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COMPARISON OF CARDIOPULMONARY CHANGES DURING CYCLE AND TREADMILL TESTS

PORÓWNANIE ZMIAN SERCOWO-PŁUCNYCH PODCZAS TESTÓW NA ROWERZE I BIEŻNI

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Summary

Background. Our pilot study aimed to investigate cardiopulmonary differences between vita maxima incremental cycle and treadmill tests among elite youth cyclists.

Material and methods. 8 elite youth cyclists (6 male, 2 female; age: 17.125±1.8 years) completed a cycle ergometer test using a road racing bike on a Tacx Smart Flux roller, followed by a vita maxima treadmill test 48 hours later. Aerobic capacity, cardiopulmonary, and metabolic parameters were measured during both tests.

Results. Based on the paired sample t-test, and Wilcoxon signed-rank test, the maximal load values (W) on the treadmill were significantly higher ($t=3.52$; $p<0.05$) than in the cycle test. Volume of utilized oxygen (VO_2; ml/min) and volume of exhaled CO_2 (VCO_2; ml/min) values ($t=4.76$ and $t=3.45$; $p<0.05$), maximal fat oxidation (Fatmax; g/day) ($t=4.34$; $p<0.05$), maximum rate of oxygen consumption (VO_2max; ml/kg/min) ($t=4.9$; $p<0.05$) and rate of oxygen consumption at lactate threshold (VO_2atLT; ml/kg/min) ($t=4.04$; $p<0.05$) also showed significantly higher values than in treadmill test. Pearson's correlation study showed significant correlation between VO_2atLT, and most other parameters (VO_2, ventilation (VE; BTPS l/min), load at lactate threshold (load at LT), energy expenditure (EE; g/day)).

Conclusions. The differences in results may be because of sport-specific adaptation to cycling and the characteristics of running and cycling, such as the different muscle contraction composition (concentric and eccentric) and different metabolic demands. These findings must be taken into account when testing cyclists on a treadmill, and planning their training loads based on these results.

Keywords: treadmill test, bicycle ergometry test, stress test, athletes

Streszczenie

Wprowadzenie. Badanie pilotażowe miało na celu zbadanie sercowo-płucnych różnic przyrostowej vita maxima podczas testów na rowerze i bieżni przeprowadzonych wśród czołowych młodych rowerzystów.

Materiał i metody. Ośmioro czołowych młodych rowerzystów (sześciu mężczyzn i dwie kobiety w wieku 17.125±1.8 roku) wykonało najpierw cykl na ergometrze rowerowym z wykorzystaniem roweru wyścigowego Tacx Smart Flux roller, a 48 godzin później test vita maxima na bieżni. Podczas obydwu testów zmierzono wydolność tlenową oraz parametry sercowo-płucne i metaboliczne.

Wyniki. Na podstawie badania t par próbek i testu Wilcoxona dla par obserwacji ustalono, że maksymalne wartości obciążenia (W) na bieżni były znacząco wyższe ($t=3{,}52$; $p<0{,}05$) niż na rowerze. Wartości zużycia tlenu (VO_2; ml/min) i wydalonego dwutlenku węgla (VCO_2; ml/min) ($t=4{,}76$ i $t=3{,}45$; $p<0{,}05$), maksymalna oksydacja tłuszczu (Fatmax; g/dzień) ($t=4{,}34$; $p=<0{,}05$), maksymalne zużycie tlenu (VO_2max; ml/kg/min) ($t=4{,}9$; $p<0{,}05$) i zużycie tlenu na progu mleczanowym (VO_2atLT; ml/kg/min) ($t=4{,}04$; $p<0{,}05$) okazały się z kolei istotnie wyższe w teście na bieżni. Badanie korelacji Pearsona wykazało korelację między VO_2atLT i większości pozostałych parametrów (VO_2, wentylacja (VE; BTPS l/min), obciążenie na progu mleczanowym (load at LT), wydatek energetyczny (EE; g/dzień)).

Wnioski. Różnice w uzyskanych wynikach mogły zostać spowodowane predyspozycjami do wykonywania konkretnego sportu, w tym wypadku jazdy na rowerze oraz różnicami między jazdą na rowerze i bieganiem w zakresie struktury kurczliwości (współśrodkowy i niewspółśrodkowy), a także różnymi wymaganiami metabolicznymi. Obserwacje muszą być uwzględnione podczas badania rowerzystów na bieżni i planowania obciążenia ich treningów.

Słowa kluczowe: test na bieżni, test ergometru rowerowego, test wysiłkowy, sportowcy

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Introduction

Monitoring the performance of elite athletes with sport-specific protocols and devices is highly effective [1-3]; several studies have compared the cardiopulmonary capacity of different elite athletes in laboratory tests. Different sports have different adaptation responses to specific long term endurance training, which is influenced by exercise intensity, duration, frequency [4], and the differences in contributions of exercising muscle mass of the lower and upper limbs [5-7]. Other studies have compared the performance of a population or a sport on different cardiopulmonary measuring instruments [1,8]. Most physiological and biomechanical comparative research on running and cycling has been conducted among triathletes. In this sport, the specific adaptation of both cycling and running to long term endurance training needs to be tested. However, because of triathletes' specific adaptation to both running and cycling, they cannot be directly compared to runners, cyclists, or other athletes who have been measured on different test instruments. In triathlon, there is generally no difference in the maximum rate of oxygen consumption (VO_2max; ml/kg/min) measured in cycle ergometry and treadmill running [9-11]. Finding out the differences in cardiopulmonary parameters among athletes of any sport, measured using different instruments, can be beneficial in several ways. We can compare the characteristics of each measuring device in terms of cardiovascular and respiratory load, and we can adjust the measurement protocol of a non-sport-specific device to meet the particular needs of a given sport. Different sport-specific devices are not available in every sports science laboratory: cycle ergometers and treadmills are the most popular devices used to test athletes' cardiovascular and respiratory capacity. Our pilot study aimed to determine whether the cardiopulmonary parameters of the sport-specific cycle ergometer vita maxima test differ from the non-sport-specific treadmill test among elite youth cyclists. We hypothesized that the VO_2max and metabolic parameters measured during vita maxima treadmill test would be significantly different from those measured in the cycle ergometer test.

VO_2max

The level of long-term endurance depends on how long an athlete can energize the functioning muscles; VO_2max is a good predictor of the level of endurance, and the most widely used parameter among endurance athletes. It is important to know the limiting factors of VO_2max in order to compile a training load to develop the highest possible level of endurance. The most important limiting factor of VO_2max is the oxygen delivering capacity of the cardiorespiratory system towards the functioning muscles; this capacity determines 70-85% of VO_2max [12]. New research has shown that the pulmonary system is another limiting factor of maximal oxygen uptake, under certain conditions: the pulmonary system as a limiting factor is mainly observed among elite athletes who are more likely to achieve a decrease in O_2 saturation during maximal exercise than untrained persons [13]. This may be due to the much higher stroke volume (40 vs 25 ml/min) of elite athletes, reducing the red blood cell transit time in lung cells, therefore providing less time to saturate the blood with O_2 [13]. Mitochondria in the muscle may also play a role in limiting endurance performance. An increase in the number of muscle mitochondria and the number of mitochondrial enzymes helps endurance performance by altering metabolism rather than increasing VO_2max [14]: this is achieved by higher levels of fat oxidation, and decreased lactate production (or increased lactate utilization) in functioning muscles. Although some research suggests that muscle mitochondrial growth slightly increases oxygen uptake from the blood, it may also contribute to an increase in VO_2max [15]. The value of VO_2max also depends on the amount of muscle mass used during exercise. In a comparative study among cross-country skiers, orienteers, and kayakers, VO_2max, blood values, and lactate levels were compared. The study demonstrated specific physiological adaptations to endurance training in sports with a predominance of the upper body, lower body, and whole-body exercise among elite athletes. A higher VO_2max value was found in cross-country skiers (whole-body) compared to orienteers (lower body), which may be linked either to the greater muscle mass and training values or the higher training intensity [5]. O_2 pulse, which is considered to be an indicator of stroke volume [16], was significantly higher in skiers. According to Wagner et al., there is not just one limiting factor for maximal oxygen uptake, each step in oxygen delivery and muscle metabolism can also affect the rate VO_2max [17,18].

VO_2atLT

Besides VO_2max, the level of endurance can be characterized by the highest speed and the corresponding percentage of VO_2max the athlete can maintain for a long time without a significant increase in blood lactate levels. The VO_2max value at which lactate shuttle occurs, i.e., the VO_2 associated with the lactate threshold, is the rate of oxygen consumption at lactate threshold (VO_2atLT; ml/kg/min) value. For training load planning in modern endurance training, VO_2atLT allows more precise load control than training at the intensity level or load of a given percentage of the VO_2max (VO_2max%). Athletes with the same VO_2max value, if trained in VO_2max%, may show a significant difference in speed and metabolic load, due to differences in VO_2atLT.

Fatmax

To measure substrate oxidation we use indirect calorimetry, which records the oxidation of fat and carbohydrates (protein) during exercise testing. The level of fat oxidation during exercise depends on the intensity and duration of work, the type of exercise, gender, and diet. During moderate intensity exercise, O_2 and CO_2 are derived from the oxidation of fats and carbohydrates (proteins). While VO_2 accurately reflects tissue O_2 metabolism, for CO_2 this finding is only true at stable bicarbonate levels. In case of high glycolytic activity, the hydrogen ions from glycolysis bind to the bicarbonate and eventually decompose to CO_2 and H_2O, thereby increasing the volume of exhaled CO_2 (VCO_2; ml/min). Thus, with increased anaerobic glycolysis, fat oxidation can be easily underestimated, which also affects the assessment of the intensity associated with the maximal fat oxidation (Fatmax; g/day) [19,20]. Achten et al., found among moderately trained cyclists and triathletes, that during an incremental cycle ergometer test, Fatmax (the highest rate of fat oxidation) was at an average intensity of 63% of VO_2max, although both Fatmax and fat oxidation showed large individual differences [21]. A significant relationship can be seen between maximal fat oxidation and the time lactate concentration increase below baseline. Similarly, reduction of fat oxidation (Fatmin) coincides with the intensity associated with the lactate threshold [22]. The work and studies of Brooks [23,24] have shown that lactate is not only produced in the absence of oxygen. Lactate has been thought of as a waste-product for many years, and blamed for, among other things, fatigue and muscle soreness. Most (75%+) of the lactate formed during sustained, steady-rate exercise is removed by oxidation during exercise, and only a minor fraction (approximately 20%) is converted to glucose. Of the lactate which appears in blood, most of this will be removed and combusted by oxidative (muscle) fibers in the active muscle bed and heart [24]. It has been shown that lactic acid production is increased by intense exercise in slow fiber muscles, and oxidized in fast ones.

Material and methods

8 elite youth cyclists (6 male, 2 female; age:17.125±1.8 years) fulfilled 2 vita maxima tests; a cycle ergometer test using a Drag Celera type road racing bike on a Tacx Smart Flux roller, and a treadmill test on a Woodway PPS 55 MED treadmill. Both tests were incremental vita maxima tests. Cardiorespiratory parameters were recorded with a Cardiosys plus CAR-02-IA (RHR) cardiovascular analysis system and a Jaeger Masterscreen CPX spirometer. The starting load of the cycle test was determined according to the Hungarian Heracles Talent Program protocol, which is categorized by the age of the test subjects (U15-60W; U17&U18-80W; U19&U23-100W). The starting load was increased by 20 watts every 3 minutes until exhaustion. The starting speed of the treadmill test was 8 km/h, increased by 1 km/h, and inclination by 3 degrees every 3 minutes. Blood lactate was measured with an EKF Lactate Scout at the beginning of the test and the end of every 3 minutes. Aerobic capacity (VO_2; ml/kg/min), maximum VO_2 and VCO_2 values (ml/min), breath frequency (BF; 1/min), ventilation (VE; BTPS l/min), and metabolic characteristics, respiratory exchange rate (RER; VCO_2/VO_2), energy consumption (EE; kcal/day), maximum fat oxidation (Fatmax; g/day), RER at Fatmax, maximum blood lactate (LT), load at lactate threshold (Load at LT; watt), and rel VO_2 at lactate threshold (VO_2atLT) and the rate of oxygen consumption at lactate threshold as a percentage of VO_2max (VO_2atLT%; %) were examined. All subjects were in a steady state of training and advised to make no dramatic alteration in their training programs throughout the duration of the experiment. Athletes performed the two tests 48 hours apart in the same laboratory, under the same conditions, and at the same time of the day. Before both tests, participants continued a diet usually used before competitions, and this did not differ between the tests. The results were evaluated by descriptive statistical methods: paired-sample t-test and Pearson's correlation analysis using Microsoft Excel and SPSS programs ($p<0.05$).

Results

We examined the maximum load, the relative VO_2max, VO_2, and VCO_2 values during both the incremental cycle ergometer and treadmill tests among elite youth cyclists. Differences in breath frequency (BF) and ventilation (VE) were also recorded. Athletes spent 34±5.73 minutes on the cycle ergometer, 13.5±2 minutes on the treadmill, with a maximum speed of 12 km/h and an incline of 12 degrees. The mean values of the cardiopulmonary parameters tested are shown in Table 1.

Table 1. Mean values of cardiopulmonary parameters during cycle and treadmill test

	Load (Watt)	VO_2max (ml/kg/min)	MaxHR (BPM)	VCO_2 (ml/min)	VO_2 (ml/min)	BF (1/min)	VE (L/min)
Cycle	292.5±47.73	55.9±7.36	195.37±11.21	3831.25±662.2	3378.875±519.33	56±8.88	135.625±33.5
Treadmill	338.125±57.06	61.35±6.35	193.75±6.77	4386.62±611.75	3765.625±508.6	55.25±4.8	132.625±27.1

Notes: Load – workload in Watts; VO_2max – maximum rate of oxygen consumption (ml/kg/min); MaxHr – maximal heart rate in beats per minute; VCO_2 – carbon dioxide production in ml/min; VO_2 – volume of utilized oxygen in ml/min; BF – breath frequency/minute; VE – ventilation (liter/minute).

Blood samples were taken from fingertip at the end of every 3 minutes to measure changes in blood lactate levels. The highest values of RER, Load, Fat oxidation, Energy measured by the Jaeger Masterscreen CPX spirometer system were recorded as max RER, Fatmax, Load, and energy expenditure (EE; g/day). RER at Fatmax and VO_2 at lactate threshold also were recorded. The mean values of the metabolic parameters tested are shown in Table 2.

Table 2. The mean values of metabolic parameters

	Lactate mmol/L	RER	Load at LT(watt)	EE kcal/day	Fatmax (g/day)	RER at Fatmax	VO_2atLT (ml/kg/min)	VO_2atLT (%)
Cycle	13.93±3.53	1.15±0.06	225.96±41.55	25900±3574.09	448±105.86	0.91±0.0	51.38±8.47	91±8.47
Treadmill	12.83±1.41	1.22±0.15	253.75±50.55	279452±3574.16	691±204.72	0.88±0.0	52.18±8.9	83.75±7.26

Notes: Lactate – blood lactate mmol/liter; RER – Respiratory Exchange Ratio (VCO_2/VO_2); Load at LT – load in watts at lactate threshold; EE – Energy Expenditure (kcal/day); Fatmax – the maximal amount of fat oxidation during the test (g/day); RER at Fatmax – the value of RER when fat oxidation peaks; VO_2atLT – rate of oxygen consumption at lactate threshold (ml/kg/min); VO_2atLT% – rate of oxygen consumption at lactate threshold in the percentage of VO_2max (%).

Based on the paired sample t-test, maximal load values on the treadmill (338.125±57.06 watts) were significantly higher ($t=3.52$; $p<0.05$) than load values of cycle test (292.5±47.73 watts). VO_2 and VCO_2 values also showed significant differences: higher values were found during running ($t=4.76$ and $t=3.45$; $p<0.05$). Fatmax ($t=4.34$; $p=<0.05$), VO_2max ($t=4.9$; $p<0.05$) and VO_2atLT (ml/kg/min) ($t=4.04$; $p<0.05$) were significantly higher during treadmill running, also. The energy requirement (EE) of performing the incremental vita maxima treadmill test was trending higher (non-significant difference), especially in terms of fat oxidation with significant higher VO_2max (ml/kg min) values. Lactate production (LT) and RER, VO_2atLT, max HR, BR, and VE showed no significant differences between the two tests. The results of the paired sample-t-test are shown in Table 3.

Table 3. Significant values of paired sample t-test

	Load (W)	VCO_2 ml/min	VO_2 ml/min	Fatmax g/day	VO_2max ml/kg/min	VO_2atLT ml/kg/min
t value	3.519	4.769	-3.453	-3.348	4.903	4.049
p	0.009	0.002	0.010	0.012	0.001	0.004

Notes: Load – workload in Watts; VCO_2 – carbon dioxide production in ml/min; VO_2 – volume of utilized oxygen in ml/min; Fatmax – the maximal amount of fat oxidation during the test (g/day); VO_2max – maximum rate of oxygen consumption (ml/kg/min); VO_2atLT – rate of oxygen consumption at lactate threshold (ml/kg/min).

Based on Pearson's correlation analysis, VO_2atLT is significantly correlated with VO_2 (ml/min), VE, EE, and Load at LT; the latter is correlated with Fatmax.

Wilcoxon signed-rank test showed Load (Watts), VCO_2 (ml/min), VO_2 (ml/min), Fatmax (g/day), VO_2max (ml/kg/min) and VO_2atLT cycle test values were lower than the running test results; all these differences were significant, except VO_2atLT.

Table 4. Wilcoxon signed-rank test results based on negative ranks

	Load (W)	**VCO_2 ml/min**	**VO_2 ml/min**	**Fatmax g/day**	**VO_2max ml/kg/min**	**VO_2 atLT ml/kg/min**
z value	-2.380¨	-2.524¨	-2.521¨	-2.240¨	-2.521¨	-700¨
p	0.017	0.012	0.012	0.025	0.012	0.484

Notes: Load – workload in Watts; VCO_2 – carbon dioxide production in ml/min; VO_2 – volume of utilized oxygen in ml/min; Fatmax – the maximal amount of fat oxidation during the test (g/day); VO_2max – maximum rate of oxygen consumption (ml/kg/min); VO_2atLT – rate of oxygen consumption at lactate threshold (ml/kg/min).

Discussion

The results of our study on VO_2max are consistent with data found by other researchers. In a review article Shepard et al., based on 20 articles, found that the treadmill ergometer test shows 9% higher cardiopulmonar values than the cycle ergometer test [25]. Absolute VO_2peak (ml/min) was 9.7%, and relative VO_2 peak (ml/kg/min) 12.9% higher during the treadmill test. Moreover, moderate to high correlation was found between treadmill and cycle tests. They found significantly higher RER values ($p<0.05$) in the cycle ergometer tests, which differs from our results. Higher RER values during cycling were previously observed by Boileau et al. [26] in 1977; they attributed the significant difference in RER to the higher anaerobic involvement of cycling. Miles et al. [27] also found similar results in maximal and submaximal treadmill and cycle tests among adult women. In our study, the RER was 6% higher in running, while lactate level was higher in cycling (neither of these differences were significant). However, the significant difference in Fatmax in our study in the treadmill test could be explained by the higher aerobic metabolism associated with running. The cause of lower RER values measured in the cycle test may be due to sport-specific adaptation to cycling. R.T. Withers and colleagues [2] examined the specific adaptation of cyclists and runners to sport-specific training; they found that cyclists achieved higher VO_2max (mi/min) values on the cycle ergometer than on the treadmill, but the difference was not significant. In contrast, runners' treadmill test VO_2 (ml/min) values were significantly higher than on cycle ergometer. LT, expressed in l/kg, was significantly higher among cyclists in the cycle test than runners, and VO_2atLT of runners was significantly higher on the treadmill than cyclists. From these data, it was concluded that training results in specific adaptation to the movement patterns performed during sport-specific training. Billat and colleagues compared kayakers, swimmers, and cyclists on sport-specific ergometers: each athlete performed the test on a device appropriate for their sport. They examined fatigue time at the speed of vVO_2max (the minimum speed, at which the maximal oxygen uptake is reached) and VO_2max in each sport. vVO_2max showed no significant difference between sports (except kayaking and cycling), whilst relative VO_2max was not significantly different between cycling and running, however, VO_2 expressed in ml/min was significantly different across all sports (except kayaking and swimming) [3]. The results show that cardiopulmonary values measured in sport-specific devices differ less between sports among well-trained endurance athletes. Loftin et al. compared the results of cycle ergometer and treadmill VO_2 values among slightly obese young people. In their research, they compared VO_2, Ventilation (VE), VCO_2, and HR values. The relative VO_2 peak was 7.0%, and the absolute VO_2 was 5.6% higher for the treadmill test [28]; they concluded that VO_2max is specific to the exercise modality. Besides, the muscles adapt specifically to a given exercise task over a period resulting an improvement in cardiovascular parameters such as a ventilatory threshold, sometimes without a change in VO_2max [29]. The mechanism which causes these differences in AT and VO_2max are not yet fully understood; there may be a relative adaptation of cardiac output, which affects VO_2max, recruitment of muscle mass, and the oxidative capacity of muscle mass. Carlsson M et al. found that pedaling cadence also affects the metabolic responses during cycling and running [30,31]. The mean delta efficiency during running (42%) was found to be significantly greater than that during cycling (25%). The contribution of concentric and eccentric muscle actions, in combination with the fact that eccentric muscle actions require much less metabolic energy than concentric contractions, may explain the difference between the running and cycling delta efficiency. Cycling includes only concentric contractions, but during running, eccentric muscle actions play an important role. Especially at steeper inclines (like those in our protocol, where athletes reached 12 degrees incline at 12 km/h speed), more concentric contractions must be produced to overcome the external force, whereas eccentric muscle action decreases. Comparing the vita maxima cycling and treadmill test among youth cyclists we can conclude that cardiopulmonary values may differ due to both sport-specific adaptation (both at cardiopulmonary and muscular level) and the different muscles contraction composition (concentric and eccentric). Incremental vita maxima treadmill running requires significantly higher VO_2max (ml/kg/min), load (watts), VO_2, VCO_2, (ml/kg), and higher VO_2atLT among youth elite cyclists than the incremental cycle test. These findings must be considered when testing cyclists on a treadmill, and planning their training loads based on these results.

Conclusions

Comparing the results of vita maxima incremental cycle and treadmill test, we can see significant differences in VO_2, VCO_2, Fatmax, VO_2max, and VO_2atLT using the paired sample t-test. Pearson's correlation study showed significant correlation between VO_2atLT and most other parameters (VO_2, VE, Load at LT, EE). Based on these results we can state that vita maxima treadmill running test requires a higher power output, has higher energy requirement, higher fat oxidation rates, and higher VO_2max values. When young elite cyclists are tested on a treadmill ergometer, its higher oxygen demand (higher VO_2max results) should be considered based on the above findings. The VO_2atLT% shows significantly higher values during the running test, thus training load can be overestimated when based on this parameter. A significantly higher Fatmax during treadmill test suggests greater aerobic metabolism, in line with running. Considering these findings further research is needed to develop a treadmill protocol that is closer to the sport-specific metabolism and cardiopulmonary characteristics of cycling.

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