Paediatr Croat. 2015;59:195-202
IZVORNI ZNANSTVENI RAD / *ORIGINAL SCIENTIFIC PAPER*
www.paedcro.com
http://dx.doi.org/10.13112/PC.2015.29

Reference values for cardiopulmonary exercise testing in children and adolescents in northwest Croatia

Daniel Dilber[1], Ivan Malčić[1], Tomislav Ćaleta[2], Ana Zovko[3]

The already published reference values for cardiopulmonary exercise test (CPET) might not be representative for our population. Our aim is to create reference values for CPET in children and adolescents in northwest Croatia. Exercise testing according to modified Bruce treadmill protocol was performed in 164 healthy children aged 11-17 years. Results are presented as mean and standard deviation. Mann-Whitney test was used for continuous variables without normal distribution. Boys reached significantly higher peak oxygen consumption (VO2) at anaerobic threshold (AT) with mean 37.13±8.9 mL/kg/min compared with 31.95±6.6 mL/kg/min in girls. The same finding was recorded for VO2 at peak exercise (peak VO2) where boys reached significantly higher peak VO2 of 51.3±8.9 as compared with 41.49±6.51 mL/kg/min in girls. During incremental work, systolic pressure increased from mean 109.86±14.2 mm Hg to 145.43±11.9 mm Hg, with no significant difference between girls and boys. During incremental work, together with linear increase in heart rate and systolic pressure, oxygen pulse that represents cardiac output, showed linear increase with significantly higher values in boys. Compared with girls, boys had significantly higher tidal volume at rest and reached significantly higher peak minute ventilation. This study has comprehensively provided a reference set of data for the most important cardiopulmonary variables in a population of healthy children and adolescents in northwest Croatia. Our findings showed strong correlation with previous reports and gave a basis for further research.

Keywords: exercise test; child; adolescent; reference values

INTRODUCTION

Physical exercise requires interaction of physiological control mechanism to enable the cardiovascular and ventilatory systems to couple their behaviors to support their common function, i.e. meeting the increased respiratory demands (oxygen consumption) and carbon dioxide (CO_2) production of the contracting muscles. Therefore, by studying external respiration and cardiovascular response during exercise, it is possible to address functional competence of the body coupling external to cellular respiration. Cardiopulmonary exercise testing (CPET) is a novel method that offers a unique opportunity to study the cellular, cardiovascular and ventilatory system responses simultaneously under precise conditions of metabolic stress (1).

Cardiopulmonary exercise testing in pediatric cardiology differs in many aspects from the tests performed in adult cardiology. Children's cardiovascular responses during exercise testing present different characteristics, particularly oxygen uptake, lower arterial partial pressure of carbon dioxide (PaCO2) set-point during exercise, resulting in greater ventilatory efficiency (the relationship of the liters of ventilation required to eliminate a liter of CO2) VE/VCO2 in younger population, heart rate and blood pressure response, which are essential in interpreting respiratory and hemody-

[1] Department of Pediatrics, Division of Cardiology, Zagreb University Hospital Center, School of Medicine, University of Zagreb
[2] Zagreb University Hospital Center
[3] Cardiology Department, Dubrava University Hospital, Zagreb, Croatia

Correspondence to:
Asst. Prof. Daniel Dilber, MD; Department of Pediatrics;
Division of Cardiology; Zagreb University Hospital Center; Kišpatićeva 12;
HR-10000 Zagreb, Croatia; e-mail: dilber_daniel@yahoo.com

Primljeno/Received: 15. 8. 2015., Prihvaćeno/Accepted: 11. 11. 2015.

namic data (1-8). Diseases that are associated with myocardial ischemia are rare in children (8). The main indications for CPET in children are already established (8, 9). Cardiopulmonary exercise testing has a unique role in cardiopulmonary capacity in young athletes with physiological changes of the heart and differentiation from pathological changes and risk of sudden death (10) has an important role in recognition of exercise induced arterial hypertension and exercise induced asthma (11). CPET in children with congenital heart disease (CHD) has several indications. The first is to assess physical capacity or aerobic capacity of a child with CHD. This can be used to provide recommendations for physical activity in sports, occupation, or rehabilitation. The second indication for exercise testing in CHD is to provide indications for surgery or medications, or additional more invasive/demanding tests. Moreover, the stress of the CPET can be used to evaluate the success of interventions such as pacemaker implantation, closure of shunt (normalizing in exercise SaO2%), or ablation of arrhythmogenic substrates. In addition, CPET can be used to diagnose inherited arrhythmia syndromes (e.g., LQTS and CPVT) or chronotropic incompetence. The third indication for CPET is to evaluate the adequacy of medication, for instance, β-blockers, angiotensin-converting enzyme inhibitors and digoxin in heart failure. The fourth indication is to assess the risk of future disease complications, for instance, complex premature ventricular contractions (PVCs) during exercise in hypertrophic cardiomyopathy, arrhythmias and risk of sudden death late after tetralogy of Fallot repair (12), to assess ability to increase oxygen delivery and CO2 elimination in patients with half of the heart, where there is no ventricle that is pumping blood in the lung and all pulmonary inflow depends on total cavopulmonary connection and pulmonary resistance (13). An additional indication for CPET is to inspire confidence in children and parents, to teach children and parents about preventive effects of sports in life in healthy children or in a population of children with CHD, where parents are often overprotecting their children, even though the underlying disorder is only mild and might not be restrictive for performing physical activities including competitive sports (9, 13-17)

The parameters that are measured during CPET include simple measures such as peak work rate (WRpeak) and heart rate (HR) response to exercise, peak oxygen uptake (VO2peak), and more recently proposed measures as the ventilation to carbon dioxide exhalation (VE/VCO2) slope. Additional ventilatory control parameters during exercise in children are minute ventilation (VE), assessment of anaerobic threshold (AT), respiratory compensation point (RCP), oxygen uptake (VO2), carbon dioxide output (VCO2), ventilatory equivalents for carbon dioxide and oxygen (VE/VCO2, VE/VCO2), oxygen pulse (VO2/HR), physiological dead space-tidal volume ratio (VD/VT), end-tidal pCO2 (PETCO2), end-tidal pO2 (PETO2), gas exchange ratio (R), the increase in oxygen uptake in response to a simultaneous increase in work rate (ΔVO2/ΔWR), breathing reserve (BR), and heart rate reserve (HRR) (1). 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 (2-6). On the other hand, each laboratory should have its own reference set of values. Moreover, published reference values might not be representative for today's children (2-6). To obtain reference data for exercise testing in healthy children and adolescents in Croatia, we investigated CPET results of 164 Croatian school children coming from the northwest part of Croatia, with an age range of 11-17 years. This is the first report on CPET in healthy children in Croatia and a rare report providing mean values of all CPET parameters in children in one place.

Since children have relatively undeveloped knee extensors, treadmill testing is preferred over cycle ergometry in young children (8). An often used protocol is the Bruce treadmill protocol, which was originally designed for adults (18), but is now also applied worldwide in children from the age of 4 years (19, 20).

METHODS

The study population consisted of 164 healthy children and adolescents coming from northwest Croatia, mainly from the capital of Zagreb and its surroundings. They were recruited from a pediatric cardiac outpatient clinic, where they presented for heart murmur or rare supraventricular or ventricular monotopic, uniform exstrasystoles and normal 24-hour electrocardiogram (ECG) in the period between July 2013 and July 2014. All children were examined in the pediatric cardiology outpatient clinic, only those with normal ECG and normal echocardiography were included. We excluded all children with a history of acute illness within 2 weeks, or a history of chronic disease. Before CPET, all children performed spirometry testing according to guidelines (21) and only those with normal findings were included. Body height and weight were measured before testing. We excluded all those with body mass index (BMI) of more than 95 percent or less than 5 percent. All parents signed an informed consent after explanation of the type of investigation and purpose of the study. Sports activities were performed only at a recreational level. All children came to the hospital by car, or they came by bike or walking if their place of residence was within 10-min walk distance from the hospital. Exercise testing was performed in upright position with a treadmill with breath-by-breath respiratory gas analysis (Cortex, Metalyzer 38, Germany). Subjects breathed through a low impedance turbine volume transducer for measurement of expiratory volume. CPET was performed with the standard symptom-limited Bruce protocol with incremental increase of speed and inclination every 3 minutes (22). The cuff blood pressure was also measured every three minutes until peak exercise and then at 3-min rest. All participants were verbally encouraged to exercise to exhaustion, as assessed using a cut-off greater than 1.01 for the respiratory exchange ratio (RER) at peak exercise. All equipment was calibrated according to the instructions of the manufacturer before testing. HR was measured by continuous 12-lead ECG. Peak VO2 was defined as the mean of the two highest consecutive values of 15-s averages of VO2. The VE/VCO2 slope was obtained by linear regression analysis of the data acquired throughout the exercise. Resting HR was measured after at least 3 min in sitting position before exercise testing, and peak HRpeak was defined as the highest HR achieved during exercise. HR reserve was calculated as the difference between HRpeak and resting HR. HR was also recorded at 1 and 2 min after cessation of the exercise, and HR recovery was calculated as the difference between HRpeak and the HR at these recovery points. WRpeak was measured in absolute values. The AT indicates the highest oxygen uptake that can be sustained during exercise without developing lactic acidosis. As CO2 is released increased by the bicarbonate buffering of the lactic acid, VE and VCO2 increase out of proportion to the increase in VO2, thereby allowing noninvasive determination of anaerobic threshold (AT). In each subject, the AT was measured by finding the VO2 above which VE/VO2 and PET O2 increased without an increase in VE/VCO2 or a decrease in PET CO2, as previously described. VO2 *versus* WR (ΔVO2/ΔWR) was measured as the slope obtained by linear regression analysis of VO2 (mL/min) *versus* WR (W). The quotient of the VO2 and HR is oxygen pulse (O2 pulse); its value depends on the stroke volume and the difference between the arterial and mixed venous blood oxygen content. According to Fick principle, O2 pulse correlates with stroke volume. According to Cooper *et al*. (23, 24), we used end-tidal CO2 (PETCO2) to estimate PaCO2. Statistical analysis was performed with SPSS 11.5 (SPSS, Inc., Chicago, Illinois, USA). Values are presented as mean and standard deviation unless stated otherwise. Mann-Whitney test was used for continuous variables without normal distribution. A p value less than 0.001 was considered statistically significant.

RESULTS

Subject characteristics are shown in Table 1. No significant differences were found in anthropometric data between boys and girls. Just two patients were excluded because they were obese or underweight.

TABLE 1. Baseline characteristics in boys and girls

Sex	All	Boys	Girls
Age (yrs)	14.1±2.8	14.1±2.8	14.1±2.8
Height (cm)	164±16.7	165.9±18.3	161±13.5
Weight (kg)	56.4±17.5	58.8±19.4	52.6±13.3
Body mass index (BMI) (kg/m²)	20.5±3.6	20.9±4	20.1±2.9
BMI (‰)	50.6±27	49±27	52.7±26
Number	164	99	65

All participants performed CPET without complication and were able to complete the protocol to volitional exhaustion with no other symptoms. No ECG abnormalities were noted during exercise testing.

Table 2 shows baseline and CPET data. Compared with boys, girls reached AT at a significantly lower workload. The same finding was recorded with peak workload. Compared with boys, girls had a significantly higher resting heart rate before exercise testing. Compared with boys, girls reached a significantly higher peak heart rate. Heart rate reserve between girls and boys showed no significant difference.

Boys reached a significantly higher peak VO2 during incremental testing. Linear increase of systolic pressure showed no significant difference between girls and boys.

During incremental work, together with linear increase in heart rate and systolic pressure, oxygen pulse showed linear increase with significant difference between girls and boys. Linear relationship between heart rate and increase in stroke volume is best illustrated in graphic presentation (Figure 1).

Breathing frequency showed no significant sex difference between at rest, at anaerobic threshold point or peak exercise.

Increase in tidal volume during incremental work showed no significant difference between girls and boys. Boys reached significantly higher peak minute ventilation compared with girls. In both girls and boys, linear increase in work was followed by linear increase in minute ventilation during exercise till AT, followed by a more pronounced increase of minute ventilation in relation to increase of VO2 after AT till peak exercise (Figure 2).

DISCUSSION

In most individuals, peak VO2 is limited by the amount of O2 that the cardiopulmonary system can deliver to the exercising muscles, hence the peak VO2 detected during progressive exercise test is an excellent indicator of the capabilities

TABLE 2. Cardiopulmonary exercise data in boys (n=99) and girls (n= 65)

CPET parameter	All	Boys	Girls
W (AT)	113.88±51.8 W	123.56±58.7 W	99.14±34.4*W
W (peak)	157.1±64.3 W	170.33±70.8W	136.94±46.5*W
HR rest	95.91±16.5 bpm	91.83±15.3 bpm	102.12±16.5* bpm
HR (AT)	160.72±18.8 bpm	156.42±20 bpm	167.26±14.8 bpm
HR (peak)	183.36±16.4 bpm	181.48±19 bpm	186.22±11.1* bpm
HRR	88.99±18.6 bpm	91.48±17.6 bpm	85.2±20 bpm
HR01 percentage	0.31±0.24	0.34±0.29	0.26±0.13
HR02 percentage	0.7±0.22	0. 72±0.22	0.68±0.22
RER peak	1.14±0.1	1.16±0.1	1.12±0.1
VO2 AT	35.08±8.41 mL/kg/min	37.13±8.9 mL/kg/min	31.95±6.6* mL/kg/min
VO2 peak	47.22±8.9 mL/kg/min	51.3±8.9 mL/kg/min	41.49±6.51* mL/kg/min
VO2 percentage AT	74.4±17	72.82±18.1	76.8±15*
VO2/HR rest	3.75±1.7 mL	4.34±1.8 mL	2.85±1.1*mL
VO2/HR AT	12.11±4.8 mL	13.55±5.2 mL	9.91±3*mL
VO2/HR peak	14.43±6.7 mL	16.13±7.5 mL	11.83±4*mL
ΔVO2/ΔWR	10±0.5 mL/minW	10.2±0.5 mL/minW	9.8±0.5 mL/minW
sysRR rest	109.86±14.2 mm Hg	112.61±15.5 mm Hg	105.48±10.6 mmHg
sysRR peak	145.43±11.9 mm Hg	147.7±12.6 mm Hg	142±9.9 mm Hg
sysRR 4.min	118.31±11.3 mm Hg	119.94±11.9 mm Hg	115.79±9.99 mm Hg
BF rest	19.71±5.3 L/min	19.71±5 L/min	19.7±5.8 L/min
BF AT	33.5±11.3 L/min	38.64±13 L/min	38.24±8.2 L/min
BFpeak	49.58±10.7 L/min	49.64±11.7 L/min	49.49±9.1 L/min
VT rest	0.59±0.2 L	0.65±0.3 L	0.49±0.2* L
VT AT	1.41±0.6 L	1.54±0.7 L	1.21±0.4 L
VT peak	1.99±0.3 L	2.22±0.6 L	1.84±0.8 L
VE AT	50.87±18.2 L/min	54.79±19.8 L/min	44.91±13.7 L/min
VE peak	80.03±27.8 L/min	89.09±30.1 L/min	67.29±19.6* L/min
VE/VO2 AT	24.94±4.1	24.57±4.6	25.51±3.2
VE/VO2 peak	29.42±3.3	28.88±3.2	30.24±3.4
VE/VCO2 AT	27.48±2.8	27±2.9	28.16±2.8
VE/VCO2 peak	28.52±3.2	28.16±3.3	29.08±2.8*
VD/VT AT	0.10±0.03	0.09±0.03	0.12±0.02*
VD/VT peak	0.08±0.03	0.07±0.03	0.1±0.02
PETCO2 AT	39.09±4.6 mm Hg	39.85±4.8 mm Hg	37.9±4.2 mm Hg
PETCO2 peak	37.74±4.6 mm Hg	38.68±4.5 mm Hg	36.29±4.6 mm Hg
Number	164	99	65

W AT – work rate achieved at anaerobic threshold (AT); Wpeak – maximal work rate achieved (W); HR rest – resting heart rate in beats *per* minute measured after at least 3 min in sitting position before exercise testing; HRpeak – maximal heart rate at peak exercise (beats/min); HR reserve, maximal heart rate – resting heart rate (beats/min); HR01 percentage, percentage heart rate recovery at 1 min (HRmax-HRpresent)/(HRmax-HRrest)*100%; HR02 percentage, percentage heart rate recovery at 2 min (HRmax-HRpresent)/(HRmax-HRrest)*100%; RERpeak – maximal respiratory exchange ratio; VO2AT – oxygen uptake at anaerobic threshold (mL/kg *per* min); VO2 percentage AT, (VO2 at anaerobic threshold/VO2max)*100%; VO2peak – maximal oxygen uptake (mL/kg/min); VO2/HR oxygen pulse at rest – anaerobic threshold and peak exercise expressed in mL; sysRR at rest – peak and 4 minute recovery, BF – breathing frequency at rest, anaerobic threshold and peak exercise in breaths *per* minute, VT – tidal volume in L at rest, anaerobic threshold and peak exercise, VE – minute ventilation in L *per* minute at rest, anaerobic threshold and peak exercise, VE/VO2 slope of respiratory minute volume to VO2 uptake at AT and peak exercise; VE/VCO2, slope of respiratory minute volume to CO2 production; VD/VT – dead space ventilation at anaerobic threshold and peak exercise, PETCO2 – end-tidal CO2 at anaerobic threshold and peak exercise; *p<0.001 for difference between boys and girls

of the patient's cardiovascular system. Peak VO2 varies with age; it tends to increase and reach maximum during adolescence, and to decline progressively thereafter. It also differs significantly between males and females and depends on body mass. *Cooper et al*. report on peak VO2 for 109 children that were not obese and were aged 6-17 years; peak VO2

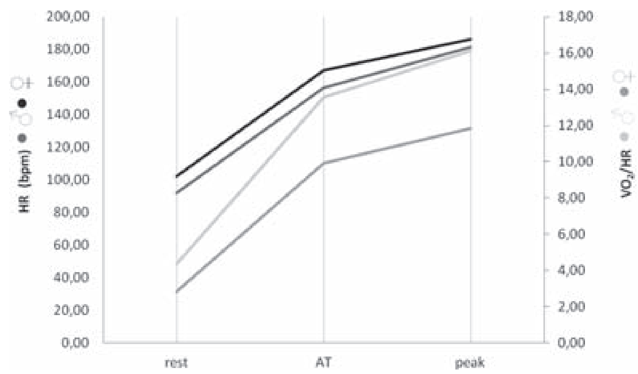

FIGURE 1. Linear relationship between heart rate (HR) and stroke volume (VO2/HR) increase at AT (anaerobic threshold) and peak VO2 (peak oxygen consumption).

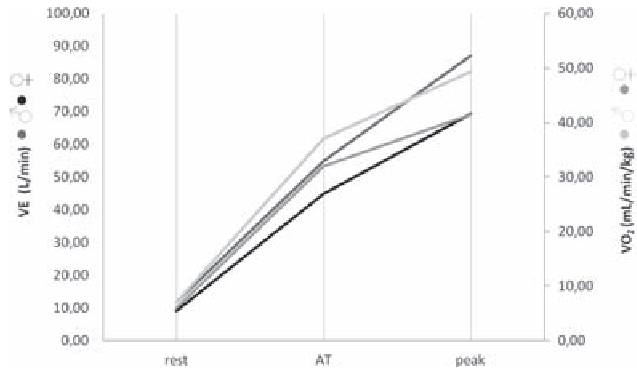

FIGURE 2. Relationship between minute ventilation (VE) and oxygen uptake (VO2) during incremental work at AT (anaerobic threshold) and peak VO2 (peak oxygen consumption).

correlated similarly with either weight or height and gave predicted equations for boys and girls, which are quite similar to the values we found (3, 6, 7). At the time when reduction in physical activity along with obesity in children has become apparent worldwide, these findings together with the fact that just two children had to be excluded because of overweight (>95 percent BMI) with mean BMI 20.5±3.6 kg/m^2 are still encouraging.

During a progressive exercise test, the anaerobic threshold occurs when aerobic metabolism is insufficient to meet energy requirements. It is not affected by patient effort or motivation and may be determined on a submaximal exercise test. Prediction equations exist for the calculation of normal values for AT on the basis of age, size and gender. AT is also commonly expressed as percentage of the predicted peak VO2. In the absence of cardiovascular disease, it is rarely below 40% of the predicted value (1, 3, 6). Values that are below 40% can be found in patients with conditions that significantly impair the ability to increase cardiac output or oxygen delivery during exercise (9, 15). With 35.08 mL/kg/min as the mean value and 74.4% of the predicted value, our findings of VO2 at AT are in correlation with the findings in healthy schoolchildren reported elsewhere (2, 4, 6). If a patient does not expend maximal or near maximal effort on exercise test, the peak exercise data may not accurately reflect the true status of the cardiopulmonary system (9, 15). Measurement of the respiratory exchange ratio (RER), which is the ratio of VCO2 over VO2 during exercise, often helps provide this information. In our group of patients, the mean RER during exercise was 1.14±0.1 and speaks for valuable data. During a progressive exercise test, HR linearly increases in proportion with VO2. The equations as predicted peak HR calculated as 220-age (years) should be used with caution (1, 6, 15, 24). The maximum or peak HR achieved declined with age in all studies. No consistent differences have been found between boys and girls. Scandinavian children were found to have an average peak HR of 205 bpm, whereas North American children aged 8-18 had an average peak HR of 187 bpm (6). We found the mean peak HR of 183.36±16.4 bpm, with a statistically significantly higher peak HR in girls. We also found a statistically significantly higher resting heart rate in girls. This finding, together with the finding that the heart rate reserve showed no statistically significant difference, probably suggests that girls exercised at a higher frequency due to increased emotional or stress reaction. The concept of HRR can be useful for estimating relative stress of the cardiovascular system during exercise. The mean predicted peak HR may not be reached because of normal population variability, poor motivation, poor cooperation, especially in younger children, parental overprotection, medications such as β-blockers, or because of heart, peripheral vascular, lung, endocrine or musculoskeletal diseases. Patients with sinus node dysfunction cannot increase their heart rate to normal levels at peak exercise.

In contrast, patients that cannot increase forward stroke volume tend to compensate if for by increasing their heart rate more rapidly during exercise. Chronotropic incompetence (inability to increase HR or prolonged heart rate recovery) is common after surgery for CHD and has been associated with poor prognosis (9, 15). In our study, we found 31% HR recovery after 1 minute. This corresponds to previous studies in children (6). HR recovery is believed to be mainly influenced by vagal autonomic activity, BMI, and fitness. Normal values may be calculated by dividing the predicted peak VO2 by the predicted HR and have already been given for children (4, 6, 8). In correlation with these findings, we found a linear increase in VO2/HR during incremental work, with statistically significantly higher values in boys. In adults, a maximal exercise systolic pressure above 220 mm Hg has been considered an excessive rise, in children maximal blood pressure rarely exceeds 200 mm Hg in normal subjects (8, 15). We found an increase of the mean systolic pressure from 109.86±14.2 to peak 145.43±11.9 mm Hg, with no sex differences, and systolic blood pressure recovery to resting values at recovery minute 4. It has been shown before that VE rises linearly in proportion with VCO2 during incremental work until a point above anaerobic threshold, when the accumulating lactic acidosis engenders compensatory increase in VE out of proportion to the increase in VCO2 (2, 3, 9, 27, 28). As mentioned here, we found linear increase of minute ventilation during work to peak of 80.03±27.8 L/min, as a result of linear increase of tidal volume and breathing frequency. As previous findings report that boys reached significantly higher peak VE compared with girls, this is consistent with our findings (27-30). In correlation with our finding at rest, boys had significantly higher lung volumes (29). Both girls and boys showed gradual reduction of dead space ventilation during incremental work. Previous studies showed no sex differences in breathing frequency increase, VE /VCO2, and end-tidal PCO2 (3, 9, 27-30). The VE/VCO2 slope may represent gas exchange efficiency during exercise or equivalent of the number of liters of air that must be breathed out to eliminate 1 liter of CO2. It is reported in healthy children to be around or less than 28, as we found in our population (6, 27-30). The VE/VCO2 slope has been shown to be one of the main predictors after CHD repair (14, 25). Previous reports showed that adults took longer than children to recover from exercise. Also, PaCO2 seems to be controlled at lower levels in children compared to adults. These observations were corroborated indirectly by the measurements of end-tidal PCO2 (PETCO2) and showed that pre-exercise and peak-exercise values were significantly lower in children as compared with PETCO2 in adults (23, 27, 28). Results showed that younger children breathed more during exercise to eliminate a given amount of CO2 to keep PaCO2 set point slightly but significantly lower than older children or adults. As we confirmed in our study, PET CO2 is lower at peak exercise than at AT and in healthy children usually is below 35-40 (6, 27, 28).

CONCLUSION

This paper gives a comprehensive overview of all cardiorespiratory parameters than can be obtained during CPET including cellular, cardiovascular and ventilatory system responses. Such reports are rare, especially in children, and are limited to either respiratory, cardiovascular, or a few parameters. The reduction in physical activity, together with obesity, smoking and other bad habits of social misbehavior that have become apparent worldwide, especially in teenagers, can be expected but were not demonstrated in the present study. Concerning cultural, anthropometric and all other ethnic differences, it is important to have own normal values for a group of population. This study has provided normal values of healthy children and adolescents in northwest Croatia. Although the results may vary between regions, this study gives a basis for further research and improvement of medical care in this sensitive population, while also providing a basis for CPET research in other populations such as young athletes, group of grown up CHD patients, respiratory diseases such as asthma, cystic fibrosis or other chronic diseases during and after treatment. Further researches are needed to obtain these results in Croatia.

Abbreviations:

cardiopulmonary exercise test – CPET
peak work rate – WRpeak
heart rate – HR
peak oxygen uptake – VO2peak
the ventilation to carbon dioxide exhalation slope – VE/VCO2
minute ventilation – VE
anaerobic threshold – AT
respiratory compensation point – RCP
oxygen uptake – VO2
carbon dioxide output – VCO2
equivalents for carbon dioxide and oxygen – VE/VCO2, VE/VCO2
oxygen pulse – VO2/HR
physiological dead space-tidal volume ratio – VD/VT
end-tidal pCO2 – PETCO2
end-tidal pO2 – PETO2
gas exchange ration – RER
increase in oxygen uptake in response to a simultaneous increase in work rate – ΔVO2/ΔWR
breathing reserve – BR
heart rate reserve – HRR

NOVČANA POTPORA/*FUNDING*
Nema/*None*

ETIČKO ODOBRENJE/*ETHICAL APPROVAL*
Nije potrebno/*None*

SUKOB INTERESA/*CONFLICT OF INTEREST*
Autori su popunili *the Unified Competing Interest form na www.icmje.org/coi_disclosure.pdf (dostupno na zahtjev)* obrazac i izjavljuju: nemaju potporu niti jedne organizacije za objavljeni rad; nemaju financijsku potporu niti jedne organizacije koja bi mogla imati interes za objavu ovog rada u posljednje 3 godine; nemaju drugih veza ili aktivnosti koje bi mogle utjecati na objavljeni rad./*All authors have completed the Unified Competing Interest form at www.icmje.org/coi_disclosure.pdf (available on request from the corresponding author) and declare: no support from any organization for the submitted work; no financial relationships with any organizations that might have an interest in the submitted work in the previous 3 years; no other relationships or activities that could appear to have influenced the submitted work.*

REFERENCES

1. Wasserman K, Hansen JE, Sue DY, et al. Principles of Exercise Testing and Interpretation: Including Pathophysiology and Clinical Applications. 5th ed. Baltimore, Maryland, USA: Lippincott, Williams & Wilkins, 2011.
2. Washington RL, van Gundy JC, Cohen C, Sondheimer HM, Wolfe RR. Normal aerobic and anaerobic exercise data for North American school-age children. J Pediatr. 1988;112:223-33. doi: 10.1016/S0022-3476(88)80059-3

3. Cooper DM, Weiler-Ravell D, Whipp BJ, Wasserman K. Aerobic parameters of exercise as a function of body size during growth in children. J Appl Physiol. 1984;56:628-34. doi:10.3389/fphys.2015.00226
4. Gulmans VA, de Meer K, Binkhorst RA, Helders PJ, Saris WH. Reference values for maximum work capacity in relation to body composition in healthy Dutch children. Eur Respir J. 1997;10:94–7. doi: 10.1183/09031936.97.10010071.
5. Binkhorst RA, Saris WH, Noordeloos AM, van 't Hof MA, de Haan AF. Maximal oxygen uptake of children (6–18 years) predicted from maximal and submaximal values in treadmill and bicycle tests. Human Kinetics Publishers, Champaign, Illinois, 1985.
6. Ten Harkel AD, Takken T, Van Osch-Gevers M, Helbing WA. Normal values for cardiopulmonary exercise testing in children. Eur J Cardiovasc Prev Rehabil. 2011;18:48-54. doi: 10.1177/ 1741826711410517.
7. 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;22:254-60. doi: 10.1046/j.1475-097X.2002.004.
8. Washington RL, Bricker JT, Alpert BS, et al. Guidelines for exercise testing in the pediatric age group. From the Committee on Atherosclerosis and Hypertension in Children, Council on Cardiovascular Disease in the Young, the American Heart Association. Circulation. 1994;90:2166-79. doi 10.1161/01.CIR.90.4.2166.
9. Takken TAC Blank, EH Hulzebos, van Brussel M, Groen WG, Helders PJ. Cardiopulmonary exercise testing in congenital heart disease: (contra) indications and interpretation. Neth Heart J. 2009;17:385-92. doi: 10.1007/BF03086289.
10. Firoozi S, Sharma S, McKenna WJ. Risk of competitive sport in young athletes with heart disease. Heart. 2003;89:710-4. doi10.1136/heart.89.7.710.
11. Abu-Hasan M, Tannous B, Weinberger M. Exercise-induced dyspnea in children and adolescents: if not asthma then what? Ann Allergy Asthma Immunol. 2005;94:366-71. doi: 10.1016/S1081-1206(10)60989-1.
12. D'Andrea A, Caso P, Sarubbi B, et al. Right ventricular myocardial dysfunction in adult patients late after repair of tetralogy of fallot. Int J Cardiol. 2004;94:213-20. doi 10.1148/radiol.11101993.
13. Müller J, Christov F, Schreiber C, Hess J, Hager A. Exercise capacity, quality of life, and daily activity in the long-term follow-up of patients with univentricular heart and total cavopulmonary connection. Eur Heart J. 2009;30:2915-20. doi: 10.1093/eurheartj/ehp305.
14. Diller GP, Dimopoulos K, Okonko D, et al. Exercise intolerance in adult congenital heart disease: comparative severity, correlates, and prognostic implication. Circulation. 2005;112:828-35. doi: 10.3410/f.1044092.494001.
15. Rhodes J, Ubeda Tikkanen A, Jenkins KJ. Exercise testing and training in children with congenital heart disease. Circulation. 2010;122:1957-67. doi: 10.1161/CIRCULATIONAHA.110.958025.
16. Dua JS, Cooper AR, Fox KR, Graham Stuart A. Exercise training in adults with congenital heart disease: feasibility and benefits. Int J Cardiol. 2010;138:196-205. doi: 10.1016/j.ijcard.2009.01.0.
17. Müller J, Böhm B, Semsch S, Oberhoffer R, Hess J, Hager A. Currently, children with congenital heart disease are not limited in their submaximal exercise performance. Eur J Cardiothorac Surg. 2013;43:1096-100. doi: 10.1093/ejcts/ezs712.
18. Bruce RA, Kusumi F, Hosmer D. Maximal oxygen intake and nomographic assessment of functional aerobic impairment in cardiovascular disease. Am Heart J. 1973;85:546–62. doi: 10.1016/0002-8703(73)90502-4.
19. Wessel HU, Strasburger JF, Mitchell BM. New standards for the Bruce treadmill protocol in children and adolescent. Pediatr Exerc Sci. 2001;13:392–401. doi 10.1007/s00421-009-1236.
20. van der Cammen-van Zijp MH, Ijsselstijn H, Takken T, et al. Exercise testing of pre-school children using the Bruce treadmill protocol: new reference values. Eur J Appl Physiol. 2010;108:393-9. doi: 10.1007/s00421-009-1236.
21. American Thoracic Society. Guidelines for methacholine and exercise challenge testing-1999. Am J Respir Crit Care Med. 2000;161:309-29. doi: 10.1164/ajrccm.163.1.16310b.
22. Cumming GR, Everatt D, Hastman L. Bruce treadmill test in children: normal values in a clinic population. Am J Cardiol. 1978;41:69-75. doi 10.1016/0002-9149(78)90134-0.
23. Cooper DM, Weiler-Ravell D, Whipp BJ, Wasserman K. Growth-related changes in oxygen uptake and heart rate during progressive exercise in children. Pediatr Res. 1984;18:845-51. doi: 10.1203/00006450-198409000-00008.
24. Cooper KH, Purdy J, White S, Pollock M, Linerud AC. Age-fitness adjusted maximal heart rates. Med Sci Sports. 1977;10:78-86. doi: 10.1159/000399552.
25. Radojevic J, Inuzuka R, Alonso-Gonzalez R, et al. Peak oxygen uptake correlates with disease severity and predicts outcome in adult patients with Ebstein's anomaly of the tricuspid valve. Int J Cardiol. 2013;163:305-8. doi 10.1016/j.ijcard.2011.06.047.
26. Fick A. The output of the heart. Physikalisch-Medicinische Gesellschaft 1870; 2:XVI.
27. Nagano Y, Baba R, Kuraishi K, et al. Ventilatory control during exercise in normal children. Pediatr Res. 1998;43:704-7. doi10.1203/00006450-199805000-00021.
28. Cooper DM, Kaplan MR, Baumgarten L, Weiler-Ravell D, Whipp BJ, Wasserman K. Coupling of ventilation and CO2 production during exercise in children. Pediatr Res. 1987;21:568-72. doi: 10.1203/00006450-198706000-00012.
29. Swain KE, Rosenkranz SK, Beckman B, Harms CA. Expiratory flow limitation during exercise in prepubescent boys and girls: prevalence and implications. J Appl Physiol. 2010;108:1267-74. doi 10.1152/japplphysiol.00123.2009.
30. Blais S, Berbari J, Counil FP, Dallaire F. A systematic review of reference values in pediatric cardiopulmonary exercise testing. Pediatr Cardiol. 2015; doi: 10.1007/s00246-015-1205-6.

SAŽETAK

Referentne vrijednosti kardiopulmonalnog testa opterećenja u djece i adolescenata u sjeverozapadnoj Hrvatskoj

D. Dilber, I. Malčić, T. Ćaleta, A. Zovko

Referentne vrijednosti kardiopulmonalnog odgovora dobivenog spiroergometrijskim testiranjem djece i mladih ranije su objavili inozemni autori i vrijednosti vježbanja su tipične za određenu populaciju. Naš cilj je izraditi referentne vrijednosti kardiopulmonalnog odgovora u tijeku vježbanja u populaciji sjeverozapadnog dijela Hrvatske. Spiroergometrijsko testiranje prema modificiranom Bruce protokolu na traci u 164-ero ispitanika u dobi od 11 do17 godina. Rezultati su izneseni kao srednje vrijednosti sa standardnim devijacijama. Mann-Whitneyjev test primijenjen u ocjeni varijabli koje nisu imale normalnu distribuciju. Dječaci su postigli značajno višu potrošnju kisika (VO2) u točki anaerobnog praga (AT) sa srednjom vrijednošću 37,13 ± 8,9 ml/kg/min u odnosu na djevojčice koje su postigle 31,95 ± 6,6 ml/kg/min. Jednako tako dječaci su postigli značajno višu vršnu potrošnju kisika 51,3 ± 8,9 u odnosu na 41,49 ± 6,51 ml/kg/min kod djevojčica. Tijekom porasta rada sistolički tlak je rastao sa 109,86 ± 14,2 mmHg do 145,43 ± 11,9 mmHg u vršnom vježbanju, bez značajnih razlika među spolom. Porastom opterećenja, zajedno s linearnim porastom srčane frekvencije i sistoličkog tlaka, bilježi se i linearan porast srčanog izbačaja dobivenog neinvazivnim mjerenjem temeljenim na potrošnji kisika i Fickovom načelu. Postignute vršne vrijednosti srčanog izbačaja značajno su više kod dječaka. U odnosu na djevojčice dječaci su imali značajno veći volumen udisaja u mirovanju te su postigli značajno veću minutnu ventilaciju u vršnom vježbanju. Prikazani su parametri kardiopulmonalnog i metaboličkog odgovora u tijeku spiroergometrijskog testiranja i iznesene referentne vrijednosti. Dobivene vrijednosti ne razlikuju se značajno u odnosu na druge studije i temelj su za daljnja istraživanja.

Ključne riječi: test vježbanja; djeca; adolescenti; referentne vrijednosti