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Original Article

The Effects of Type of Exercise on Ventilatory Efficiency (VE/VCO2) in 11-16-Year-Old Healthy Individuals: A Randomized Clinical Trial

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Abstract
Background: The ventilatory equivalent for CO_2 (VE/VCO_2) is the simplest way to predict ventilatory efficiency. This study aimed to investigate the impact of treadmill and cycle ergometer exercise tests on ventilatory outcomes in healthy adolescents.
Methods: In this clinical trial with cross-over design, 52 adolescents aged 11-16 years old (age: 13.8±0.17 years, height: 157.4±0.95 cm, weight: 51.73±1.24 kg, represented as mean±standard error), went through treadmill and cycle ergometer exercise tests with a 6-day wash-out during July-August 2019, Tehran, Iran. Through a RAMP (raise, activate, mobilise, and potentiate) protocol, participants were asked to perform the maximal treadmill or cycle ergometer exercise and continue the test until exhaustion. Gas exchange and heart rate (HR) were obtained breath by breath during the test. Time, HR, VE/VCO2, minute ventilation) VE), end-tidal carbon dioxide pressure (PetCO2), and dead space (VD) to tidal volume (VT) ratios (VD/VT) were transferred to the computer and recorded. All data were reported at two-time points: Anaerobic threshold (AT) V-slop method and peak. Independent t-test was then performed to compare the two types of exercises using SPSS 16, and $P<0.05$ was considered significant.
Results: The results showed a significant difference in two points regarding the type of exercise for Time and VE/VCO2, but for HR ($P=0.004$), VE ($P=0.0001$), PetCO2 ($P=0.008$), and VD/VT ($P=0.004$), a significant difference was only observed in AT point.
Conclusion: Several physiological mechanisms that occurred during the development stage could affect individuals' respiratory parameters; however, in general, the type of exercise test affected VE/VCO2.
Keywords: Ventilation, Gender, Exercise, Adolescents, Exercise equipment, VE/VCO2

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Background

The ventilatory equivalent for CO_2 (VE/VCO_2) is the simplest way to predict ventilatory efficiency (1). This index can be examined throughout the exercise using a body gas analyzer, and it expresses the slope of the relationship between ventilation (V_E) and carbon dioxide output (VCO_2) throughout the exercise activity (2). VE/VCO_2 is inversely related to oxygen uptake (VO_2), which is justified by lung perfusion, and VE/VCO_2 is a better predictor than VO_2 because, unlike VE/VCO_2, the accurate assessment of VO_2 depends on the subject's maximum effort (3).

Numerous studies have investigated the effect of exercise on the partial pressure of O2 in arterial blood (VO_2), partial pressure of CO2 in arterial blood (VCO_2), and ventilatory efficiency index (VE/VCO2) in children and adolescents. Parazzi et al summarized the results of those studies in their systematic review and reported that the VE/VCO_2 index decreases progressively throughout a physical exercise (4). However, different types of exercise have led to different results.

In one study, a submaximal exercise test on a treadmill in 100 adolescents aged 10-13 years old revealed that the VE/VCO2 decreases during progressive exercise in males but remains unaltered for the female subjects (5). In another study, after the maximal exercise test in children aged 9-11 on cycle ergometers, no difference was observed in the VE/VCO2 in both genders (6). It seems that there is not a defined line of research in this regard; therefore, it is difficult to interpret and compare the results.

There is still controversy about VE/VCO2, and VE and VCO2 have a reasonably linear relationship up to the anaerobic threshold (AT), but after the AT, ventilation is driven by acidosis as well as CO2 (7). Actually, up to the time point of AT, the relation between minute ventilation (VE) and VCO2 is linear, but at the time point of VO2 peak, this correlation turns into a curved-shape diagram

(8). Therefore, it is important to measure V_E/VCO_2 separately at these two-time points.

There is still disagreement about the best type of exercise test to assess cardiorespiratory function. Therefore, since treadmill and cycling are the most commonly used sports activities, it is important to recognize the differences in their effects on respiratory performance. In addition, one of the important issues of research methodology roots back to measurement protocols. Myers et al reported that although the hemodynamic responses to RAMP (raise, activate, mobilise, and potentiate) and periodic protocols were similar, there were significant differences in the gas exchange rate during a workload below the maximum VO_2 (9). The authors claimed that the ratio of VO_2 to the amount of work in RAMP protocol is larger than that in periodic protocols due to the higher workload. They also found that the difference between predicted and evaluated VO_2 is minimal (9). It could be concluded that the type of incremental activity protocol can affect respiratory efficiency (10).

Objectives

Hence, this interventional study was conducted to find out whether different types of exercise performed through the RAMP protocol could affect V_E/VCO_2 in different ways at two-time points (AT and VO_2 peak) in healthy adolescents.

Methods

Participants

This study was a randomized clinical trial, and participant recruitment was done by advertising on a highly-visited advertising website (https://divar.ir/s/tehran) in July-August 2019 in Tehran, Iran. The sample size of this study was calculated using G*Power software and according to the effect size reported in the study by Marinov et al (1.4 ± 1 for VE/VCO_2) (11). Overall, 52 volunteer male (n = 26) and female (n = 26) adolescents who were eligible according to the inclusion and exclusion criteria participated in this study. They were 11-16 years old and healthy without any major pulmonary, cardiovascular, or metabolic diseases such as diabetes. Adolescents who took any medication or dietary supplement were excluded from this study. Written informed consent was obtained from the participants and their parents before the beginning of the test procedure.

Study Protocol

We used a cross-over design in this clinical trial. On the first visit, participants were acquainted with the procedure of the study, the technique of respiratory gas analysis, and devices (cycle ergometer and treadmill), and their height, weight, and body mass index were measured using standardized measures. On the second visit, 52 individuals were randomly allocated to the cycle ergometer (n = 26) or the treadmill test (n = 26). After a 6-day wash-out, participants were referred to the laboratory to receive the opposite intervention (Those who used the cycle ergometer in the previous session used the treadmill, and the ones who used the treadmill practiced with the cycle ergometer). We made sure that the female participants were not in their menstruation period on the day of the exercise test. All tests were scheduled for the morning hours at 21 ± 1°C temperature in a laboratory setting. A warm-up consisting of stretching of the major muscle groups and slow walking was carried out preceding the main exercise. Participants were ordered to continue the test until they reached a level of exhaustion where they could not perform the exercise anymore. At all stages, respiratory gas was measured using a gas analyzer, and heart rate (HR) was recorded. The RAMP protocol was performed during both exercises. Through this protocol, muscle temperature and engagement, blood flow, and neural activation increased slowly, preventing the sudden increase in HR (12). In both tests, to ensure that the participants have reached the maximum oxygen consumption, at least two of the following conditions had to be observed: 1) the oxygen consumption diagram reaches and remains monotonous and does not increase despite the increase in workload, 2) the respiratory exchange ratio is equal to 1.15, 3) HR is equal to 95% of the maximum HR, and 4) the participant feel the exhaustion according to the index of 10-point perception of effort (13).

Treadmill Exercise

To determine VO2 max, the RAMP protocol was used on Italian-made Technogym Med treadmills. Before performing the protocol, all participants were informed of the test and how it worked and were also asked to continue the test until reaching the state of exhaustion. To determine the onset rate and the rate of gradual increase of the protocol using the Cardiovascular Readiness Questionnaire and trial and error, six participants from each group were tested based on their ability (pilot study). On the test day, the participants first did stretching and flexing warm-up exercises in the laboratory for 10 minutes, then they used the treadmill for two minutes to reduce stress, and then the main protocol of the treadmill was performed with a slope of one percent (14). According to the results of the pilot study, the initial velocity for starting was 30% of the final velocity, and, for determining the amount of the gradual increase per minute, the initial velocity was subtracted from the final velocity and divided by 10 (15). The participants performed the activity until exhaustion was achieved, and in all stages, the oxygen uptake was measured using a respiratory gas analyzer, and HR was also recorded.

Cycle Ergometer Exercise

Maximal exercise test was performed on a motor-driven and electronically controlled cycle ergometer Monark-839 (Sweden). The protocol of this test was started with an initial strength of 30% of the maximum resistance where VO_2 max could be achieved (based on the results of the pilot study). In participants aged 11 to 12 years, the protocol was performed by a workload of 10 W per minute (1 W every 6 seconds), in participants aged 13 and 14 years, a workload of 15 W per minute (1 W every 4 seconds) was applied, and adolescents aged 15-16, it was performed with a maximum workload of 20 W/min (1 W every 3 seconds). Pedaling was also between 40 and 60 rounds per minute (14, 16).

Data *Collection*

Gas exchange measures (MetaLyzer3B-R2- Cortex Germany) and HR (Custo Cardio 200 – Custo Med Germany) were obtained breath by breath during the test. Time, HR, VE/VCO_2, VE, end-tidal carbon dioxide pressure ($PetCO_2$), and dead space (VD)/tidal volume (VT) were transferred to the computer and recorded. All data were reported at two-time points: AT V-slop method and peak.

Statistical Analysis

Descriptive statistics were used to assess the results. Data were expressed as mean ± standard error. After confirming the normal distribution of data using the Kolmogorov-Smirnov test, an independent t-test was used to compare variables between the two types and gender. Then, data were analyzed by SPSS software version 16 (SPSS Inc. Released 2007. SPSS for Windows, Version 16.0. Chicago, SPSS Inc) at the significance level of $P < 0.05$.

Results

As represented in Figure 1, the design of this clinical trial was cross-over, and participants were randomly assigned to first engage in maximum treadmill exercise and then in the cycle ergometer test or contrariwise. There were no dropouts during the study period.

Table 1 summarizes the characteristics of the study participants. As shown in Table 2, there was a significant difference for time and VE/VCO2 in two points by type of exercise, but for HR ($P = 0.004$), VE ($P = 0.0001$), PetCO2 ($P = 0.008$), and VD/VT ($P = 0.004$), the significant difference was only observed in AT point. It should be noted that results related to gender impact on each protocol are reported in Supplementary file 1.

Discussion

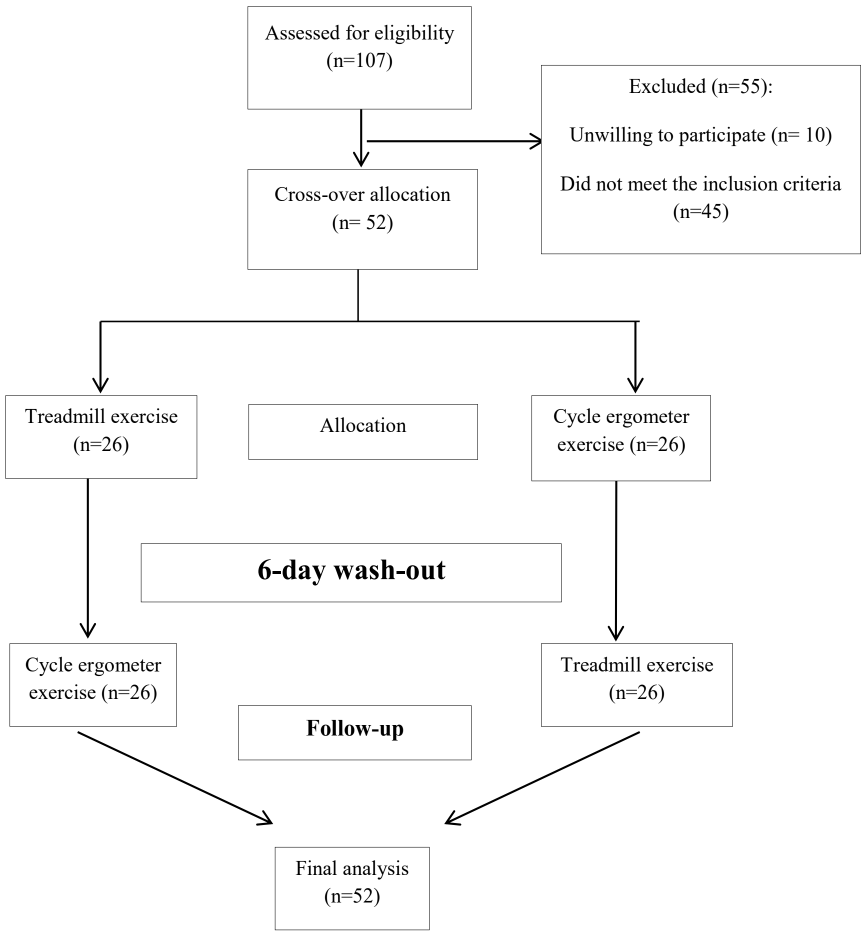

Figure 1. Flowchart of Participant Recruitment

Table 1. Anthropometric and Demographic Characteristics of the Participants

Variable	Mean ± SE
Age (y)	13.8 ± 0.17
Height (cm)	157.4 ± 0.95
Weight (kg)	51.73 ± 1.24
BMI	20.57 ± 0.37

Note. BMI: Body mass index; SE: Standard error; Data are represented as Mean ± SE.

Table 2. Exercise Parameters Obtained through Each Intervention

Variable		Type	Mean	SE	*P* value
Time (s)	AT	Treadmill	5.38	0.28	0.003
		Cycle	6.57	0.27	
	Peak	Treadmill	9.47	.27	0.0001
		Cycle	11.91	.22	
HR (1/min)	AT	Treadmill	159.19	2.65	0.0001
		Cycle	142.83	2.28	
	Peak	Treadmill	185.29	2.03	0.16
		Cycle	181	2.26	
VE/VCO2	AT	Treadmill	32.61	0.41	0.001
		Cycle	30.62	0.4	
	Peak	Treadmill	35.20	0.48	0.028
		Cycle	33.70	0.47	
VE (L/min)	AT	Treadmill	35.10	1.89	0.0001
		Cycle	26.81	1.29	
	Peak	Treadmill	63.7	2.35	0.36
		Cycle	60.46	2.6	
PetCO2 (mm Hg)	AT	Treadmill	30.90	0.36	0.008
		Cycle	32.38	0.40	
	Peak	Treadmill	29.18	0.40	0.06
		Cycle	30.26	0.4	
VD/VT -	AT	Treadmill	0.135	0.003	0.004
		Cycle	0.12	0.003	
	Peak	Treadmill	0.137	0.003	0.15
		Cycle	0.131	0.003	

Note. HR: Heart rate; VO2: Partial pressure of oxygen; VCO2: Partial pressure of carbon dioxide; VE/VCO2: Ventilatory efficiency index; PetCO2: End-tidal carbon dioxide pressure; VE: Minute ventilation; AT: Anaerobic threshold; VD/VT: Dead space/tidal volume ratio; SE: Standard error.
Data are represented as Mean ± SE; * Significant *P* value at 0.05.

The results of the present research showed that the type of exercise test has a significant effect on respiratory performance at two points of AT and VO_2 peak. To our knowledge, most studies have used one type of exercise test (cycle ergometer or treadmill) to determine respiratory efficiency. Therefore, one of the strengths of this study is the simultaneous assessment of two types of exercise tests (i.e., cycle ergometer and treadmill); hence, it is not possible to compare the results directly with previous research.

Since more muscles are activated and more lactic acid is produced and exerted to the blood flow on the treadmill compared to cycle ergometer exercise, the heart needs to beat faster to deliver this lactic acid to the lungs (higher HR), and the lungs have to increase ventilation to exert lactic acid in the form of CO_2 through exhalation (higher VE) (17, 18). Higher muscle blood flow and higher cardiac output observed in treadmill runners in comparison to cyclers confirm this justification (19). Treadmills and cycling are exercises that are performed by contractions in the muscles of the lower limbs. Many researchers believe that the differences observed in the AT and VO2 max when comparing these two types of activity are attributed to differences in ventilation responses (reduction in arterial oxygen saturation, O_2 emission capacity, respiratory fatigue, and pulmonary mechanics), the position on a cycle ergometer, and muscle utilization (lower efficiency of the peripheral muscles) (20, 21).

However, these mechanisms have been proven in studies performed among adult participants. Due to the obvious differences between juveniles and adults, more research is needed in this area.

Ventilatory efficiency is affected by many factors; for instance, increased pulmonary dead space or low hemoglobin levels could increase ventilatory response during exercise (22). In this research, participants had no metabolic disorder; hence, no difference was observed between the two groups in terms of VE/VCO_2. Different effects of treadmill and cycle ergometer exercise on acid-base balance in blood should have caused the different results regarding VE and HR (23).

This study has several strengths. To the best of our knowledge, this was the first study comparing the effect of treadmill and cycle ergometer exercises on the ventilatory equation in adolescents. The second strength of this study is its cross-over design in which the participants were assigned to a sequence of two exercises. In this design, the influence of confounding variables is reduced as each subject has his/her own control, and it is statistically more efficient than the parallel design. Finally, unlike previous studies in which periodic or continuous approaches were used, we used the RAMP progressive protocol, which prepared the participants' bodies for the exercise test by slowly increasing the body temperature and muscle activation. There are also several limitations in this study. Since our participants were not professional athletes, we did not assess the level of their usual physical activity to be able to investigate the effect of their level of activeness on the ventilatory outcomes. We also did not report the data separately for age categorization adolescents, which is suggested to be done in future investigations. In addition, although the data for the beginning of activity (baseline) was available in this study, they were not reported since they were affected by warming up. It is suggested that the resting values and baseline (after warm-up) be reported in future research.

Conclusion

In the end, it is inferred from the research findings that although several physiological mechanisms occurring during growth can affect the respiratory parameters of individuals, in general, the type of exercise test and gender can impact respiratory performance. In the meantime, it was found that the RAMP protocol can be a suitable alternative to other increasing protocols because its load-bearing properties are commensurate with the level of physical fitness of individuals. Therefore, it can be used for sports coaches or other research related to adolescents.

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Authors' Contribution

Rostam Alizadeh and Najmeh Rezaeinezhad: Conceptualization, Data curation, Formal analysis, Funding acquisition, Investigation, Methodology, Project administration, Resources, Software, Supervision, Validation, Visualization, Writing–original draft and Writing–review & editing.

Competing Interests

The authors declare that they have no conflict of interests concerning this article.

Ethical Approval

The protocol of this study was approved by the Ethics Committee of Ilam University of medical sciences (reference no: IR.MEDILAM.REC.1398.010).

Supplementary Files

Supplementary file 1. Exercise Parameters Obtained through Each Intervention by Gender.

References

1. Habedank D, Reindl I, Vietzke G, Bauer U, Sperfeld A, Gläser S, et al. Ventilatory efficiency and exercise tolerance in 101 healthy volunteers. Eur J Appl Physiol Occup Physiol. 1998;77(5):421-6. doi: 10.1007/s004210050354.
2. Ashikaga K, Itoh H, Maeda T, Itoh H, Ichikawa Y, Tanaka S, et al. Ventilatory efficiency during ramp exercise in relation to age and sex in a healthy Japanese population. J Cardiol. 2021;77(1):57-64. doi: 10.1016/j.jjcc.2020.07.008.
3. Rosato E, Leodori G, Gigante A, Di Paolo M, Paone G, Palange P. Reduced ventilatory efficiency during exercise predicts major vascular complications and mortality for interstitial lung disease in systemic sclerosis. Clin Exp Rheumatol. 2020;38 Suppl 125(3):85-91.
4. Parazzi PL, Marson FA, Ribeiro MA, Schivinski CI, Ribeiro JD. Ventilatory efficiency in children and adolescents: a systematic review. Dis Markers. 2015;2015:546891. doi: 10.1155/2015/546891.
5. Marinov B, Kostianev S, Turnovska T. Ventilatory response to exercise and rating of perceived exertion in two pediatric age groups. Acta Physiol Pharmacol Bulg. 2000;25(3-4):93-8.
6. Lintu N, Viitasalo A, Tompuri T, Veijalainen A, Hakulinen M, Laitinen T, et al. Cardiorespiratory fitness, respiratory function and hemodynamic responses to maximal cycle ergometer exercise test in girls and boys aged 9-11 years: the PANIC Study. Eur J Appl Physiol. 2015;115(2):235-43. doi: 10.1007/s00421-014-3013-8.
7. Arena R, Myers J, Aslam SS, Varughese EB, Peberdy MA. Influence of subject effort on the prognostic value of peak VO2 and the VE/VCO2 slope in patients with heart failure. J Cardiopulm Rehabil. 2004;24(5):317-20. doi: 10.1097/00008483-200409000-00006.
8. Ingle L, Goode K, Carroll S, Sloan R, Boyes C, Cleland JG, et al. Prognostic value of the VE/VCO2 slope calculated from different time intervals in patients with suspected heart failure. Int J Cardiol. 2007;118(3):350-5. doi: 10.1016/j.ijcard.2006.07.105.
9. Myers J, Buchanan N, Walsh D, Kraemer M, McAuley P, Hamilton-Wessler M, et al. Comparison of the ramp versus standard exercise protocols. J Am Coll Cardiol. 1991;17(6):1334-42. doi: 10.1016/s0735-1097(10)80144-5.
10. Lee JS, Jang SI, Kim SH, Lee SY, Baek JS, Shim WS. The results of cardiopulmonary exercise test in healthy Korean children and adolescents: single center study. Korean J Pediatr. 2013;56(6):242-6. doi: 10.3345/kjp.2013.56.6.242.
11. Marinov B, Kostianev S, Turnovska T. Ventilatory efficiency and rate of perceived exertion in obese and non-obese children performing standardized exercise. Clin Physiol Funct Imaging. 2002;22(4):254-60. doi: 10.1046/j.1475-097x.2002.00427.x.
12. Kaminsky LA, Whaley MH. Evaluation of a new standardized ramp protocol: the BSU/Bruce Ramp protocol. J Cardiopulm Rehabil. 1998;18(6):438-44. doi: 10.1097/00008483-199811000-00006.
13. Edvardsen E, Hem E, Anderssen SA. End criteria for reaching maximal oxygen uptake must be strict and adjusted to sex and age: a cross-sectional study. PLoS One. 2014;9(1):e85276. doi: 10.1371/journal.pone.0085276.
14. Myers J, Bellin D. Ramp exercise protocols for clinical and cardiopulmonary exercise testing. Sports Med. 2000;30(1):23-9. doi: 10.2165/00007256-200030010-00003.
15. da Silva SC, Monteiro WD, Cunha FA, Myers J, Farinatti PT. Determination of best criteria to determine final and initial speeds within ramp exercise testing protocols. Pulm Med. 2012;2012:542402. doi: 10.1155/2012/542402.
16. Barker AR, Williams CA, Jones AM, Armstrong N. Establishing maximal oxygen uptake in young people during a ramp cycle test to exhaustion. Br J Sports Med. 2011;45(6):498-503. doi: 10.1136/bjsm.2009.063180.
17. Cairns SP. Lactic acid and exercise performance: culprit or friend? Sports Med. 2006;36(4):279-91. doi: 10.2165/00007256-200636040-00001.
18. Casaburi R, Patessio A, Ioli F, Zanaboni S, Donner CF, Wasserman K. Reductions in exercise lactic acidosis and ventilation as a result of exercise training in patients with obstructive lung disease. Am Rev Respir Dis. 1991;143(1):9-18. doi: 10.1164/ajrccm/143.1.9.
19. Matsui H, Kitamura K, Miyamura M. Oxygen uptake and blood flow of the lower limb in maximal treadmill and bicycle exercise. Eur J Appl Physiol Occup Physiol. 1978;40(1):57-62. doi: 10.1007/bf00420989.
20. Millet GP, Vleck VE, Bentley DJ. Physiological differences between cycling and running: lessons from triathletes. Sports Med. 2009;39(3):179-206. doi: 10.2165/00007256-200939030-00002.
21. Prefaut C, Durand F, Mucci P, Caillaud C. Exercise-induced arterial hypoxaemia in athletes: a review. Sports Med. 2000;30(1):47-61. doi: 10.2165/00007256-200030010-00005.
22. Pianosi P, D'Souza SJ, Esseltine DW, Charge TD, Coates AL. Ventilation and gas exchange during exercise in sickle cell anemia. Am Rev Respir Dis. 1991;143(2):226-30. doi: 10.1164/ajrccm/143.2.226.
23. Verstappen FT, Huppertz RM, Snoeckx LH. Effect of training specificity on maximal treadmill and bicycle ergometer exercise. Int J Sports Med. 1982;3(1):43-6. doi: 10.1055/s-2008-1026061.