ORIGINAL ARTICLE

Assessment of cardiorespiratory function in adolescent athletes affected by COVID-19: a comparative analysis

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Authors' Contribution: A – Study design; B – Data collection; C – Statistical analysis; D – Manuscript Preparation; E – Funds Collection

Abstract

Background and Study Aim Given the global spread of COVID-19 and its profound effects on public health, understanding its impact on the physical health and performance of young athletes is crucial for developing guidelines to support their recovery and well-being. The goal of this research was to assess the impact of the COVID-19 infection and possible consequences on the functional abilities of schoolchild athletes, and determine whether there are differences compared to their peers who did not suffer the infection.

Material and Methods This study involved 100 teenagers (median age 15.7±1.167), who engage in two different sports (basketball and soccer), divided into two groups. The first group comprised young athletes (n=53, age 15.79±1.854) who had contracted COVID-19 and underwent 14 days of home isolation. The second group consisted of healthy child athletes (n=47, age 15.60±1.313). Participants underwent a comprehensive pre-participation sports medical examination, which included a cardiopulmonary exercise test (CPET) on a treadmill. CPET assessed various physiological parameters: maximum oxygen consumption (VO2max); heart rates at the first and second ventilatory thresholds (HR at VT1 and HR at VT2); respiratory exchange ratio (RER); maximal pulmonary ventilation (VEmax); ventilatory efficiency (VE/VCO2); oxygen pulse (O2/HR); maximum heart rate (HRmax); three-minute heart rate recovery; and potential electrocardiographic changes.

Results The results indicate that COVID-19 infection has led to statistically significant impairments in the cardiorespiratory functions of child athletes. Notably, there were significant reductions in maximum oxygen consumption (VO2max), maximal pulmonary ventilation (VEmax), oxygen pulse (O2/HR), as well as heart rates at the first ventilatory threshold (HR at VT1), maximum heart rate (HRmax), and heart rate recovery following maximal effort, all demonstrating p-values less than 0.05.

Conclusions The assessed parameters demonstrated that the functions were statistically significantly impaired in child athletes who had recovered from COVID-19 compared to their healthy peers of the same age. However, the infection appeared to have a minimal impact on heart rate variability at ventilatory thresholds. These findings offer valuable insights for coaches and sports medicine physicians in adjusting training programs and supporting the rehabilitation process for young adolescent athletes resuming their training after recovering from COVID-19.

Keywords: VO_2max, SARS-CoV-2, aerobic capacity, heart rate, pulmonary ventilation, oxygen pulse

Glossary

- VO_2max – Maximal Oxygen Consumption.
- VE/VCO_2 – Ventilatory Efficiency.
- VE max – Maximal Pulmonary Ventilation.
- RER – Respiratory Exchange Ratio.
- O_2/HR – Oxygen Pulse.
- HR max – Maximal Heart Rate.
- HR VT_1 – Heart Rate at First Ventilatory Threshold.
- HR VT_2 – Heart Rate at Second Ventilatory Threshold.
- Velocity at VT_1 – Speed at First Ventilatory Threshold.
- Velocity at VT_2 – Speed at Second Ventilatory Threshold.
- RCP – Respiratory Compensation Point.

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Introduction

The COVID-19 virus pandemic, which began in 2020, had enormous consequences for the life and health of young athletes [1]. For the first time in their careers, young athletes had to face a different approach to the organization of their training during the competition season itself [2]. All these circumstances and an unusually long break without organized training or only training at home, affected the physical abilities of young athletes [3]. During the eight-week quarantine, young athletes could maintain their level of physical fitness with only limited training at home. In some cases, this led to a decrease in functional abilities, as well as a decrease in speed among young soccer players, with a simultaneous increase in body fat and muscle atrophy [4, 5]. At the same time, young athletes were not exempt from infection with the COVID-19 virus, and some, just like non-athletes, were exposed to hospitalization due to more severe symptoms, as well as heart problems during the pandemic [6, 7]. To avoid any risk of an athlete training and competing while infected, PCR tests, as well as cardiopulmonary exercises tests (CPET) were often performed to evaluate cardiovascular health prior returning to training and competition [8]. CPET is a standard protocol for the direct measurement of functional abilities, primarily maximum oxygen consumption (VO_2max), as a direct measure of aerobic capacity. In healthy adolescent athletes aged 15 to 18 years, according to some authors, VO_2max ranges from 45 to 62 mL/kg/min, depending upon the sport [9, 10, 11, 12, 13, 14]. Previous research that has dealt with the topic of young athletes and COVID-19 infection is quite limited. Some works have shown that, post COVID-19 recovery, the maximum consumption of oxygen was similar compared to healthy young athletes, but a drop in respiratory reserves (42%), as well as abnormal spirometry (42%), were observed when compared to peers who had not suffered from COVID-19 [15].

Most of the papers that dealt with the impact of quarantine and cessation of training for eight weeks on functional and motor skills showed a drop in the training efficiency of young athletes [16, 17, 18, 19, 20]. No research detailing the specific assessment of the functional abilities of young adolescent players after a prolonged COVID-19 infection.

As such, the goal of this research is to explain the new challenges related to the COVID-19 infection of young athletes, as well as the consequences that remain on their functional body responses to the infection. The study will also show the importance of diagnostics among young athletes to enable the safest participation in training and competitions and will provide useful advice on protocols for a gradual return to sports for young athletes after a COVID-19 infection.

Hypotheses. H° The null hypothesis of this research is that there will be no statistically significant difference between young players who are healthy and who are infected by Covid 19 infection. H^1 An alternative hypothesis states that the impact of COVID-19 on cardiorespiratory abilities will be more pronounced in kids with infection in terms of parameters such as VO_2max, VEmax, O2/HR, HR at VT1, HRmax, and heart rate recovery upon maximal effort, compared to heart rate variability at ventilatory thresholds.

This study aims to evaluate the impact of COVID-19 infection on the functional abilities of teenage athletes, with a specific focus on cardiorespiratory parameters. By comparing the performance metrics of athletes who have recovered from COVID-19 with those of their healthy peers, the study seeks to uncover insights into the potential consequences and discernible differences in aerobic capacity, heart rate, pulmonary ventilation, and oxygen pulse.

Materials and Methods

Participants

One hundred male children athletes (N=100) from two sports, soccer and basketball, with an average age of 15.70±1.85, from Serbia participated in this longitudinal experimental study and were divided into two groups. The experimental group comprised athletes who had tested positive for COVID-19 via PCR and underwent home isolation for 14 days (n=53, age 15.79±1.854). The control group included healthy adolescent athletes of the same age who had not contracted COVID-19 and had no interruption in training (n=47, age 15.60±1.313).

All subjects and their parents provided written informed consent to participate in the study after the testing procedures were explained verbally and in writing. The conducted research does not violate the rights of the players examined, according to the ethical standards of the Helsinki Declaration of the Human Rights Committee (VMA Declaration of Helsinki, 2013). The Ethical Committee of Sports Cardiology Association of Serbia approved all the performed procedures (Decision No. 2/21, adopted on September 28, 2021).

Research Design

All athletes usually performed 4-6 training sessions per week (about 90-120 minutes each), participating in an official game during the weekend. The criterion for inclusion in the study for COVID-19 athletes was the age < 18, as well as a positive PCR test for COVID-19, and a minimum of 14 days' break from training and competition. All tests were performed during the competitive season.

Athletes infected with the COVID-19 virus were asymptomatic or had mild-symptomatic complaints in the forms of fever, malaise for a maximum of

2, 3 days, as well as loss of smell and/or taste. Before performing CPET, all subjects filled out a survey concerning their basic data, personal, and family history. A pre-participation sports medical examination was performed in the outpatient sports medicine clinic "Vita Maxima" in Belgrade, Serbia, which allowed for insight into their health condition, while an assessment of the health capacity for participation in the study, i.e., for the application of the maximum CPET, was carried out.

The basic sports medical examination included: determination of body height, assessment of complete body composition (body weight, height-to-weight ratio (BMI), body fat percentage (FAT%)), and a 12-channel electrocardiogram (ECG) at rest with determination of heart rate. Physical examination was performed by measuring arterial blood pressure on both arms and auscultating the heart and lungs.

During the study a pre-participation sports medical examination and CPET of young athletes between October 2021 and June 2022 were conducted. The goal of the sports medical examination was to determine the general health capacity of non-COVID-19 athletes, as well as athletes after infection with the COVID-19 virus. An appropriate sports medical examination was a prerequisite for participation in the study and performance of CPET on a treadmill. CPET was used to determine maximal oxygen consumption (VO_2max), respiratory exchange ratio (RER), maximum pulmonary ventilation (VEmax), ventilatory efficiency (VE/VCO_2), oxygen pulse (O_2/HR), heart rates achieved at first and second ventilatory thresholds (HR at VT1 and HR at VT2), maximum heart rate (HRmax) and three-minute heart rate recovery after CPET.

All participants received medical clearance and a negative PCR test for COVID-19 within 48–72h before testing.

Test Protocol

A treadmill (HP-COSMOS®) was used to perform a CPET. An electrocardiogram of the heart at rest was performed using a 12-channel ECG (Fukuda). Maximum oxygen consumption (VO_2max), maximum minute ventilation (VEmax), and respiratory exchange ratio (RER), as well as ventilatory equivalents for oxygen (O_2) and carbon dioxide (CO_2) were assessed by monitoring breath-by-breath gas exchange (O_2 and CO_2) using the Quark CPET system (Cosmed®, Rome, Italy). To conduct the test, a standard protocol for young athletes was used with an initial speed of 5 km/h and an elevation of 0°. After the introductory part of the test, which serves as a warm-up, the speed of the treadmill was increased by 1 km/h every 60 seconds in order to achieve the maximum effort. Subjects were equipped with face mask and mobile ECG device (Quark C12x-T12x) during the CPET to evaluate respiratory and cardiological parameters. The CPET was considered maximal when three of four parameters below are accomplished:

- the value of the achieved maximum heart rate is ⩾ 90% or more of the predicted theoretical maximum heart rate for gender and age, which is calculated based on the formula: 220 – number of years,
- respiratory exchange ratio (RER) > 1.10,
- plateau in maximal oxygen consumption, despite increased loads (differences in VO_2max values less than 150 mL/min at the end of the CPET),
- a subjective feeling of exhaustion.

The cardiopulmonary exercise test was performed by trained and expert persons, as was the calibration, which was done according to the so-called STPD criteria (ST-standard temperature/standard gas temperature: 0°; P-pressure/pressure: 760 mmHg; D-dry equivalent/dry air) after every fifth test to adequately determine the measured parameters.

Statistical Analysis

To describe parameters of importance, depending on their nature, the following were used: frequency, percentages, sample mean, sample median, sample standard deviation, rank, and 95% confidence intervals. To test the normality of the distribution, Kolmogorov-Smirnov tests were used, as were graphs: histogram and normal QQ plot. To test for differences in maximum oxygen consumption between young athletes in two groups, as well as to examine the differences between them in aerobic and anaerobic capacity and heart rate response, we use the Independent T test and the Mann Whitney U test. To analyze the power of the study sample, a post hoc calculation of the power of the sample was performed for the results of the comparison between the two study groups (n=27). Two-way dependent t-test was used, with $\alpha=0.05$. The effect size was determined by the mean of each group (COVID-19 vs. healthy group) for the variable VO_2pred (%) for adolescents' basketball and soccer athletes [10, 12] (COVID-19 participants: 83.9±9.87% and healthy group participants: 93.1±11.77 %) and standard deviation of the groups. Thus, the value of sample power was $(1-\beta) = 0.989$, which is considered a large sample power. The sample size calculation was performed using G*Power 3.1. Statistical data processing was performed using the statistical package SPSS 22.0 for Windows. Differences were considered significant when the p value was less than 0.05.

Results

Descriptive statistics of all participants in the study are presented in Table 1. Results showed that

Table 1. Descriptive statistics of functional abilities of all participants in the study.

Variables	Participants	N	Mean	Standard deviation
VO_2max (mL/kg/min)	COVID-19 infection	53	45,58	4,65
	healthy group	47	56,52	6,19
VE/VCO2	COVID-19 infection	53	24,77	4,24
	healthy group	47	25,17	2,88
RER (CO_2/O_2)	COVID-19 infection	53	1,16	0,064
	healthy group	47	1,13	0,059
O_2/HR (mL/beat)	COVID-19 infection	53	17,23	4,00
	healthy group	47	21,90	4,25
VEmax (L/min)	COVID-19 infection	53	113,02	27,30
	healthy group	47	143,14	26,65
HR at VT1 (bpm)	COVID-19 infection	53	143,90	13,85
	healthy group	47	150,70	12,08
HR at VT2 (bpm)	COVID-19 infection	53	171,98	12,06
	healthy group	47	173,27	9,49
HRmax (bpm)	COVID-19 infection	53	191,94	5,78
	healthy group	47	190,89	6,39
HR recovery 1st minute (bpm)	COVID-19 infection	53	160,39	14,72
	healthy group	47	160,70	12,60
HR recovery 2nd minute (bpm)	COVID-19 infection	53	136,52	14,73
	healthy group	47	132,23	12,71
HR recovery 3rd minute (bpm)	COVID-19 infection	53	125,11	13,67
	healthy group	47	120,55	11,74

Abbreviations: VO2max - maximum oxygen consumption; VE/VCO2 – ventilatory efficiency; RER (CO2/O2) – respiratory exchange ratio; O2/HR – oxygen pulse; VEmax – maximum minute ventilation; HR (beats per minute) – heart rate; VT1 – first ventilatory threshold; VT2 – second ventilatory threshold.

adolescent athletes who had suffered a COVID-19 infection had statistically significantly lower values of aerobic capacity or VO_2 max ($p<0.001$) compared to their peers from the control group (Figure 1). Also, a significant difference was recorded in young players after COVID-19 infection in the area of maximal pulmonary ventilation and Oxygen pulse compared to their healthy peers ($p<0.001$) (Figure 2, and Figure 3).

Furthermore, anaerobic capacity, the respiratory gas exchange ratio (RER), as a measure of lactate tolerance, was much higher in COVID-19 group of adolescents ($p < 0.05$). This means that young athletes who had suffered from COVID-19 infection were exposed to much greater anaerobic metabolic fatigue at the end of the CPET (Figure 4). No statistically significant difference was observed in terms of ventilatory efficiency (VE/VCO_2) ($p=0.589$) (Figure 5).

Discussion

Aerobic and Anaerobic Capacity

The primary findings of this research showed that adolescent athletes after a COVID-19 infection suffered visible consequences from the effects of the virus on their cardiorespiratory abilities. Decreased values of vital parameters compared to healthy peers were observed ($p < 0.001$). The virus and de-training for 14 days had a greater effect on the decline in ability during the competition season than the summer break without training. Adolescent athletes from this study who had suffered a COVID-19 infection had statistically significantly lower values of aerobic capacity or VO_2 max (45,58 mL/kg/min), compared to their peers from the control group (56,52 mL/kg/min), but also lower values than young players from earlier studies prior to the pandemic, who had a range of VO_2 max values from 51.7 mL/kg/min to

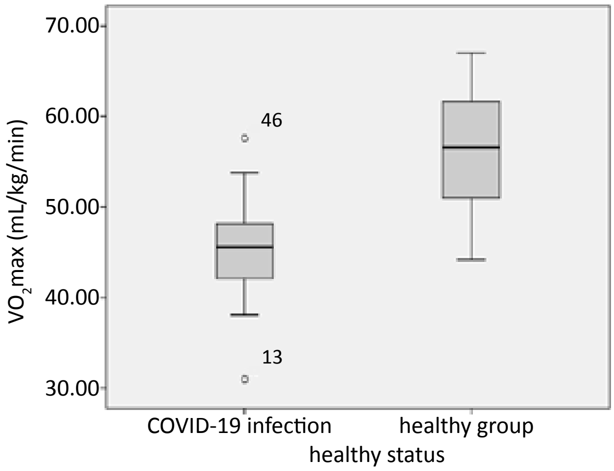

Figure 1. The aerobic capacity (VO_2max) of adolescent athletes after COVID-19 infection compared to their healthy peers. Abbreviation: VO_2max (mL/kg/min) - maximum oxygen consumption

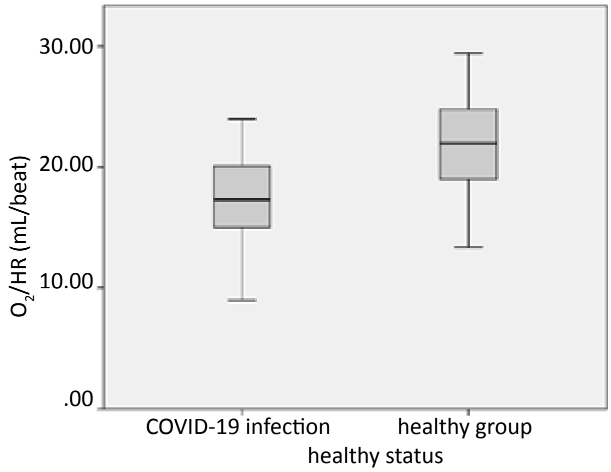

Figure 2. Oxygen pulse of adolescent athletes after COVID-19 infection compared to their healthy peers. Abbreviation: O_2/HR (mL/beat) - oxygen pulse.

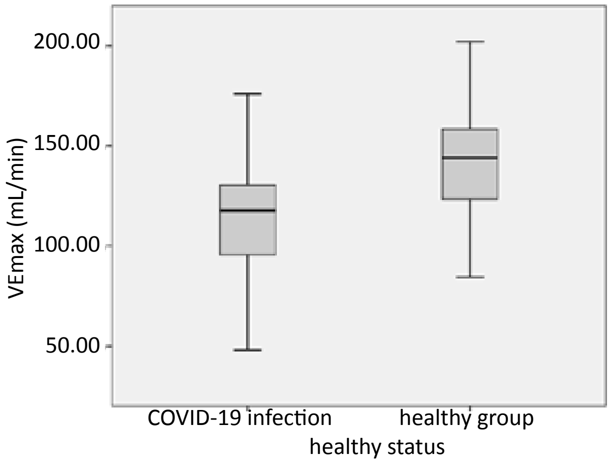

Figure 3. Maximum minute ventilation, of adolescent athletes after COVID-19 infection compared with their healthy peers. Abbreviation: VEmax (mL/min) - maximum minute ventilation.

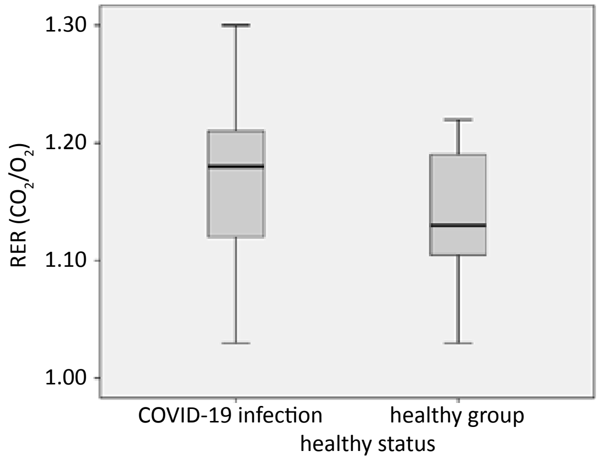

Figure 4. Respiratory exchange ratio (RER) of adolescent athletes after COVID-19 infection compared with their healthy peers. Abbreviation: RER – Respiratory exchange ratio

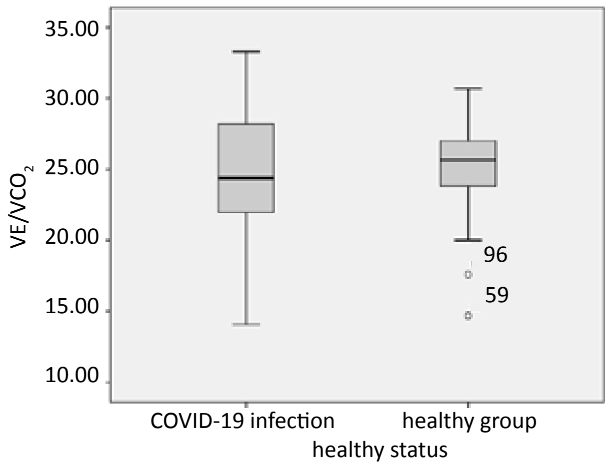

Figure 5. Ventilatory efficiency (VE/VCO_2 slope) of adolescent athletes after COVID-19 infection compared to their healthy peers.

59,4 mL/kg/min [21, 22, 23, 24 25]. At the same time, in terms of anaerobic capacity, the respiratory gas exchange ratio, as a measure of lactate tolerance, was much higher in COVID-19 group of adolescents ($p < 0.05$). This means that young athletes who had suffered from COVID-19 infection were exposed to much greater anaerobic metabolic fatigue at the end of the CPET. Furthermore, an early transition from aerobic to anaerobic metabolism pathways for energy production was seen, which can explain higher maximal RER values. Even though the greater anaerobic fatigue was seen in COVID-19 group of participants, the results in both groups, in terms of RER, are within the parameters expected for gender and age, as well as sports disciplines [26].

Pulmonary ventilation and oxygen pulse

In the area of maximal pulmonary ventilation, our research showed that post COVID-19 adolescent athletes obtained a far lower level of VEmax compared to the control group ($p < 0.001$). However, results from both research groups also coincided with the results of student basketball players from Russia [27]. Furthermore, the adolescent COVID-19 athletes from our study had a lower maximal pulmonary ventilation than healthy athletes from other sports disciplines aged 18-24 [28]. The virus affected the respiratory system of adolescent athletes at the cellular level, more so than detraining itself, since one study showed that, among young athletes aged 15,4 years, there was no drop in VO_2max, VE/VCO_2, VEmax after 42 days of detraining [29].

In terms of the oxygen pulse variable (O_2/HR), as an indirect indicator of the work of the left ventricle of the heart, a significant difference was recorded in young players after COVID-19 infection (18,66 mL/beat) compared to their healthy peers (23,13 mL/beat). This is an indication that it is possible that the virus had affected the function of the left ventricle of the heart, whose task is to deliver oxygen-enriched blood to active muscles. Even though the values from both study groups were within normal limits for age and gander, it was obvious that oxygen delivery to the working muscles was decreased, which can explain the lower VO_2max values in COVID-19 group of athletes [30].

No statistically significant difference was observed in terms of ventilatory efficiency (VE/VCO_2), even though the numerical difference was present. The VE/VCO_2 values coincide with the results from earlier research on this topic for both our study groups, which means that COVID-19 did not affect ventilatory efficiency of young athletes and respiratory function [31, 32].

Heart rate response

Regarding heart rate response parameters, our research observed that COVID-19 infection significantly affected the heart rate response at the first ventilatory threshold. After recovering from a COVID-19 infection, the young athletes faced with a decrease in cardiac capacity, since they reached VT1 at the lower heart rates, indicating that they had entered anaerobic fatigue earlier than their healthy peers during CPET. Yet, at the same time, there was no statistically significant difference in terms of achieved heart rate at VT2 between the groups, even though the numerical difference was observed.

Furthermore, the results of this study coincide with the results of elite athletes from earlier studies [33,34]. However, it is interesting that heart rate recovery after maximum effort was much weaker and, statistically, significantly lower in adolescent athletes after COVID-19 infection, compared to their healthy peers. The difference was observed in the second and third minutes of heart rate recovery after CPET ($p < 0.05$), which may indicate that the COVID-19 infection affects cardiac muscle in terms of decreased exercise tolerance and slower recovery.

The limitation of this study relates primarily to the small number of respondents who had had COVID-19. Further research could be extended to other young athletes from other disciplines, while research could also go in the direction of continuing to monitor young athletes with new medical examinations several months after their recovery from COVID-19. The duration of follow-up or observation period may have been relatively short, which could limit the understanding of long-term effects of COVID-19 infection on cardiorespiratory fitness in young athletes. Addressing these limitations and conducting further research with larger, more diverse samples and longer follow-up periods can provide a more comprehensive understanding of the impact of COVID-19 on the cardiorespiratory fitness of young athletes.

Conclusions

Research has shown that the COVID-19 infection has left certain consequences on the cardiorespiratory fitness of young adolescent athletes. It does so first of all in maximum oxygen consumption, pulmonary ventilation, and oxygen pulse, which is to be expected given that COVID-19 infection has proven to be a virus that affects both cardiovascular and respiratory functions, especially at the cellular level. For healthy athletes, detraining for several weeks did not cause such a big drop as it did in athletes after infection from the coronavirus and a break of 14 days. Infection did not greatly affect respiratory efficiency or heart rate variability, which was at level for sex, age and sport discipline. At the same time, heart rate recovery after maximal effort was lower in the second and third minutes of recovery. These findings can be useful to coaches and doctors of sports medicine when calculating training and returning to the training process of young athletes after their recovery from COVID-19 infection. Naturally, much more research is needed on this topic to gain a broader and better picture of the effects of the virus on the cardiorespiratory functions of athletes.

Within the pediatric sports population, young athletes are at risk of injury during the return to training following a COVID-19 infection and deconditioning. It is necessary to be careful and properly dose individual training for a young athlete after coronavirus disease.

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Conflicts of Interest

The authors declare no conflict of interest.

References

1. World Health Organization. *The Corona Virus Disease Pandemic (COVID-19)* [Internet]. WHO; 2021 [updated 2021 May; cited 2021 May 17]. Available from: https://www.who.int/health-topics/coronavirus#tab=tab_1
2. Mohamadian M, Chiti H, Shoghli A, Biglari S, Parsamanesh N, Esmaeilzadeh A. COVID-19: Virology, biology and novel laboratory diagnosis. *The Journal of Gene Medicine*, 2021;23(2): e3303. https://doi.org/10.1002/jgm.3303
3. Elrobaa IH, New KJ. COVID-19: Pulmonary and Extra Pulmonary Manifestations. *Frontiers in Public Health*, 2021;9: 711616. https://doi.org/10.3389/fpubh.2021.711616
4. Oliveira LDP, Aquino R, De Castro FMP, Pimenta PM, Gonçalves LGC, Nobari H, et al. *Does COVID-19 confinement period affect the body composition and physical performance of young elite soccer players?*. 2022 Jul [Accessed 10th April 2024]. https://doi.org/10.21203/rs.3.rs-1662768/v1
5. Kalinowski P, Myszkowski J, Marynowicz J. Effect of Online Training during the COVID-19 Quarantine on the Aerobic Capacity of Youth Soccer Players. *International Journal of Environmental Research and Public Health*, 2021;18(12): 6195. https://doi.org/10.3390/ijerph18126195
6. Nedeljkovic IP, Giga V, Ostojic M, Djordjevic-Dikic A, Stojmenovic T, Nikolic I, et al. Focal Myocarditis after Mild COVID-19 Infection in Athletes. *Diagnostics*, 2021;11(8): 1519. https://doi.org/10.3390/diagnostics11081519
7. Mitrani RD, Alfadhli J, Lowery MH, Best TM, Hare JM, Fishman J, et al. Utility of exercise testing to assess athletes for post COVID-19 myocarditis. *American Heart Journal Plus: Cardiology Research and Practice*, 2022;14: 100125. https://doi.org/10.1016/j.ahjo.2022.100125
8. Mihalick VL, Canada JM, Arena R, Abbate A, Kirkman DL. Cardiopulmonary exercise testing during the COVID-19 pandemic. *Progress in Cardiovascular Diseases*, 2021;67: 35–39. https://doi.org/10.1016/j.pcad.2021.04.005
9. Montgomery PG, Pyne DB, Minahan CL. The Physical and Physiological Demands of Basketball Training and Competition. *International Journal of Sports Physiology and Performance*, 2010;5(1): 75–86. https://doi.org/10.1123/ijspp.5.1.75
10. Apostolidis N. Physiological and technical characteristics of elite young basketball players. *Journal of Sports Medicine and Physical Education,* 2004;44(2):157–163.
11. Carvalho HM, Coelho-e-Silva MJ, Eisenmann JC, Malina RM. Aerobic Fitness, Maturation, and Training Experience in Youth Basketball. *International Journal of Sports Physiology and Performance*, 2013;8(4): 428–434. https://doi.org/10.1123/ijspp.8.4.428
12. Mohammed Z, Zohar BF, Gourar B, Ali B, Idriss MM. VO_2 max levels as a pointer of physiological training status among soccer players. *Acta Facultatis Educationis Physicae Universitatis Comenianae*, 2018;58(2): 112–121. https://doi.org/10.2478/afepuc-2018-0010
13. Albano D, Serra E, Vastola R. Correlation between running impacts and VO2max in young football players through GPS technology. In: *Journal of Human Sport and Exercise - 2019 - Summer Conferences of Sports Science*, Universidad de Alicante; 2019. https://doi.org/10.14198/jhse.2019.14.Proc5.20
14. Castagna C, Manzi V, D'Ottavio S, Annino G, Padua E, Bishop D. Relation Between Maximal Aerobic Power and the Ability to Repeat Sprints in Young Basketball Players. *The Journal of Strength and Conditioning Research*, 2007;21(4): 1172. https://doi.org/10.1519/R-20376.1
15. Moulson N, Gustus SK, Scirica C, Petek BJ, Vanatta C, Churchill TW, et al. Diagnostic evaluation and cardiopulmonary exercise test findings in young athletes with persistent symptoms following COVID-19. *British Journal of Sports Medicine*, 2022;56(16): 927–932. https://doi.org/10.1136/bjsports-2021-105157
16. Salazar H. Negative impact of COVID-19 home confinement on physical performance of elite youth basketball players. *Sport Perform. Sci. Rep*. 2020;10:1–3.
17. Pelemiš V, Zoretić D, Prskalo I. Physical Performance and Morphological Characteristics of Young Basketball Players before and after COVID-19. *Children*, 2023;10(3): 493. https://doi.org/10.3390/children10030493
18. Fitzgerald HT, Rubin ST, Fitzgerald DA, Rubin BK. Covid-19 and the impact on young athletes. *Paediatric Respiratory Reviews*, 2021;39: 9–15. https://doi.org/10.1016/j.prrv.2021.04.005
19. Škutāne S, Krišjānis K, Ilze A. Physical conditioning of basketball players aged 14–15 in year 2020/2021. *Lase Journal Of Sport Science*, 2022;13(2):83–101.
20. Leonte N, Moantă Ad, Saftel A, Ghițescu Gi,

Tocalaă C. Anaerobic capacity assessment of junior basketball players after the pandemic lockdown in Romania. *Discobolul – Physical Education, Sport and Kinetotherapy Journal*, 2021; 590–599. https://doi.org/10.35189/dpeskj.2021.60.s6
21. Taghread Ahmed Elsayed Ahmed, Heba Ali Ibrahim Seleem, Ghada Mohamed Youssef Elsayed. Effects of Eight Weeks Aquatic-Non-aquatic Training program on Aerobic Fitness and Physical preparation in junior Basketball Player. *Life Sci J.* 2019;16(1):111-118.
22. Mackała K, Kurzaj M, Okrzymowska P, Stodółka J, Coh M, Rożek-Piechura K. The Effect of Respiratory Muscle Training on the Pulmonary Function, Lung Ventilation, and Endurance Performance of Young Soccer Players. *International Journal of Environmental Research and Public Health*, 2019;17(1): 234. https://doi.org/10.3390/ijerph17010234
23. Gantois P, Aidar FJ, Gama De Matos D, De Souza FR, Da Silva LM, De Castro KR. Repeated sprints and relationship with anaerobic and aerobic fitness of basketball players. *Journal of Physical Education and Sport,* 2017;17(2): 910–915.
24. Mendez-Cornejo J, Gomez-Campos R, Andruske CL, Sulla-Torres J, Urra-Albornoz C, Urzua-Alul L, et al. Maximum Oxygen Consumption: Validity of the Run Test of 20 Meters and Proposal of Equations for Prediction in Young People. *Journal of Exercise Physiology Online*. 2020;23(1):24–37.
25. Kollos C, Tache S. Anthropometric indicators and aerobic exercise capacity in young basketball players. *Palestrica of the Third Millennium Civilization & Sport*, 2013;14(3):195–199.
26. Costache AD, Roca M, Honceriu C, Costache II, Leon-Constantin MM, Mitu O, et al. Cardiopulmonary Exercise Testing and Cardiac Biomarker Measurements in Young Football Players: A Pilot Study. *Journal of Clinical Medicine*, 2022;11(10): 2772. https://doi.org/10.3390/jcm11102772
27. Zakharova A. Cardiovascular Health and Physical Capacity in Student and Elite Basketball Players. In: *International Conference «Responsible Research and Innovation,* 2017. P. 1032–1039. https://doi.org/10.15405/epsbs.2017.07.02.133
28. Castagna C, Impellizzeri FM, Belardinelli R, Abt G, Coutts A, Chamari K, et al. Cardiorespiratory Responses to Yo-yo Intermittent Endurance Test in Nonelite Youth Soccer Players. *The Journal of Strength and Conditioning Research*, 2006;20(2): 326. https://doi.org/10.1519/R-17144.1
29. Alvero-Cruz JR, Ronconi M, Garcia Romero J, Naranjo Orellana J. Effects of detraining on breathing pattern and ventilatory efficiency in young soccer players. *The Journal of Sports Medicine and Physical Fitness*, 2018;59(1). https://doi.org/10.23736/S0022-4707.17.07619-8
30. Béres B, Györe I, Petridis L, Utczás K, Kalabiska I, Pálinkás G, et al. Relationship between biological age, body dimensions and cardiorespiratory performance in young soccer players. *Acta Gymnica*, 2021;51. https://doi.org/10.5507/ag.2021.001
31. Petek BJ, Churchill TW, Gustus SK, Schoenike MW, Nayor M, Moulson N, et al. Characterization of ventilatory efficiency during cardiopulmonary exercise testing in healthy athletes. *European Journal of Preventive Cardiology*, 2023;30(5): e21–e24. https://doi.org/10.1093/eurjpc/zwac255
32. Salazar-Martínez E, Matos TRD, Arrans P, Santalla A, Orellana JN. Ventilatory efficiency response is unaffected by fitness level,ergometer type, age or body mass index in male athletes. *Biology of Sport*, 2018;35(4): 393–398. https://doi.org/10.5114/biolsport.2018.78060.
33. Ramos-Campo DJ, Rubio-Arias JA, Ávila-Gandía V, Marín-Pagán C, Luque A, Alcaraz PE. Heart rate variability to assess ventilatory thresholds in professional basketball players. *Journal of Sport and Health Science*, 2017;6(4): 468–473. https://doi.org/10.1016/j.jshs.2016.01.002
34. Bjerring AW, Landgraff HE, Stokke TM, Murbræch K, Leirstein S, Aaeng A, et al. The developing athlete's heart: a cohort study in young athletes transitioning through adolescence. *European Journal of Preventive Cardiology*, 2019;26(18): 2001–2008. https://doi.org/10.1177/2047487319862061

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