Article

Impact of COVID-19 infection on cardiorespiratory fitness, sleep, and psychology of Endurance Athletes– CAESAR study

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Abstract: COVID-19 has harmful impact on health. It is especially important for endurance athletes (EAs). Sleep and psychology influence sport performance. Aims of this study were: (1) investigation of the consequences of mild COVID-19 on sleep and psychology and (2) assessment of the consequences of the infection on cardiopulmonary exercise test (CPET) results. 49 EAs (males= 43; 87.76%, females= 6; 12.24%, age= 39.9±7.8 years, height= 178.4±6.8 cm, weight= 76.3±10.4 kg; BMI= 24.0±2.6 kg·m^{-2}) underwent maximal cycling or running CPET pre- and post- COVID-19 and completed a survey. Exercise performance was deteriorated after COVID-19 (maximal oxygen uptake; VO_2max= 47.81±7.81 vs 44.97±7.00 ml·kg·min^{-1} respectively pre- and post- infection; p<0.001). Waking up at night affected heart rate (HR) at the respiratory compensation point (RCP) (p=0.028). Sleep time influenced pulmonary ventilation (p=0.013), breathing frequency (p=0.010), and blood lactate concentration (Lac) (p=0.013) at RCP. Maximal power/speed (p=0.046) and HR (p=0.070) linked with the quality of sleep. Stress management and relaxation techniques linked with VO_2max (p=0.046), maximal power/speed (p=0.033), and maximal Lac (p=0.045). Cardiorespiratory fitness was deteriorated after mild COVID-19 and was correlated with sleep and mental health. Medical Professionals should encourage EAs to maintain proper mental health and sleep after COVID-19 infection to facilitate recovery.

Keywords: COVID-19, Endurance athletes, mental health, sleep, cardiopulmonary exercise testing, cardiorespiratory fitness, exercise capacity, physical exercise, psychology

1. Introduction

The ongoing pandemic of Coronavirus disease 2019 (COVID-19) has had a significant impact on various aspects of people's lives for almost three years.[1]. Not only does the disease itself pose a threat to individuals' physical health, but misinformation and lack of trust in medical treatment and prevention methods can also contribute to increased

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uncertainty and stress.[2,3]. The lockdown measures implemented to slow the spread of the virus have also greatly affected people's lifestyles, activities and mental health.[4]. COVID-19 infection has been shown to have an adverse effect on the heart function of patients who survived the infection [5]. A greater tendency to reduced left ventricular ejection fraction, end-diastolic volume, stroke volume was found. This can then negatively affect the physical activity of patients [6]. Clinicians and psychologists are therefore searching for new coping strategies to address the mental health impacts of the pandemic.[7]. It is also well known that COVID-19 can also affects the sleeping patterns and endurance of the patients and that is why mental health, sleeping and endurance are crucial concepts affected by COVID-19

A particularly difficult time in the lives of EAs and other people is the COVID-19 pandemic. EAs from Poland, Romania, and Slovakia had the highest level of mental stress during the fourth wave [8]. EAs also adopted different coping strategies that affected mental health differently. Returning to regular training and physical fitness may not be easy due to mental aspects [9]. Proper activity maintenance can prevent further stress related to the pandemic and lockdown [10]. Physical activity has been shown to be associated with reduced hospitalization, intensive care unit admissions and mortality of COVID-19 patients. People who mainly perform resistance and endurance exercises are less likely to be hospitalized [11]. It turns out that the diet before COVID-19 infection also influenced the development of the disease. The effectiveness of eating a high-quality diet, as well as a plant-based diet, had a positive effect on the risk of hospitalization [12]. Not only the lockdown but also the COVID-19 disease had an impact on the adverse lifestyle changes and sports results achieved by EA [13]. Coaches, medical doctors, and EA will try to counteract these problems to come to the previous competition level and fitness [14]. Moreover, some may need rehabilitation [15]. The mental health of patients 12 months after the disease presents symptoms of mental disorders, lack of concentration and focus, increasing with the severity of the infection [16]. Significant improvement was noted 2 years after infection, which is reassuring, but it should be remembered that undergoing COVID-19 infection consequences for mental health can influence future health state of the EA [17]. It was tested that the course of mental disorders related to COVID-19 depends on age and sex [18,19]. Commonly reported post-illness psychiatric symptoms are anxiety (6.5% to 63%), depression (4% to 31%), and post-traumatic stress disorder (12.1% to 46.9%), patients reported lower quality of life up to 3 months after illness [20]. These data show that this is not a problem for individuals, but for a large group of patients, it can bother their everyday functioning and motivation.

Another aspect is the impact of the disease on patients' sleep. It turns out that patients often report insomnia related to infection but is usually mild [21]. Endurance athletes during the pandemic have been found to experience changes in their training, competition, and sleep patterns which can negatively affect their performance [22]. Results from the study indicate that athletes who reported sleep disturbances had lower endurance

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performance, average marathon finishing times decreased during the pandemic. A meta-analysis shows the neurological and neuropsychiatric changes post-COVID-19, on average 31% of patients experience sleep disorders [23]. This is a worrying phenomenon because sleep is a key aspect of the proper functioning of the body. This effect is especially challenging for EA, as sleep loss is associated with poorer athletic performance as well as exercise efficiency [24].

The aim of our study is twofold: to understand how contracting COVID-19 affects sleep and mental health and to evaluate how a previous mild COVID-19 infection impacts results on endurance performance scores among EAs. These are aspects that we will struggle with during the pandemic, and EA will have to find solutions to counteract them until a fully effective vaccine or drug is found and the population shows a greater willingness to use vaccinations [25].

2. Materials and Methods

2.1.General study information

We conducted a study that included: a double CPET assessment, and a mental health and sleep questionnaire. EAs underwent CPET before and after COVID-19 infection. During the second CPET, they also received the survey. Exercise tests were performed between June 2021 and December 2022 at the SportsLab sports diagnostics center (SportsLab, Warsaw, Poland). Participants underwent CPET before and after the disease with the same type (cycling or running). Interval between infection and both CPETs have been measured to control the effect of time elapsed and adjust analysis. The sample consists of amateur EAs at various fitness levels according to reference standards for VO_{2max} [26] [27]. After infection and directly before the second CPET, each EA underwent a medical evaluation by a Physician (cardiology or internal medicine specialist) which consisted of taking their medical history, physical examination, 12-lead ECG, echocardiography, and complete blood count. EA have been screened for ongoing long-lasting COVID-19 (eg. respiratory and circulatory) consequences preventing them from performing CPET.

Inclusion criteria: the interval between the first CPET and COVID-19 infection <3 years, mild COVID-19 infection (which did not require hospitalization) confirmed by PCR or antigen test, participation in the survey, (4) no ongoing long-lasting COVID-19 consequences preventing from CPET (eg. related to circulatory and respiratory systems), and (5) present negative COVID-19 PCR or antigen test.

Exclusion criteria: pulmonary condition (COPD, uncontrolled bronchial asthma, blood saturation <95%), cardiovascular disease (arrhythmia confirmed by ECG, ischemia of myocardium, QT prolongation confirmed by ECG, morphological heart abnormalities confirmed by echocardiography, uncontrolled hypertension >160/100 mmHg), [28] present mental condition, (4) an orthopedic condition that prevents EA to perform CPET, (5) deviations in CBC (leukocytosis $>10{,}000 \cdot mm^{-3}$, anemia with blood hemoglobin $<10 g \cdot dL^{-1}$).

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A visual representation of the recruitment procedure is provided in Figure 1.

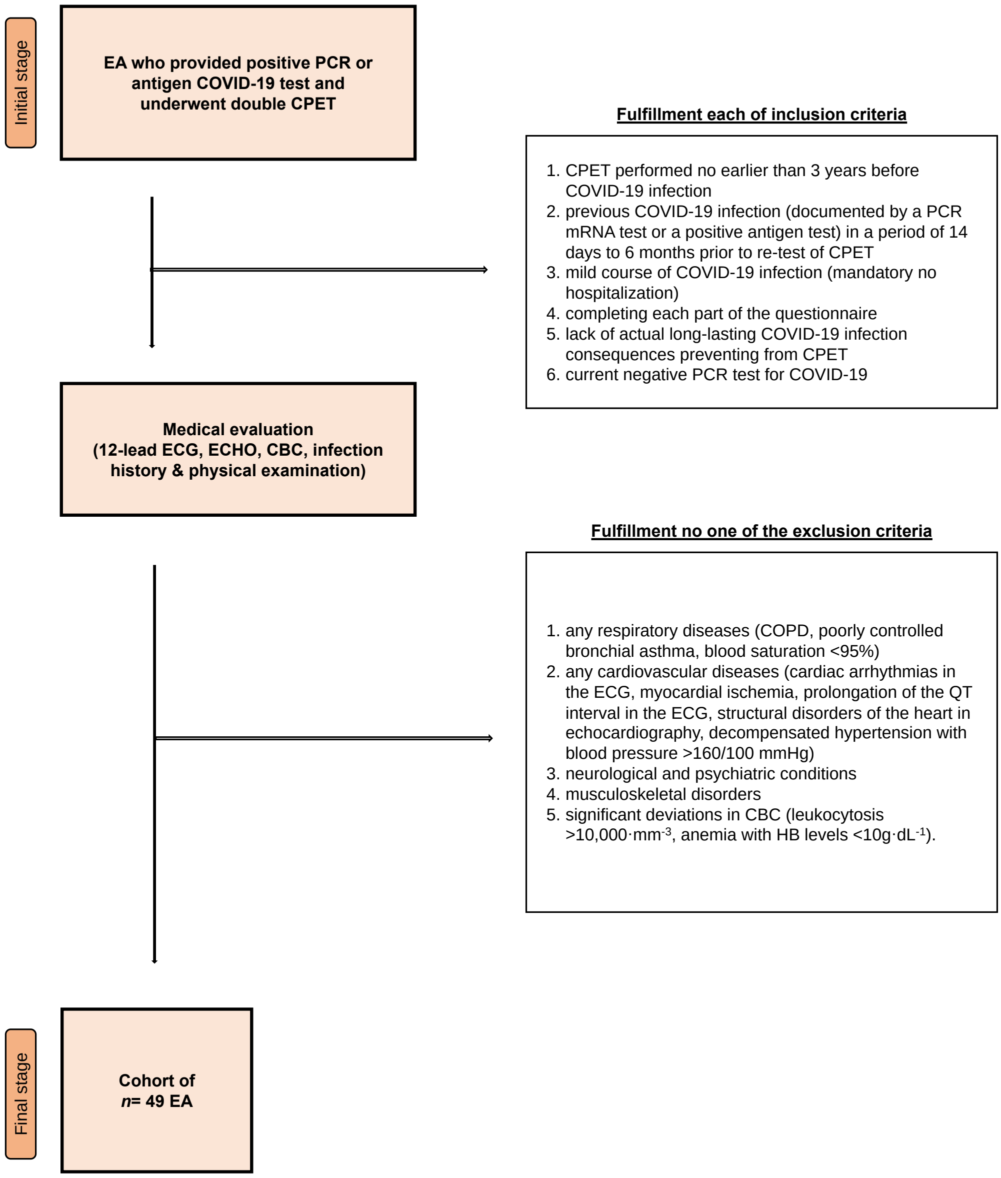

Figure 1. Recruitment procedure. Abbreviations: EA, endurance athlete; PCR, polymerase chain reaction; COVID-19, coronavirus disease 2019; CPET, cardiopulmonary exercise test; ECG, 12-lead electrocardiogram; ECHO, echocardiography examination; CBC, complete blood count; COPD, Chronic obstructive pulmonary disease.

2.2.Questionnaire

We used the previously validated PaLS (Pandemic against LifeStyle) questionnaire [29-31], which covered the following domains: basic information about the subjects, their training experience, health status, and infection details, mental health, coping strategies, and mood state (14 questions) and sleep habits (12 questions). The basic information part consisted of questions examining demographic data, primary sports discipline, training

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and competition experience, and any previous long-lasting COVID-19 consequences. We have added a point to each section in which the EAs rated on a scale of -5/0/+5 the impact of the COVID-19 pandemic, the restrictions introduced, the course of the disease, and the resulting lifestyle changes. Negative values represented a harmful effect, positive values a positive effect, and 0 meant no association. The scale allowed for adjusting to noticed changes in intensities.

2.2.1.Mental health part

Mental health was assessed by the original questions. EAs were asked about implemented methods: coping strategies (rapid return to work, neglecting or acceptance of the current condition, usage of stimulants and alcohol, looking for support among others, expanding knowledge about the virus, joking about the infection, usage of relaxation techniques), infection-related mood changes (concentrating on the situation, more often suffering negative emotions) and observed mental health disorders (giving up, more positive or more negative outlook on life, criticizing themselves, strong expressions of negative emotions). EAs could choose one of the following answers: "I did not try this method", "I used it in my everyday life, but only to a small extent", "I used this method often, or it was one of the basic methods to cope with COVID-19 induced stress", "I used this method regularly".

2.2.1.Sleep part

Sleep was assessed by the Athens Insomnia Scale [32] and the three additional questions related to usual habits: hour of walking sleep (participants declared precise time when they walk into the bed), sleep time (described in hours and minutes), and time spent in front of the devices emitting blue light (also described in hours and minutes).

2.3.CPET procedure & somatic measurements

Each subject performed an intensity-adjusted, maximal effort–limited CPET either running (mechanical treadmill, h/p/Cosmos quasar, Germany) or cycling (cycle ergometer, RBM elektronik-automation GmbH, Leipzig, Germany). The selected modality was the same post-infection as pre-infection. During pre-infection CPET participants chose their modality based on their preferences and primary sport discipline. During examinations constant beath-by-breath gas exchange (Hans Rudolph V2 Mask, Hans Rudolph Inc, Shawnee, Kansas), blood lactate (Super GL2 analyzer, Müller Gerätebau GmbH, Freital, Germany), and cardiopulmonary (Cosmed Quark CPET device, Rome, Italy) monitoring were used. The cycling test began with 3-5 minutes of freewheel pedaling followed by a gradual increase in intensity (20 Watts/2 minutes for females and 30 Watts/2 minutes for males). The running protocol also started with a 3–5-minute warmup at a speed varying between 7-12 km per hour and a constant 1% inclination followed by a gradual increase in speed (1 km/2 minute both for females and males). CPET termination was obtained when the subject declared volitional exhaustion, and maximal effort was additionally confirmed by a heart rate (HR) or maximal oxygen uptake (VO_{2max}) plateau (lack of growth in exercise parameter with growing CPET resistance). Participants were verbally encouraged by the physiologist to achieve the maximum score. Anaerobic threshold (AT) and respiratory

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compensation point (RCP) were determined based on actually recommended guidelines [33]. Before each exercise test, a body composition examination was performed (the Tanita body analyzer, Tanita, MC 718, Japan). The used multifrequency was 5 kHz/50 kHz/250 kHz. Obtained endpoints were weight, height, body mass index (BMI), lean mass, body fat percentage (BF), fat mass, VO_2, HR, pulmonary ventilation (VE), speed (for running CPET), power (for cycling CPET), breathing frequency (f_R), and blood lactate concentration (Lac).

2.4. Data analysis

The results are shown as number (n) and percentage (%) for categorical variables and average with standard deviation for continuous variables. Data is shown in line with APA Guidelines (https://apastyle.apa.org/; accessed on 16th March 2023). The Shapiro-Wilk test was used to evaluate the normal distribution. Relationships between CPET and somatic measures (weight, BMI, lean mass, BF, fat mass, VO_2, HR, VE, running speed, cycling power, f_R, and Lac) and questionnaire results (sleep and mental health outcomes) were assessed via Kruskal-Wallis rank's ANOVA. Differences between pre-/post-COVID-19 results of exercise and somatic performance (weight, BMI, lean mass, BF, fat mass, VO_2, HR, VE, running speed, cycling power, f_R, and Lac) were obtained from Student's t-test for independent means. The participant's number was set before conducting recruitment procedures at the effective significant minimum using G*Power (version 3.1.9.2; Germany). The p=0.05 was considered as a significance borderline. Data analysis was performed in STATISTICA (version 13.3, StatSoft Polska Sp. z o.o., Kraków, Poland) and SPSS (version 28; IBM SPSS, Chicago, IL, USA).

3. Results

3.1. Cohort description

Among 49 EAs who were recruited for this study, 87.8% (n=43) were males and 12.2 % (n=6) were females. Males were 40.7 (7.0) years old and 178.5 (6.8) cm in height, while females were 38.1 (6.4) years old and 178.4 (6.9) cm in height. There were 63.3% (n=31) running and 26.7% (n=18) cycling exercise examinations. Participants had to be prespecified in running or cycling, but also could add other supplemental trained disciplines. 30.6% (n=15) of participants declared additional disciplines which included triathlon, football and martial arts. 8.2% (n=4) of the cohort trained for 1-2 years, 28.6% (n=14) for 3-5 years, 38.8% (n=19) for 6-10 years, and 21.3% (n=12) had >10 years of training experience. 46.9% (n=23) of EAs withdrew from some type of competition due to undergoing COVID-19 infection. Individuals assessed their general health status on the -5/0/+5 scale as 4.8 (0.5) pre- and as 4.1 (0.5) post-COVID-19 infection, while 20.4% (n=10) of them declared suffering from COVID-19 consequences lasting longer than 2 weeks in the past. The time from the first to the second CPET was 591.7 (282.2) days. The period between pre-COVID-19 CPET and the termination of the infection (defined as negative PCR) was 436.4 (290.4) days, while the period between post-COVID-19 CPET and termination of the infection was 155.3 (82.52) days.

3.2. CPET performance

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CPET performance stratified by infection status is presented in Table 1. Between pre- and post-exercise tests, significant differences were found in key parameters, such as VO_2 at AT (35.0 (6.4) vs 32.4 (5.9) ml·kg·min^{-1}, $p<0.001$), RCP (43.9 (7.3) vs 40.5 (6.6) ml·kg·min^{-1}, $p<0.001$), and maximal (47.8 ((7.8) vs 45.0 (7.0) ml·kg·min^{-1}, $p<0.001$). VO_2 was higher before infection. We also observed a deterioration of HR at AT (145.1 (10.8) vs 141.1 (10.0) bpm, $p<0.001$) and RCP (168.8 (9.0) vs 165.1 (9.7) bpm, $p<0.001$). Other significantly different variables were running speed at AT ($p=0.044$) and RCP ($p<0.001$), VE at RCP ($p<0.001$), and Lac at RCP ($p=0.013$).

Table 1. CPET Performance.

Variable	Pre-COVID-19	Post-COVID-19	p-value
Weight (kg)	76.6 (10.0)	76.7 (10.9)	0.951
BMI (kg·m^{-2})	24.0 (2.5)	24.0 (2.7)	0.931
Lean mass (kg)	63.4 (7.6)	63.5 (8.0)	0.774
BF (%)	17.1 (4.7)	16.9 (5.1)	0.604
Fat mass (kg)	13.3 (4.7)	13.2 (5.2)	0.848
VO_{2AT} (ml·kg·min^{-1})	35.0 (6.5)	32.4 (6.0)	<0.001
VO_{2Ata} (ml·min^{-1})	2650.0 (470.9)	2446.1 (400.3)	<0.001
HR_{AT} (beats·min^{-1})	145.1 (10.9)	141.1 (10.1)	0.001
VE_{AT} (l·min^{-1})	70.8 (18.7)	68.1 (14.7)	0.090
S_{AT} (km·h^{-1})	11.4 (1.4)	11.1 (1.3)	0.044
P_{AT} (Watts)	162.8 (25.9)	154.8 (25.9)	0.066
fR_{AT} (breaths·min^{-1})	32.1 (9.0)	32.1 (8.1)	0.706
Lac_{AT} (mmol·L^{-1})	2.0 (0.9)	2.1 (0.9)	0.630
VO_{2RCP} (ml·kg·min^{-1})	43.9 (7.4)	40.5 (6.7)	<0.001
VO_{2RCPa} (ml·min^{-1})	3324.3 (512.9)	3063.7 (440.1)	<0.001
HR_{RCP} (beats·min^{-1})	168.8 (9.2)	165.1 (9.8)	<0.001
VE_{RCP} (l·min^{-1})	106.8 (21.7)	98.9 (18.3)	<0.001
S_{RCP} (km·h^{-1})	14.3 (1.9)	13.8 (1.5)	<0.001
P_{RCP} (Watts)	245.2 (42.0)	232.2 (39.7)	0.061
fR_{RCP} (breaths·min^{-1})	41.3 (8.7)	40.1 (8.9)	0.876
Lac_{RCP} (mmol·L^{-1})	4.9 (1.4)	4.3 (1.1)	0.013
VO_{2max} (ml·kg·min^{-1})	47.8 (8.0)	45.0 (7.1)	<0.001
VO_{2maxa} (ml·min^{-1})	3623.5 (552.1)	3406.0 (474.5)	<0.001
HR_{max} (beats·min^{-1})	180.8 (10.1)	179.8 (10.0)	0.273
VE_{max} (l·min^{-1})	143.0 (26.9)	138.50 (23.9)	0.068
S_{max} (km·h^{-1})	16.6 (1.6)	16.4 (1.7)	0.264
P_{max} (Watts)	310.0 (37.2)	312.2 (49.1)	0.811
fR_{max} (breaths·min^{-1})	58.9 (14.4)	57.3 (11.0)	0.959
Lac_{max} (mmol·L^{-1})	9.7 (2.3)	9.6 (2.4)	0.880
VO_{2AT} (ml·kg·min^{-1})	35.0 (6.5)	32.4 (6.0)	<0.001

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Abbreviations: COVID-19, coronavirus disease 2019; BMI, body mass index; BF, body fat; VO_{2AT}, oxygen uptake at the anaerobic threshold; VO_{2ATa}, absolute oxygen uptake at the anaerobic threshold; HR_{AT}, heart rate at the anaerobic threshold; VE_{AT}, pulmonary ventilation at the anaerobic threshold; S_{AT}, speed at the anaerobic threshold; P_{AT}, power at the anaerobic threshold; fR_{AT}, breathing frequency at the anaerobic threshold; VO_{2RCP}, oxygen uptake at the respiratory compensation point; VO_{2RCPa} absolute oxygen uptake at the respiratory compensation point; HR_{RCP}, heart rate at the respiratory compensation point; VE_{RCP} pulmonary ventilation at the respiratory compensation point; S_{RCP}, speed at the respiratory compensation point; P_{AT}, power at the respiratory compensation point; fR_{RCP}, breathing frequency at the respiratory compensation point; Lac_{RCP}, blood lactate concentration at the respiratory compensation point; VO_{2max}, maximal oxygen uptake; VO_{2maxa}, absolute maximal oxygen uptake; HR_{max}, maximal heart rate; VE_{max}, maximal pulmonary ventilation; S_{max}, maximal speed, P_{max}, maximal power; fR_{max}, maximal breathing frequency; Lac_{max}, maximal blood lactate concentration. Speed is presented for treadmill CPET (n=29) and power is presented for cycle ergometer CPET (n=18).

3.3. Sleep & mental health

A description of participants' responses with mean rangs where applicable is presented in Table 2 for sleep and Table 3 for mental health. We are presenting only significant ($p<0.05$) results owing to a large amount of possible response-CPET variable combinations. Briefly, the mental health of our EAs showed a strong linkage to CPET performance. Awakenings during the night influenced HR at RCP (H(2)=7.2; p=0.028). EA who described it as a considerable problem also noticed the highest HR at RCP (mean rang= 99.9 vs 71.4 vs 55.1). Sufficient total sleep duration was linked with the highest VE at RCP compared to slightly and markedly insufficient (H(2)=8.7; p=0.013; mean rang= 30.4 vs 18.5 vs 29.7). Similar associations have been observed for f_R at RCP (H(2)=4.5; p=0.104) and Lac at RCP (H(2)=8.7; p=0.013). Sleep quality correlated with maximal power or speed, both relative and absolute VO_2 at RCP and maximal, VE at RCP and maximal, and maximal HR (each $p<0.05$). All precise results stratified by answer type and exercise variable have been shown in Table 4, part A.

Table 2. Results of answers to questions related to sleep.

Question	Answer type				Lack of answer
	n (%)	n (%)	n (%)	n (%)	n (%)
Sleep induction	No problem	Slightly delayed	Markedly delayed	Very delayed or did not sleep at all	2 (4.1)
	22 (44,9)	16 (32.7)	7 (14.3)	2 (4.1)	
Awakenings during the night	No problem	Minor problem	Considerable problem	Serious problem or did not sleep at all	2 (4.1)

	8 (16.3) 71.4 for HR_{RCP}	27 (55.1) 55.1 for HR_{RCP}	12 (24.5) 99.9 for HR_{RCP}	0 (0.0)	
Final awakening	Not earlier	A little earlier	Markedly earlier	Much earlier or did not sleep at all	3 (6.1)
	28 (57.1)	15 (30.6)	3 (6.1)	0 (0.0)	
Total sleep duration	Sufficient	Slightly insufficient	Markedly insufficient	Very insufficient or did not sleep at all	2 (4.1)
	19 (38.8) 30.4 for VE_{RCP} 29.2 for f_{RRCP} 24.9 for Lac_{RCP}	25 (51.0) 18.5 for VE_{RCP} 20.4 for f_{RRCP} 13.9 for Lac_{RCP}	3 (6.1) 29.7 for VE_{RCP} 21.3 for f_{RRCP} 18.0 for Lac_{RCP}	0 (0.0)	
Sleep quality	Satisfactory	Slightly unsatisfactory	Markedly unsatisfactory	Very unsatisfactory or did not sleep at all	2 (4.1)
	22 (44.9) 27.2 for S_{RCP}/P_{RCP} 29.4 for VO_{2RCPa} 29.2 for VO_{2RCP} 29.1 for VE_{RCP} 27.6 for VO_{2max} 27.5 for VO_{2maxa} 27.3 for HR_{max} 25.9 for VE_{max}	22 (44.9) 19.3 for S_{RCP}/P_{RCP} 17.6 for VO_{2RCPa} 18.0 for VO_{2RCP} 18.3 for VE_{RCP} 18.8 for VO_{2max} 18.6 for VO_{2maxa} 19.4 for HR_{max} 19.8 for VE_{max}	3 (6.1) 35.3 for S_{RCP}/P_{RCP} 31.3 for VO_{2RCPa} 28.7 for VO_{2RCP} 28.7 for VE_{RCP} 35.3 for VO_{2maxa} 38.0for VO_{2maxa} 33.8 for HR_{max} 40.7 for VE_{max}	0 (0.0)	
Well-being during the day	Normal	Slightly decreased	Markedly decreased	Very decreased	2 (4.1)

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	28 (57.1) 27.8 for S_{RCP}/P_{RCP} 28.3 for S_{max}/P_{max}	19 (38.8) 18.5 for S_{RCP}/P_{RCP} 17.6 for S_{max}/P_{max}	0 (0.0)	0 (0.0)	
Functioning capacity during the day	Normal	Slightly decreased	Markedly decreased	Very decreased	3 (6.1)
	26 (53.1)	19 (38.8)	1 (2.0)	0 (0.0)	
Sleepiness during the day	None	Mild	Considerable	Intense	2 (4.1)
	5 (10.2)	28 (57.1)	13 (26.5)	1 (2.0)	
What hour did you usually get out of bed in the morning	7.1 (2.5)				4 (8.2)
Hours of actual sleep per night	6.8 (1.0)				
Hours spend in front of the screen of devices emitting blue light per day	7.0 (2.9)				3 (6.1)
Self-assessed impact of COVID-19 pandemic and imposed restrictions sleep (in -5/0/+5 scale)	0.4 (1.3)				2 (4.1)

Abbreviations: COVID-19, coronavirus disease 2019; HR_{RCP}, heart rate at the respiratory compensation point; VE_{RCP} pulmonary ventilation at the respiratory compensation point; f_{RRCP}, breathing frequency at the respiratory compensation point; Lac_{RCP}, blood lactate concentration at the respiratory compensation point; S_{RCP}, speed at the respiratory compensation point; P_{AT}, power at the respiratory compensation point; VO_{2RCP}, oxygen uptake at the respiratory compensation point; VO_{2max}, maximal oxygen uptake; VO_{2maxa}, absolute maximal oxygen uptake; HR_{max}, maximal heart rate; VE_{max}, maximal pulmonary ventilation; S_{max}, maximal speed, P_{max}, maximal power. Data have been shown as number (n) and (percentage) for categorical variables or as mean and (standard derivation). Kruskal-Wallis mean rang was shown only in case of significant differences ($p<0.05$). Speed is considered for running CPET, while power is considered for cycling CPET.

Interestingly, we found a much less significant relationship between self-reported mental health and sports performance. Briefly, our EA applied different coping strategies,

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and their habits to improve mental state varies significantly. Undertaking activities to improve one's situation (e.g. by learning more about COVID-19) has been linked to lean body mass (H(3)=8.2; p=0.042). It is worth noting that, joking about the COVID-19 infection influenced up to five CPET variables: HR at AT (H(3)=8.2; p=0.042), absolute VO_2 at RCP (H(3)=9.1; p=0.029), VE at RCP (H(3)=8.3; p=0.041), maximal relative VO_2 (H(3)=8.0; p=0.047) and maximal absolute VO_2 (H(3)=10.6; p=0.014). Expressive negative emotions (e.g. by shouting loudly or arguing with others) correlated with VE at AT (H(3)=10.9; p=0.012), and EA who often used this method observed the highest VE (mean rang= 44.0 vs 42.0 vs 34.4 and 20.4). The use of relaxation techniques altered running speed or cycling power (H(2)=6.8; p=0.033), maximal relative VO_2 (H(2)=6.1; p=0.046), and maximal Lac (H(2)=6.2; p=0.045). We did not observe any other significant association between declared mental health state or habit and CPET performance. All Kruskal-Wallis H test scores from the mental health part are presented in Table 4, part B.

Table 3. Results of answers to questions related to mental health.

Question	Answer type				Lack of answer
	I did not try this method	I used it in my everyday life, but only to a small extent	I used this method often, or it was one of the basic methods to cope with COVID-19 induced stress	I used this method regularly	
	n (%)	n (%)	n (%)	n (%)	n (%)
I wanted to return to work and duties as soon as possible to stop thinking about my illness	24 (49.0)	8 (16.3)	4 (8.2)	11 (22.4)	2 (4.1)
I was concentrating very hard on the situation I found myself in	27 (55.1)	11 (22.4)	0 (0.0)	8 (16.3)	3 (6.1)
I told myself „It can't be true that I am infected with COVID-19"	41 (83.7)	4 (8.2)	0 (0.0)	1 (2.0)	0 (0.0)
I used alcohol or other stimulants to improve my mood	37 (75.5)	7 (14.3)	1 (2.0)	1 (2.0)	3 (6.1)

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I gave up after trying to cope with the whole situation	42 (85.7)	1 (2.0)	3 (6.1)	0 (0.0)	3 (6.1)
I was looking for support from family, friends and other people	33 (67.3)	8 (16.3)	1 (2.0)	4 (8.2)	3 (6.1)
I undertook activities to improve my situation by expanding my knowledge about COVID-19	17 (34.7) 24.9 for lean mass	13 (26.5) 15.4 for lean mass	3 (6.1) 35.0 for lean mass	13 (26.5) 27.2 for lean mass	3 (6.1)
I was looking for positives in the situation I found myself in	12 (24.5)	7 (14.3)	8 (16.3)	19 (38.8)	3 (6.1)
I criticized myself for not taking precautions enough, which resulted in COVID-19 infection	40 (81.6)	6 (12.2)	0 (0.0)	0 (0.0)	3 (6.1)
I tried to joke about the COVID-19 infection	18 (36.7) 27.7 for HR_{AT} 25.6 for VO_{2RCP} 27.3 for VE_{RCP} 24.9 for VO_{2max} 26.3 for VO_{2maxa}	11 (22.4) 23.5 for HR_{AT} 28.5 for VO_{2RCP} 22.5for VE_{RCP} 28.6 for VO_{2max} 28.0 for VO_{2maxa}	4 (8.2) 41.5 for HR_{AT} 30.3 for VO_{2RCP} 34.3 for VE_{RCP} 30.3 for VO_{2max} 31.3 for VO_{2maxa}	13 (26.5) 15.2 for HR_{AT} 14.3 for VO_{2RCP} 15.8 for VE_{RCP} 15.1 for VO_{2max} 13.5 for VO_{2maxa}	3 (6.1)
I quickly accepted the state I was in	3 (6.1)	7 (14.3)	20 (40.8)	16 (32.7)	3 (6.1)

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I expressed my negative emotions expressively by screaming loudly or arguing with others	37 (75.5) 20.4 for VE_{AT}	7 (14.3) 34.4 for VE_{AT}	1 (2.0) 44.0 for VE_{AT}	1 (2.0) 42.0 for VE_{AT}	3 (6.1)
I tried to improve my mood through religious practices or meditation relaxation techniques	35 (71.4) 22.3 for S_{max}/P_{max} 23.0 for VO_{2max} 13.7 for Lac_{max}	6 (12.2) 35.8 for S_{max}/P_{max} 34.2 for VO_{2max} 21.7 for Lac_{max}	0 (0.0)	5 (10.2) 17.2 for S_{max}/P_{max} 14.4 for VO_{2max} 7.8 for Lac_{max}	3 (6.1)
Self-assessed impact of COVID-19 pandemic and imposed restrictions mental health (in -5/0/+5 scale)	0.6 (1.8)				2 (4.1)

Abbreviations: COVID-19, coronavirus disease 2019; HR_{AT}, heart rate at the anaerobic threshold; VO_{2RCP}, oxygen uptake at the respiratory compensation point; VE_{RCP} pulmonary ventilation at the respiratory compensation point; VO_{2max}, maximal oxygen uptake; VO_{2maxa}, absolute maximal oxygen uptake; VE_{AT}, pulmonary ventilation at the anaerobic threshold; S_{max}, maximal speed, P_{max}, maximal power; Lac_{max}, maximal blood lactate concentration. Data have been shown as number (n) and (percentage) for categorical variables or as mean and (standard derivation). Kruskal-Wallis mean rang was shown only in case of significant differences ($p<0.05$). Speed is considered for running CPET, while power is considered for cycling CPET.

Table 4. Relationships between sleep, mental health and CPET performance.

CPET variable	Survey question	p-value
Part A. Sleep		
HR_{RCP}	Awakenings during the night	0.028
VE_{RCP}	Total sleep duration	0.013
fR_{RCP}	Total sleep duration	0.010
Lac_{RCP}	Total sleep duration	0.013
S_{RCP}/P_{RCP}	Sleep quality	0.046
VO_{2RCPa}	Sleep quality	0.011
VO_{2RCP}	Sleep quality	0.018
VE_{RCP}	Sleep quality	0.027
VO_{2max}	Sleep quality	0.034
VO_{2maxa}	Sleep quality	0.019
HR_{max}	Sleep quality	0.070
VE_{max}	Sleep quality	0.032
S_{RCP}/P_{RCP}	Well-being during the day	0.023
S_{max}/P_{max}	Well-being during the day	0.007

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Part B. Mental health		
Lean mass	Undertaking activities to improve one's situation	0.042
HR_{AT}	Joking about the COVID-19 infection	0.042
VO_{2RCP}	Joking about the COVID-19 infection	0.029
VE_{RCP}	Joking about the COVID-19 infection	0.041
VO_{2max}	Joking about the COVID-19 infection	0.047
VO_{2maxa}	Joking about the COVID-19 infection	0.014
VE_{AT}	Expressing negative emotions expressively	0.012
S_{max}/P_{max}	Improving mood through religious practices or meditation relaxation techniques	0.033
VO_{2max}	Improving mood through religious practices or meditation relaxation techniques	0.046
Lac_{max}	Improving mood through religious practices or meditation relaxation techniques	0.045

Abbreviations: CPET, cardiopulmonary exercise test; HR_{RCP}, heart rate at the respiratory compensation point; VE_{RCP} pulmonary ventilation at the respiratory compensation point; f_{RRCP}, breathing frequency at the respiratory compensation point; Lac_{RCP}, blood lactate concentration at the respiratory compensation point; S_{RCP}, speed at the respiratory compensation point; P_{AT}, power at the respiratory compensation point; VO_{2RCPa} absolute oxygen uptake at the respiratory compensation point; VO_{2RCP}, oxygen uptake at the respiratory compensation point; VO_{2max}, maximal oxygen uptake; VO_{2maxa}, absolute maximal oxygen uptake; HR_{max}, maximal heart rate; VE_{max}, maximal pulmonary ventilation; S_{max}, maximal speed, P_{max}, maximal power; HR_{AT}, heart rate at the anaerobic threshold; VE_{AT}, pulmonary ventilation at the anaerobic threshold; Lac_{max}, maximal blood lactate concentration. Owing to a large number of combinations between the survey question and CPET variable, only significant results (with $p<0.05$) were presented. P-values were calculated by the Kruskal-Wallis H test. Speed is considered for running CPET, while power is considered for cycling CPET.

4. Discussion

In our study, we showed the impact of EAs having mild COVID-19 on mental health and sleep, as well as their correlation with cardiopulmonary exercise test scores. The main findings were: episodes of awakening during sleep affected heart rate at the respiratory compensation point, sufficient total sleep duration compared to slightly and markedly insufficient was linked with the highest pulmonary ventilation at the respiratory compensation point, (4) quality of sleep correlated with maximal power or speed and maximal heart rate, (5) EAs adopted different strategies of coping with stress, which was associated with the influence on lean body mass, (6) cardiopulmonary exercise test parameters were influenced by EAs individual behaviors and habits (i.e.. joking about the COVID-19 infection, expressive negative emotions and use of relaxation techniques). This paper focuses on outcomes of mild COVID-19 infection on sleep and mental health. Other possibly affecting covariables (including

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participants sex, age, CPET modality, nutrition, training regimen and previous sport experience) were analyzed in remaining CAESAR manuscripts [34,35].

The effect of sleep deprivation and sleep duration on athletic performance, reaction time, accuracy, strength, and endurance in EAs has been proven in many studies [36]. EAs in our study who reported insufficient sleep time had significant changes in parameters such as pulmonary ventilation, breathing frequency and blood lactate concentration at the respiratory compensation point;Lactate changes are mainly influenced by sleep deprivation at the end of the night [37]. In contrast, increasing sleep time or introducing naps could improve reaction time, alertness, vigor and mood, as well as prevent fatigue [38]. For EAs, the sleep of the correct quality and length is essential because it affects physical and mental regeneration, which is necessary to achieve high sports results [39]. The reduction in endurance parameters may be partially linked to poor sleep hygiene, so it is important to follow it. Among young EAs, up to 41% do not comply with the rules of sleep hygiene [40]. They exhibit behaviors such as exposure to blue light before falling asleep, extended wake-up time, and eating meals before falling asleep. Delayed onset and awakening after falling asleep and the presence of sleep phases unaffected by varying training severity suggest a questionable recovery in athletes after intense training [41]. The quality of sleep among EAs surveyed in our study changed parameters such as speed, power, oxygen uptake, absolute oxygen uptake, pulmonary ventilations at the respiratory compensation point and maximal oxygen uptake, absolute maximal oxygen uptake, maximal heart rate, maximal pulmonary ventilation compared to the results before getting sick with COVID-19.

The COVID-19 also affected the mental health of endurance athletes. 22.2% reported mood deterioration or symptoms of depression during the COVID-19 pandemic. Comparably, only 3.8% reported such signs when asked about the pre-pandemic period [42]. This is an alarming result considering that mental health affects CPET scores in EAs. Moreover, as the pandemic continues, this condition is getting worse. Comparing the results from 2020 to 2021, despite better access to possibilities of training, mental problems increased from 36% to 80% [43]. Among young EAs whose activity level decreased during the pandemic, an improvement in the quality of mental life was noticed after returning to regular activity [44]. Mood, stress levels, and overall mental health among EAs may be lowered at even 8 weeks after COVID-19 infection [45], which consequently adversely affects athletic performance and attitude to training. It is worth underlining, that people who have recovered from COVID-19 are at risk of memory loss, anxiety, depression and even post-traumatic stress disorder (PTSD) compared to individuals who have not had the disease [46]. This paper was directed at the impact of the disease on asymptomatic and mildly symptomatic EAs. As claimed by Petek et al. this was the most common course of COVID-19 infection in the athletic population [47]. Even non-hospitalized EAs are more likely to develop anxiety, trauma- and stress-related disorders, or fatigue [48]. Augustin et al. investigated that up to 14% of patients report fatigue at 7 months follow up and females are considered as a higher risk group [49]. EAs incorporate various treatment strategies. Briefly, progressive muscle relaxation techniques have a positive impact on anxiety and sleep quality during the ongoing COVID-19 disease [50]. Thus, it is worth considering strategy for EA during and after the disease. It is important to provide EAs with comprehensive care and assistance in recovering from COVID-19 and later returning to sports competition under stressful circumstances [51] [52].

Declared negative emotions were correlated with VE at AT. This result may be influenced by the fact that stressful circumstances can enhance the response of EAs to exertion and mobilize them to higher performance [53]. The impact of the relaxation techniques on the Lac among EAs is confirmed by a study conducted on runners [54]. Athletes using meditation or autogenic training after six months had significantly reduced Lac after exercise compared to the control group. Although, changes in VO_{2max} were not significant. Findings provided by Solberg et al. may be extrapolated to the post-pandemic period because mindfulness techniques could improve performance, endurance, and cognitive functions [55]. Finally, we found that joking about the disease affected HR, VO_2, and VE, however, the basic mechanism remains unclear. We underline, that the primary goal of this paper is not to investigate the causative mechanisms, but to draw attention of linkages between CPET changes, well-being, and underwent COVID-19 infection in the athletic population. Thus, we recommend further studies to examine the physiologic reasons for the above-described results.

Limitations

The survey results were based on self-reported answers and may not accurately reflect participants' actual habits. The time gap between the pre- and post-infection CPET tests may have an impact on the results due to variations in fitness levels among participants. It is important to exercise caution when applying the findings to other situations and to conduct additional research to confirm the conclusions about the effects of mild COVID-19 infection on exercise performance, sleep, and mental health.

5. Conclusions

The quality of sleep and mental health is greatly impacted by both the ongoing pandemic and contracting COVID-19. It is essential for EAs to have access to professional medical and psychological support. Adopting effective coping strategies can aid in the treatment and prevention of mental health issues. There is also a connection between mental health and sleep habits and athletic performance. The course of COVID-19 infection and the lifestyle of athletes have an impact on cardiorespiratory capacity and CPET test results. Therefore those working with EAs, such as coaches, clinicians, and psychologists, should be aware of the potential effects of mild COVID-19 infection and take steps to protect their health, including providing appropriate treatment recommendations.

Supplementary Materials: The following supporting information can be downloaded at: www.mdpi.com/xxx/s1, Figure S1: title; Table S1: title; Video S1: title.

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