Reference Values for Cardiopulmonary Exercise Testing in Young Male Slovak Athletes

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ABSTRACT

Background: The reference values of young athletes for cardiopulmonary exercise testing are lacking. Expert opinions encourage production of local values specific for certain population.

Patients and methods: The study population consisted of 136 healthy male caucasian athletic children and adolescents coming from one specific football school in northern Slovakia. Exercise testing with continuous electrocardiography was performed, and ventilatory parameters, oxygen uptake (VO_2), and carbon dioxide (CO_2) production were measured continuously with a respiratory gas analysis system.

Results: Peak VO_2max/kg was changing very little across the childhood, whereas the peak work rate, heart rate and O_2Pulse were. Linear regression analysis showed a significant effect of age on VE/VCO_2.

Conclusion: This work provides a reference values for the most important cardiopulmonary variables that can be obtained during cardiopulmonary exercise testing in athletic children.

KEYWORDS

cardiopulmonary exercise testing; reference values; athletic children

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INTRODUCTION

Stress tests are among the most popular non-invasive diagnostic methods in cardiological evaluation and evaluation of functional capacity of the organism. In the paediatric population, cardiopulmonary exercise testing (CPET) is considered valid but neglected diagnostic tool whose indications and location in the clinical setting are still pending for proper application (14). Adding the function of evaluation of expired air to regular stress test we get a direct insight into the functioning of oxygen transport from air to mitochondria and also into its metabolism in the body directly under stress. The way and rate of response of the organism to increasing bout of exercise can be applied in clinical practice not only to evaluate the functional parameters of athletes but also to correctly interpret the risk stratification in patients with congenital or acquired heart, lung, muscle or metabolic diseases (12). Growing amount of information about this examination and its relevance to clinical practice could become a starting point for its more frequent application in paediatric practice.

Regular pre-participation examinations in athletes should consist of physical examination and 12 lead ECG. Preparticipation screenings are meant to prevent sudden cardiac deaths (3). Athletes (in paediatrics their parents) very often ask for more thorough examination in order to gain more information about the state of their health. CPET is ideal tool to evaluate whole body state of health as it is golden standard among examinations documenting aerobic fitness of an individual.

Cardiopulmonary exercise testing differs in many aspects from the tests performed in adults (2). Results gained by CPET are dependent on the will to perform and on motivation of examined patient. To be able to evaluate one's health and level of functional capacity certain level of exhaustion must be achieved. Young athletes are much more often highly motivated, and performance results gained from their examinations are above any reference values for populations of non-athletes. On the other hand, their other than performance results are very similar to healthy non-athletes. As the physiological responses to exercise change during growth and development, appropriate paediatric reference values are essential for an adequate interpretation of the cardiopulmonary exercise test (14). Some parameters yielded from CPET in athletes of young age are incomprehensible due to lack of reference values and clinical implications. Reference values for CPET parameters may change over time and should be regularly updated or validated (14). Considering prognostic value of CPET in many diseases we can anticipate same use of this tool in training process of young athletes. Data provided by CPET might be of high value in screening for unknown underlying disease that might be aggravated by strenuous exercise.

Normal values for CPET are already published and represent a set of normal values for specific population coming from specific region with different anthropometric and cultural characteristics (16). For an adequate interpretation of CPET, the normal range of variety of CPET parameters is essential. In many studies, however, only mean or median value for the population is provided. Expert review (14) recommends reporting lower and upper limit of normal. The use of 80% of predicted as lower limit of normal should be abandoned. Instead, a Z-score should be used with a lower and upper limit of normal of −1.96 SD and +1.96 SD, respectively (14).

METHODS

The study population consisted of 136 healthy male Caucasian athletic children and adolescents coming from one specific football school in northern Slovakia (Table 1). They were recruited as healthy male athletic population of children and adolescents. Athletes were examined prospectively in the period between July 2018 and December 2019. We excluded all children with a history of acute illness within 3 weeks, history of chronic disease or smoking. Every athlete underwent spirometry (Geratherm Respiratory GmbH, Germany), 12 lead ECG (BTL Cardiopoint, Czech Republic) and orthostatic blood pressure test (Omron M3, Japan) and only those with physiological findings were included. All of the athletes were highly active individuals with professional coaching, exercising for more than two hours more than 3 times a week. All children came to the hospital by car, or they came by bike or walking if their residence was within 10 min away from the hospital. Patients were informed to consume light meal at latest 1 hour before testing and to come properly hydrated.

Tab. 1

Age group	8–10	11–14	15–19
Age	9.7 ± 1.5	12.5 ± 2	16.3 ± 2.3
Height	140.9 ± 11.3	155.0 ± 18.9	178.0 ± 13.3
Weight	31.0 ± 8.3	41.0 ± 17.8	67.0 ± 13.2
BMI	16.2 ± 2.4	17.4 ± 3.6	20.8 ± 3.3
BSA	1.1 ± 0.2	1.4 ± 0.4	1.8 ± 0.2
n	46	48	42

CPET was performed in upright position using treadmill (ITAM ERT-100, Poland) with breath-by-breath respiratory gas analysis (Geratherm Respiratory GmbH, Germany). Subjects breathed through a face mask of appropriate size and through a low impedance turbine volume transducer for measurement of expiratory volume and expiratory gas concentrations. CPET results were interval averaged (every 30 s), reported peak value represents mean value of all data collected during the final stage (if longer at least 30 s). CPET was performed with the personalized incremental ramp protocol to maximal exhaustion which was achieved between the 8th and 12th minute of exercise (6). The blood pressure was measured every three minutes until peak exercise and then every 2 minutes until full recovery. All participants were verbally encouraged to exercise to exhaustion. Cut-off values for maximal exertion were established as RER greater than 1.10, breathing rate more than 40/min and/or plateau in oxygen consumption. Before testing all equipment was calibrated according to the instructions of the manufacturer.

Resting HR was measured after at least 3 min in supine position before exercise testing and was calculated as number or RR intervals on ECG over 1 minute. Heart rate was measured by continuous 12-lead ECG during resting, warm up, peak exercise and recovery phase. Peak HR (HRpeak) was defined as the highest HR achieved during exercise. HR was recorded at 1. and 2. min after cessation of the exercise, and HR recovery (HRR1, HRR2) was calculated as the difference between HRpeak and the HR in first and second minute. VO_2max is defined as plateau in oxygen consumption with increase less than 2 ml/kg/min with increase of 10% work rate (6). VO_2peak is then defined as the highest achieved VO_2 in settings of not achieving VO_2max and is calculated as the mean of two highest consecutive values of 15-s averages of VO_2 (2). The VE/VCO_2 slope was obtained by linear regression analysis of whole measured dataset of exercise data before achieving respiratory compensation point. Peak work rate (WRpeak) was measured in absolute values and as weight adjusted value. The point of initiation of anaerobic metabolism (anaerobic threshold AT, ventilatory anaerobic threshold VAT) is defined as nonlinear elevation in production of CO_2 to consumption of O_2. VO_2 vs WR ($\Delta VO_2/\Delta WR$) was measured as the slope obtained by linear regression analysis of VO_2 (mL/min) versus WR (W). For ventilatory parameters we obtained minute ventilation, tidal volume, breathing frequency and breathing reserve (BR) at AT and peak exercise.

STATISTICS

Statistical analysis was performed with SPSS 26.0 (SPSS, Inc., Chicago, Illinois, USA). Values are presented as mean values and mean values ± 1.96 standard deviation. The effect of age on the measured parameters was determined by linear regression analysis.

RESULTS

We examined 136 boys with an age range 8–18. Subject characteristics are shown in Table 1. In order to obtain clear data capable of direct use we divided study group into subgroups according to age. Results are presented as mean value and lower and upper limit using 1.96 SD (standard deviation). We provide data that has been measured resting on treadmill, at AT and peak exercise. All participants performed CPET without complications and were able to adhere to chosen protocol. Table 2 presents CPET data and Table 3 presents regression equations for chosen parameters. There were no noted ECG abnormalities during exercise testing. According to our findings resting heart rate (71/min vs. 65/min vs. 61/min) and peak heart rate (190/min vs. 188/min vs. 180/min) declined with age in highly active children. (Figure 3) On the other hand, resting O_2Pulse (2.22 ml/beat vs. 2.68 ml/beat vs. 3.99 ml/beat) and peak O_2Pulse (8.27 ml/beat vs. 11.62 ml/beat vs. 19.41 ml/beat) raised with age. Resting breathing rate remained unchanged during whole childhood (19/min vs. 19/min vs. 18/min) whereas resting tidal volume and minute ventilation raised. VO_2max raised with age (48.29 ml/min/kg vs. 51 ml/min/kg vs. 52.81 ml/min/kg). VO_2/WR remained unchanged with age (10.28 ml/min/W vs. 10.20 ml/min/W vs. 10.32 ml/min/W). VE/VCO_2 as a marker of ventilatory effectivity declined with age (31.0 vs. 28.8 vs. 26.6). VO_2 and %VO_2 of VO_2max in AT remained stable across the childhood. WRpeak/kg (as hallmark of exercise tolerance) were growing steadily with age (4.15 W/kg vs. 4.50 W/kg vs. 4.87 W/kg) (Figure 1).

Tab. 2

Age group	8–10	11–14	15–18
Number of patients	n = 46	n = 48	n = 42
HR rest	71	65	61
±1.96 SD	(50–92)	(45–85)	(43–79)
O_2Pulse rest	2.22	2.68	3.99
±1.96 SD	(0.65–3.78)	(0.94–4.41)	(1.68–6.30)
VE rest	7.09	8.50	11.00
±1.96 SD	(1.65–12.52)	(3.63–13.37)	(3.61–18.39)
BF rest	19	19	18
±1.96 SD	(11–27)	(11–28)	(9 -27)
Vt rest	0.39	0.44	0.67
±1.96 SD	(0.08–0.70)	(0.16–0.72)	(0.11–1.23)
WR peak	134.9	193.9	320.6
±1.96 SD	(89.8–180)	(103.1–284.8)	(239–402.3)
WR peak/kg	4.15	4.50	4.87
±1.96 SD	(3.45–4.84)	(3.76–5.23)	(4.33–5.41)
VO_2max (abs.)	1.55	2.18	3.48
±1.96 SD	(0.90–2.21)	(1.18–3.19)	(2.43–4.53)
VO_2max/kg	48.29	51.00	52.81
±1.96 SD	(32.31–64.27)	(38.37–63.62)	(42.21–63.41)
RER	1.15	1.17	1.16
±1.96 SD	(0.98–1.33)	(0.96–1.37)	(0.97–1.35)
$\Delta VO_2/\Delta WR$	10.28	10.20	10.32
±1.96 SD	(6.76–13.80)	(7.25–13.15)	(7.66–12.98)
VE peak	61.6	81.6	122.5
±1.96 SD	(33.0–90.2)	(35.8–127.3)	(72.0–173.0)
BF peak	58	54	52
±1.96 SD	(41–76)	(42–66)	(34–70)
Vt peak	1.06	1.51	2.37
±1.96 SD	(0.55–1.56)	(0.72–2.31)	(1.48–3.27)
BR peak	19.65	22.63	25.93
±1.96 SD	(0–45.97)	(0–48.87)	(0–54.43)
HR peak	190	188	180
±1.96 SD	(166–213)	(169–206)	(156–204)
HRR1	39	31	21
±1.96 SD	(4–84)	(1 – 60)	(6 – 49)
HRR2	66	62	47
±1.96 SD	(37–85)	(27 – 98)	(15 – 79)
O_2Pulse peak	8.27	11.62	19.41
±1.96 SD	(5.18–11.37)	(6.02–17.22)	(13.37–25.45)

Age group	8–10	11–14	15–18
Sys BP peak	134	137	156
±1.96 SD	(107–161)	(104–170)	(127–185)
Dia BP peak	71	75	74
±1.96 SD	(53–89)	(56–93)	(56–92)
VE/VCO_2 slope	31.0	28.8	26.6
±1.96 SD	(24.9–37.0)	(23.5–34.1)	(22.3–30.9)
PET CO_2 peak	34	36	40
±1.96 SD	(29–39)	(30–41)	(33–46)
Vd/Vt peak	14.2	14.9	12.0
±1.96 SD	(7.5–20.9)	(10.6–19.1)	(7.1–16.8)
VO_2 at AT abs.	0.94	1.34	2.05
±1.96 SD	(0.40–1.47)	(0.58–2.11)	(1.20–2.90)
VO_2 at AT /kg	29.07	31.33	31.13
±1.96 SD	(13.06–44.07)	(17.24–45.42)	(20.84–42.42)
%VO_2 at AT	61	62	59
±1.96 SD	(35–62)	(37–88)	(39–79)
RER at AT	0.86	0.87	0.82
±1.96 SD	(0.68–1.04)	(0.72–1.01)	(0.65–0.99)
HR at AT	145	144	136
±1.96 SD	(109–182)	(105–183)	(106–165)
O_2Pulse at AT	6.49	9.34	15.18
±1.96 SD	(3.18–9.81)	(4.56–14.11)	(9.68–20.68)
VE at AT	26.5	36.4	48.4
±1.96 SD	(9.2–43.9)	(12.3–60.5)	(24.3–72.5)
BF at AT	38	34	30
±1.96 SD	(20–57)	(21–47)	(15–45)
BR at AT	64	66	70
±1.96 SD	(40–89)	(45–87)	(54–86)
VE/VCO_2 at AT	27.1	27.7	26.3
±1.96 SD	(22.5–31.7)	(23.4–31.9)	(22.3–30.2)
WR at AT	69.4	102.8	181.3
±1.96 SD	(28.6–110.2)	(31.9–173.6)	(91.9–270.7)
Vd/Vt at AT	10.09	13.14	12.32
±1.96 SD	(0.08–20.11)	(5.03–21.26)	(5.24–19.40)

HR rest, resting heart rate (beats/min); O_2Pulse rest (ml/beat); VE rest, resting minute ventilation (l/min); BF rest, breathing rate (1/min); Vt rest, resting tidal volume (l); WR peak, peak work rate (W); WR peak/kg, peak work rate per kg (W/kg); VO_2max abs., absolute maximal oxygen uptake (l/min); VO_2max/kg, oxygen uptake per kg (ml/min/kg); RER, respiratory exchange ratio (1); $\Delta VO_2/\Delta WR$, slope of work rate (W) to oxygen uptake (ml/min); VE peak, peak minute ventilation (l); BF peak, peak breathing rate (1); Vt peak, peak tidal volume (l); BR peak, peak breathing reserve (%); HR peak, peak heart rate (1/min); HRR1 – hear rate recovery in 1 minute (1/min); HRR2 – heart rate recovery in 2 minute (1/min); O2Pulse peak (ml/beat); Sys BP peak, peak systolic pressure (mmHg); Dia BP peak, peak diastolic pressure (mmHg); VE/VCO_2 slope, slope of respiratory minute ventilation to CO_2 production; PET CO_2 peak (mmHg); Vd/Vt peak, peak dead space ventilation (%); VO_2 at AT abs., absolute oxygen uptake at anaerobic threshold (l/min); VO_2 at AT/kg, oxygen uptake at anaerobic threshold per kg (ml/min/kg); %VO_2 at AT, percentage of maximal oxygen uptake in anaerobic threshold (%); RER at AT, respiratory exchange ratio at anaerobic threshold; HR at AT (1), heart rate at anaerobic threshold (1/min), O_2Pulse at AT (ml/beat); VE at AT, minute ventilation at anaerobic threshold (l/min); BF at AT, breathing rate at anaerobic threshold (1/min); BR at AT, breathing reserve at anaerobic threshold (%); VE/VCO_2 at at, slope of respiratory minute ventilation to CO_2 production; WR at AT, work rate at anaerobic threshold (W); Vd/Vt at AT, dead space ventilation at anaerobic threshold (%).

Tab. 3

Parameter	Regression equation
WRpeak	y = 0.1024 × (age) + 3.1829
VE/VCO_2	y = −0.6604 × (age) + 37.27
HR rest	y = −1.4176 × (age) + 204.11
HR peak	y = −1.5485 × (age) + 85.57
O_2Pulse	y = 1.5403 × (age) – 6.9403
VO_2max/kg	y = 0.596 × (age) + 43.009

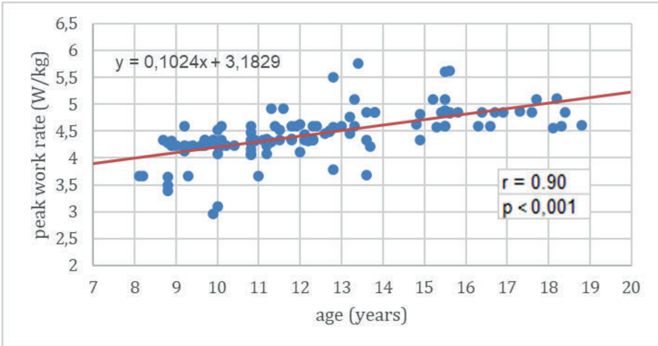

Fig. 1 The relation between age and the maximal work rate. The trendline represents linear regression of all data.

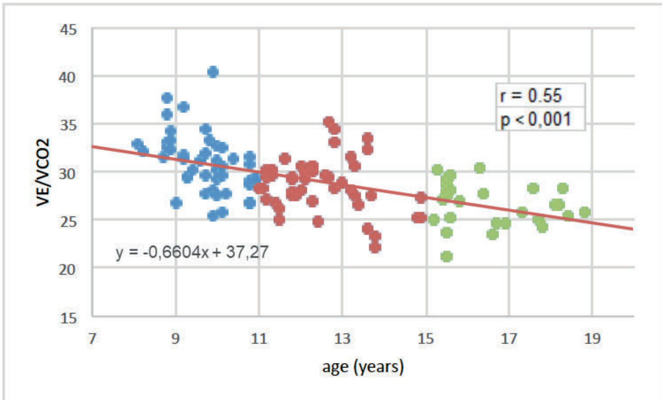

Fig. 2 The relation between age and the ventilation to carbon dioxide exhalation (VE/VCO_2) slope. The trendline represents linear regression of all data.

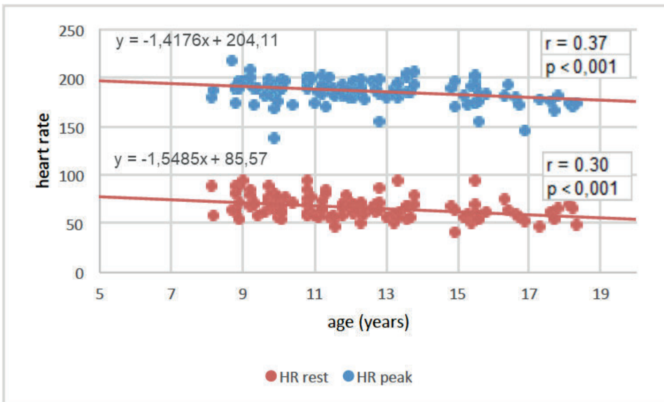

Fig. 3 The relation between age and resting heart rate (HR rest). The trendline represents linear regression of all data. The relation between age and peak heart rate (HR peak). The trendline represents linear regression of all data.

DISCUSSION

The primary aim of this study was to provide reference values for cardiopulmonary exercise testing in the cohort of healthy athletic children between 8 and 18 years of age. Data yielded are presented in Table 2. Upper and lower limit for age dependent variables are given for all 3 age groups which makes it possible to use these values as reference data.

VE/VCO_2 slope was decreasing steadily with age (Figure 2). Decrease in VE/VCO_2 slope with advancing age has been explained by a slightly lower pressure of CO_2 set point during exercise in the younger children and higher breathing efficiency in older children (larger tidal volumes and a relatively lower breathing frequency) (9, 16).

VO_2/WR remains unchanged with age. Calculation of the steepness of this slope is a valid measurement of O_2 flow or utilization in the exercising tissues (5). Our findings correlate with Harkel et al. (15). but our value was approximately 10.2 ml O_2/min per W in contrast of theirs 9.5 ml O_2/min per W in cohort very similar in account of age distribution. On the other hand, in our cohort we examined athletes where athlete's body adaptation might lead to processes which higher muscle efficiency in O_2 utilisation. Lower values are present in patients with impaired O_2 delivery to the exercising muscles such as patients with cardiac defects or malnourished patients.

During a progressive exercise test, the anaerobic threshold occurs when aerobic metabolism is insufficient to meet energy requirements. The AT indicates the highest oxygen uptake that can be sustained during exercise without developing lactic acidosis. The ability to sustain a high fractional utilization of athlete's maximal oxygen uptake (%VO_2max) in AT is considered crucial in order to maximize exercise effect. Anaerobic threshold is highly correlated to the distance running performance as compared to maximum aerobic capacity or VO_2max, because sustaining a high fractional utilization of the VO_2max for a long time delays the metabolic acidosis (4). It is not affected by patient effort or motivation and may be determined on a submaximal exercise test (2). VO_2 at AT is useful submaximal parameter in children. It is a good indicator of exercise capacity in children who are unable to perform to maximal exhaustion (12). The VO_2 at AT is a highly reproducible measure that provides insight into aerobic exercise capacity of children (13). Published data on normal values of VO_2 at AT are abundant but ranging from 45% to 75% of VO_2max (10, 18). Most recent study by Harkel et al. (16). reported 66% of VO_2max in children of age 8 and 9 and 60% of VO_2max in older children which is consistent with our findings (59–62%).

Peak VO_2 (VO_2max) kept rising throughout childhood with only very small inclination (Figure 5). Aerobic fitness is one of the most important components of physical fitness (15). The measurement of maximal VO_2max or VO_2peak during a progressive cardiopulmonary exercise test up to maximal exertion is widely considered the gold standard for assessing aerobic fitness (1). Comparing reference values for age in boys (16). with young athletes, boys of same age that are not athletes have lower VO_2max than athletes of same age. This states as a proof that regular exercise lead to increase in one's aerobic fitness even in children.

The maximum or peak HR achieved declined with age in all studies. Although in paediatric patients peak HR seems to remain constant throughout the paediatric years (11). We observed slight decline in peak HR in adolescents which is explainable with regular exercise that leads to athletic HR adaptation (Figure 3).

O_2Pulse (VO_2/HR) can be used as an indirect indicator of cardiac stroke volume (17). A plateau in the O_2Pulse at a low value implies limited cardiac output, either because of heart disease or disorders of the pulmonary circulation (7). The measurement of O_2Pulse during exercise can provide insight into the change in stroke volume during progressive exercise by assessing pattern of O_2Pulse changes in exercise and by estimating the value at peak exercise. (13). Recent study showed good correlation between O_2Pulse and stroke volume in adult patients undergoing CPET (8). In our cohort O_2Pulse was rising during examination from rest, throughout whole exercise until it reached plateau and was rising with age (Figure 4).

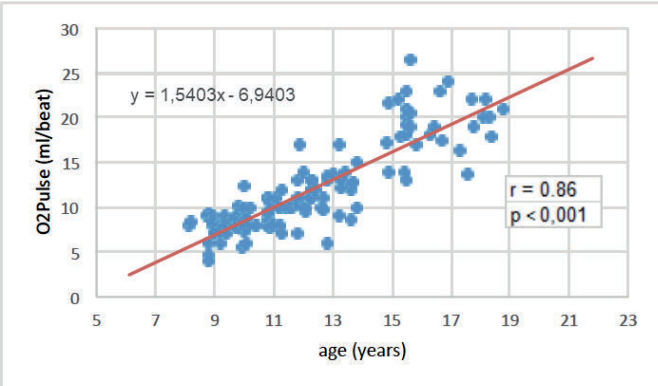

Fig. 4 The relation between age and peak O_2Pulse. The trendline represents linear regression of all data.

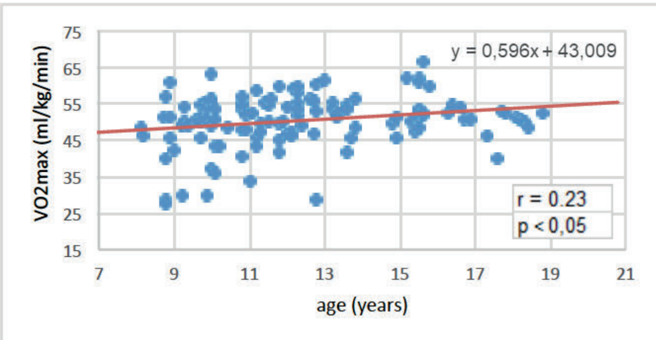

Fig. 5 The relation between age and VO_2max. The trendline represents linear regression of all data.

LIMITATIONS

Our dataset presents only male athletes reference values and is set to specific population of athletes competing in single sport. Reference values might be suitable for other types of athletes (as we found changes in CPET parameters that are expected in highly active individuals) but confirmation from specific population locally is missing.

CONCLUSION

This work comprehensively provides a reference set of data for the most important cardiopulmonary variables that can be obtained during exercise testing in young athletes in Slovakia. Our work was set in specific population as these reference values are lacking. We found that many obtained other than performance parameters are not altered by regular exercise as they are showing physiological functions of body systems and are comparable with healthy inactive children. Performance results (VO_2max, WRpeak) were growing with age and were higher than in children of same age that are not athletes.

CONFLICT OF INTEREST

No conflict of interest to declare.

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