe** **Post-Exe**	- -	- -	- -	- -	- --

VO_2max: maximal oxygen uptake; S.E: standard errors; BMI: body mass index; ß: regression coefficients; Beta: beta weights; t: t-values; p <: p-values; Pre-Exe: before exercise; Post Exe: immediately after exercise.

A comparison of pulmonary function variables before and immediately after the one-mile run (the Cureton protocol) is shown in Table 5. While the mean values for FEV_1, FVC, and VC showed a slight decrease post-exercise, these changes were not the primary focus of the regression analysis, which confirmed the predictive power of anthropometrics in both states.

Table 5. Pulmonary variables before and after the one-mile Cureton protocol in boys aged 14-16 years

Variable	Pre-Exe Mean ± SD	Post-Exe Mean ± SD*
FEV1 (L)	2.6 ± 0.81	2.43 ± 0.98

FVC (L)	2.68 ± 0.79	2.56 ± 0.84
VC (L)	4.61 ± 1.4	4.1 ± 0.99
TV (L)	2.71 ± 1.15	2.67 ± 1.14
MVV (L.min)	100.1 ± 33.2	101.14 ± 37.85

FEV1: forced expiratory volume in one second; FVC: forced vital capacity; VC: vital capacity; TV: tidal volume; MVV: maximal voluntary ventilation; *: number of participants (n=80).

It should be emphasized that the p-values for height, weight, and BMI as predictors were all highly significant ($p < 0.001$ to $p < 0.017$), meaning the probability of these relationships occurring by chance is extremely low. The high t-values (e.g., 4.450 to 6.180 for height) further confirm the strength and reliability of these predictors in the regression model.

Discussion

The main finding of this research is that fundamental body measurements, especially height, serve as strong indicators of lung function parameters in adolescent boys, both at rest and right after intense field-based aerobic exercise. This discussion will analyze these results in light of well-known and new physiological concepts, examine possible underlying mechanisms, and reflect on their practical significance. The strong predictive relationship between height and lung function metrics like FVC, FEV_1, and VC is a well-documented phenomenon in respiratory physiology and is firmly supported by global spirometry reference equations (Quanjer et al., 2012; Stanojevic et al., 2008). This correlation is fundamentally mechanical. Height is a strong surrogate for thoracic size; taller individuals possess a larger thoracic cavity, which allows for greater lung expansion. This translates directly to larger lung volumes and capacities, as the lungs themselves grow in proportion to the chest wall (Rosenthal & Bain, 2018). Our results, which show height to be a stronger predictor than weight or BMI, reinforce the concept that linear growth and the resultant increase in chest size are the primary drivers of improving lung function during adolescence. The significant, though weaker, predictive value of body weight can be attributed to its dual nature. Weight reflects both fat-free mass (FFM) and fat mass. FFM, which includes the respiratory muscles (diaphragm, intercostals, abdominals), is positively correlated with respiratory strength. Stronger muscles can generate greater transpulmonary pressures, contributing to higher volumes during forced maneuvers like FVC and FEV_1 (Laveneziana et al., 2019). However, excessive fat mass, particularly visceral adiposity, can have a detrimental effect by reducing chest wall compliance, functional residual capacity (FRC), and potentially increasing systemic inflammation, which may airway function (Dixon & Peters, 2018). This duality likely explains why weight was a significant but less powerful predictor than height in our cohort of generally healthy adolescents. A key insight from this study is that the anthropometric predictors remained robust even after the significant physiological stress of a maximal one-mile run. This suggests that the acute ventilatory response to exercise is heavily constrained by the individual's underlying, morphologically determined "hardware" – the size of their lungs and the strength of their respiratory muscles. The observed slight decrease in mean FVC, FEV_1, and VC post-exercise is a fascinating finding. While the study did not measure it directly, a potential mechanism for this transient reduction could be exercise-induced bronchoconstriction (EIB) or respiratory muscle fatigue. EIB is a common condition where vigorous physical activity triggers a narrowing of the airways, which would directly impact the ability to exhale air forcefully and rapidly, manifesting as a reduced FEV_1 and FVC (Weiler et al., 2016). Alternatively, fatigue of the expiratory muscles after sustained intense exercise could impair the ability to generate maximal expiratory flow, also reducing measured spirometry values. The stability of MVV suggests the neural drive and capacity for rapid shallow breathing may be preserved even if maximal force generation is temporarily compromised. The relatively weaker predictive power of BMI aligns with current critical views on its utility as a health metric. BMI is a poor distinguisher between muscle and fat mass. Two adolescents with the same height and BMI can have vastly different body compositions, leading to different respiratory muscle strength and lung mechanics. Therefore, it is a less precise predictor of physiological function like ventilation compared to direct measures of body size and composition. The finding that directly measured VO_2max was a weaker predictor than height is also physiologically logical. VO_2max is the gold standard measure of cardiorespiratory fitness and represents the integrated function of the pulmonary, cardiovascular, and muscular systems. While lung size is a crucial component, VO_2max can be limited by other factors not related to lung volume, such as cardiac output, hemoglobin concentration, and skeletal muscle oxidative capacity (Bassett & Howley, 2000). Therefore, an individual can have large lungs (high FVC predicted by height) but a lower VO_2max due to limitations in other systems.

Limitations:

The study was conducted exclusively on healthy adolescent boys from a specific geographic region (Miandoab City), which limits the generalizability of the results and the predictive equations generated, as they may not directly apply to girls, other age groups, clinical populations, or adolescents from different ethnic or geographic backgrounds with varying body proportions. Additionally, the use of a field test (one-mile run time) and a predictive equation to estimate maximal oxygen consumption (VO_2max) is a practical but less accurate method compared to direct cardiopulmonary exercise testing (CPET) with gas analysis; direct measurement would have provided a more precise and reliable value for VO_2max as a physiological variable. The study also did not assess or control for pubertal stage, despite the age range of 13-16 years encompassing a period of highly variable pubertal development that significantly impacts both anthropometry and physiological function. Another major limitation is the reliance on Body Mass Index (BMI), which does not distinguish between fat mass and fat-free mass (muscle); utilizing body composition measures such as skinfold thickness, bioelectrical impedance, or DEXA scans would have allowed for a more nuanced analysis of how muscle mass versus adiposity specifically influences pulmonary function. Furthermore, the observed post-exercise decrease in spirometry values (FEV_1, FVC) suggests the potential presence of exercise-induced bronchoconstriction (EIB) in some participants; however, without a specific diagnostic test for EIB, such as a post-exercise bronchodilator challenge, it is impossible to confirm this mechanism or determine its prevalence within the sample, which represents a significant limitation in interpreting the post-exercise pulmonary response.

Implications and Future Directions

This research underscores a critical practical application: in field settings and sports science, simple anthropometric measurements can provide a remarkably accurate estimation of an adolescent's pulmonary capacity and their expected ventilatory response to exercise. This allows coaches and practitioners to set realistic, individualized expectations and norms.

Future research should build upon these findings by incorporating Body Composition: Using DEXA or bioelectrical impedance to differentiate between fat mass and fat-free mass would clarify the specific role of muscle versus fat in predicting lung function. Also, by directly measuring EIB**:** Including pre- and post-exercise spirometry with a bronchodilator challenge would definitively determine if the observed post-exercise decline is due to EIB. Longitudinal design can also longitudinal design can also tracking these variables over time would provide powerful insight into how the relationship between anthropometry and lung function evolves throughout growth and puberty.

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Conclusion

In summary, this study demonstrates that the immediate ventilatory response to intense field exercise in adolescents is strongly affected by basic physical traits, with standing height emerging as the most significant predictor. The temporary reduction in lung function following exercise suggests the involvement of dynamic factors such as exercise-induced bronchoconstriction (EIB) or muscle fatigue, which operate alongside the underlying anatomical structure. These results emphasize the value of applying personalized, anthropometry-based criteria when evaluating and interpreting pulmonary function in young athletes, offering a more detailed and precise insight into their physiological capacity and reactions.

Author Contributions

Mortaz Beiramy collected the data and wrote the manuscript; Fakhreddin Yaghoob Nezhad critically reviewed the manuscript.

Funding

This research received no external funding.

Institutional Review Board Statement

Not applicable.

Informed Consent Statement

Not applicable.

Acknowledgments

The authors are grateful for the adolescent's boys and their family without which the study could not have been carried out.

Conflicts of Interest

The author declares no conflict of interest.

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How to Cite: Beiramy, M, & Yaghoob Nezhad, F. (2024). Anthropometric Predictors of Acute Ventilatory Responses to Maximal Field Exercise in Adolescents, *Journal of New Approaches in Exercise Physiology*, 6(12), 38-58.
DOI: 10.22054/nass.2025.88149.1185