

The long-term impact of COVID-19 on the physical activity, motor fitness, and maximum heart rate values of female university students

Research Article

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Abstract

Aim: This study examined the relationship between COVID-19 and the maximum heart rate (HR_{max}) achieved by female university students during maximal physical effort. It also analyzed how participants' physical activity (PA) levels and anthropometric and physiological characteristics were related to HR_{max} 10 months after the World Health Organization (WHO) declared that COVID-19 was no longer a Public Health Emergency of International Concern.

Materials and methods: Eighty-two female university students aged 19.0–28.0 years (21.23 ± 1.57) were assigned to three groups: G_1 – 40 healthy participants, G_2 – 29 participants with confirmed COVID-19, and G_3 – 13 participants previously hospitalized due to COVID-19. Body composition was evaluated by bioelectrical impedance analysis. PA was assessed with the International Physical Activity Questionnaire, and HR_{max} was measured during the 12-min Cooper test performed on a rowing ergometer.

Results: Healthy students (G_1) showed the highest PA levels, followed by groups G_2 and G_3 . Group G_1 also exhibited more favorable body composition, with lower values of body mass, body mass index, waist-to-hip ratio, visceral fat, fat mass, fat-free mass, and skeletal muscle mass ($p < 0.001$). Maximum heart rate was highest in group G_1 (175 beats per minute, bpm) and exceeded the values noted in groups G_2 and G_3 by 7 and 15 bpm, respectively ($p = 0.028$).

Conclusions: Female students hospitalized due to COVID-19 had lower PA levels, reduced motor fitness, and worse body composition, which may explain their lower HR_{max} values observed 10 months after the pandemic.

Keywords: Exercise · Motor skills · Physiological parameters · Young adult · Pandemic

1. Introduction

The coronavirus disease 2019 (COVID-19), caused by severe acute respiratory syndrome coronavirus 2 (SARS-CoV-2), emerged in Wuhan, China, in December 2019 (Huang et al., 2020) and rapidly spread across the globe, becoming one of the deadliest pandemics of the century (Das, 2020).

By February 2025, the COVID-19 pandemic has resulted in more than 7.08 million deaths globally, presenting a significant healthcare and scientific challenge in the 21st century (Ray et al., 2025). The pandemic severely affected public health and revealed serious weaknesses in healthcare systems, particularly in low-resource countries where medical services were disrupted or became inaccessible

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(Menendez et al., 2020; World Health Organization, 2021, 2025). According to the US experts, post-COVID conditions may be considered chronic, infection-associated syndromes due to their lasting physiological and psychological consequences (Unger, 2025).

The pandemic has not only strained global healthcare systems but also reshaped nearly every aspect of daily life. Restrictions on movement, remote education, and prolonged social isolation significantly altered people's lifestyles and behaviors. These disruptions had a particularly strong impact on physical activity (PA), which plays a fundamental role in maintaining mental, social, and physical well-being (Seman et al., 2021). Regular PA supports the immune system, reduces stress, and counteracts the negative psychological effects of isolation (Katz et al., 2016). However, numerous studies have shown that during the pandemic, PA levels declined across most populations, especially among university and college students (Ács et al., 2020; Faraji et al., 2020; López-Valenciano et al., 2021; Rivera et al., 2021). This decline was largely attributed to restrictions on sports facilities, online education, and reduced social interaction. Interestingly, Sweden was an exception, as the absence of lockdowns resulted in minor lifestyle improvements among university students during the first 6 months of the pandemic (Larsson et al., 2022).

Research on gender-related differences in PA during the pandemic produced mixed findings. Goicochea et al. (2022) reported that women remained more active than men, whereas a study conducted among Malaysian university students found no significant differences between the sexes (Hakim et al., 2021). Further analyses indicated that Polish university students of both sexes experienced a simultaneous decline in PA and strength-endurance abilities during the pandemic (Podstawski et al., 2022). Similarly, Hao et al. (2025) reported that university students from Macau exhibited lower levels of flexibility, cardiorespiratory fitness, and muscle strength regardless of whether they had been infected with SARS-CoV-2. These findings collectively suggest that the pandemic had a broad and persistent influence on the physical fitness and well-being of young adults worldwide.

While many individuals recovered fully from COVID-19, others continued to experience a variety of symptoms long after the acute phase of infection. These persistent symptoms, often referred to as long COVID or post-acute sequelae of SARS-CoV-2, have become a major public health concern. Meta-analyses revealed that up to 80% of individuals diagnosed with COVID-19 reported at least one symptom persisting for more than 2 weeks after infection (Lopez-Leon et al., 2021). More than 50 post-COVID-19 effects have been documented, including fatigue, dyspnea, anosmia, lung

dysfunction, and neurological complications (Kingstone et al., 2020; Maury et al., 2020; Baldini et al., 2021; Alahmari et al., 2023). Fatigue, headache, attention disorders, and hair loss were among the most common manifestations (Alwan, 2020). Notably, long COVID has been observed even in asymptomatic or mildly symptomatic individuals, often appearing weeks or months after apparent recovery.

Toward the end of the pandemic, Podstawski et al. (2024) examined the health markers of Polish male university students with and without a history of COVID-19. The results indicated that men who had been hospitalized exhibited lower PA levels, reduced motor fitness (including HR_{max}), and higher body fat mass – values approaching the upper limit of the overweight range. However, comparable data concerning female university students remain scarce. Moreover, to date, no research has analyzed selected anthropometric and physiological characteristics in students with and without a history of COVID-19 1 year after the official end of the pandemic. In Poland, the public health emergency associated with SARS-CoV-2 infection was officially declared over on July 1, 2023 (Regulation of the Minister of Health of 14 June, 2023).

Therefore, the aim of this study was to examine the relationship among COVID-19 history, PA levels, and selected anthropometric and physiological characteristics in female university students 10 months after the end of the public health emergency in Poland.

2. Materials and methods

2.1 Participants

The study was conducted from May 1 to May 30, 2024 (summer semester) in the Human Research Wellness Laboratory at the University of Warmia and Mazury in Olsztyn (UWM), and it involved 82 female students aged 19.0–28.0 years (21.23 ± 1.57). All surveyed women were of legal age. Women who were competitive athletes were excluded from the study to ensure that highly trained individuals with high motor abilities do not distort the overall results of the study population. As a result, the female students who participated in the study followed the same curriculum in fitness classes as their peers who were not recruited for the study. The study involved only women in the preovulatory (follicular phase) to ensure consistency and comparability of results across the participants (McNulty et al., 2020; Elorduy-Terrado et al., 2025). The control group (G_1) comprised 40 women (49% of all subjects) without a history of SARS-CoV-2 infection or COVID-19

symptoms. Twenty-nine students had been infected with SARS-CoV-2 but had not been hospitalized (G_2 – 35%), whereas 13 participants had been hospitalized due to COVID-19 (G_3 – 16%). Potential participants were informed about the purpose of the study during obligatory physiology and anthropometrics classes as well as functional training classes at the University of Warmia and Mazury in Olsztyn (UWM). A total of 86 female students agreed to participate in the study, and they were notified by e-mail and text message whether they had met the inclusion criteria and were provided with the date of the final recruitment. Four students were excluded from the study because they were unable to present a medical certificate confirming their history of COVID-19. Ultimately, 82 female university students (42 COVID-19 patients and 40 healthy controls) meeting the inclusion criteria were recruited for the study. The infection was confirmed by a real-time reverse transcription polymerase chain reaction test. In addition, students who had been hospitalized due to COVID-19 symptoms were requested to present a medical certificate from the hospital in which they had been examined and/or treated. The physical pre-test involved a physician who verified that the subjects had not been taking any medications or dietary supplements, were in good health, and had no history of blood diseases or other diseases affecting biochemical and biomechanical markers. None of the evaluated participants had respiratory or circulatory disorders.

For the needs of the quantitative analysis, the participants' PA levels were evaluated using the Polish short version of the standardized and validated International Physical Activity Questionnaire (IPAQ) (Biernat et al., 2007). Before the study, the participants were asked to indicate the average time (in minutes) spent on PA per week (minimum of 10 min). The energy expenditure associated with the declared weekly PA levels was expressed in metabolic equivalent of task (MET) minutes per week (Podstawski et al., 2023). The MET is the ratio of the metabolic rate during exercise to the resting metabolic rate, and 1 MET denotes the amount of oxygen consumed in 1 min, which is estimated at 3.5 mL/kg/min. Based on the declared frequency, intensity, and duration of PA (“how often, how much, how long”), the respondents were classified into groups with low PA (<600 MET-min/week), moderate PA (600 to 1,500 METs per week), and high PA levels ($\geq 1,500$ MET-min/week).

2.2 Ethical statement

The research was conducted in accordance with the guidelines and policies of the Health Science Council and the Declaration of Helsinki, and it was approved by the Ethics

Committee of the University of Warmia and Mazury in Olsztyn (37/2011). Each participant was provided with detailed information about the purpose of the study, potential risks, and the research protocol. The protocol included detailed information on measurement procedures and motor fitness testing techniques that could be practiced during training sessions immediately prior to the study. All female students gave their voluntary and informed consent to participate in the study by signing an informed consent form.

2.3 Procedures, data collection, and equipment

Before the study, the participants received detailed instructions on how to perform the maximal symptom-limited cardiopulmonary exercise test (12-min Cooper test on a rowing ergometer, 12-MCTRE), and each of them practiced the rowing technique during the sessions preceding the study. They were asked to drink at least 1 L of water on the day of the test and 0.5 L of water 2 h before the trial. The participants did not consume any foods or other fluids until the final body measurements at the end of the experiment. Anthropometric measurements were taken before motor tests. The students were asked to refrain from strenuous exercise the day before the trial, and they assisted the authors in taking the measurements.

2.3.1 Anthropometric measurements and body composition analysis

Body height was measured to the nearest 1 mm with a calibrated InLab S50 stadiometer (InBody Co., Seoul, Republic of Korea) in accordance with the relevant guidelines. Body mass (measured to the nearest 0.1 kg), the body mass index (BMI), and body composition parameters, including body fat percentage (BFP) and skeletal muscle mass (SMM), were determined by bioelectrical impedance with an InBody 270 Bioelectrical Impedance Analyzer (Biospace Co., Inc., Seoul, Republic of Korea). This foot-to-foot, hand-to-hand, and hand-to-foot device features two stainless steel footpad electrodes mounted on a platform scale and a tetrapolar 8-point tactile electrode system with two stainless steel handles. The previous research has shown that bioelectrical impedance analysis with the use of the InBody 270 analyzer is a viable tool for measuring body composition and is as effective as other measurement methods, such as dual-energy X-ray absorptiometry (Czartoryski et al., 2020; Garcia et al., 2020). The platform scale uses a single load cell to measure body mass (and stature) and calculate the BMI.

The BFP is calculated by summing the results of the segmental lean analysis to determine total lean body mass, fat mass, and the proportion of fat mass to total body mass. Muscle mass percentage (M%) is calculated by evaluating the water content in different segments of the body using the provided equations. The visceral fat level (VFL) is estimated using the provided regression equations which, according to the manufacturer, had been derived by comparing visceral fat in computerized tomography scans and impedance scans of the torso region in a segmental lean analysis.

2.3.2 12-Minute Cooper test on a rowing ergometer

The participants' strength endurance was evaluated based on the distance (in m) covered during the 12-MCTRE, according to the technique presented by Podstawski *et al.* (2022). The 12-MCTRE was performed on a Concept 2 PM5 standardized rowing ergometer (PH Markus, Szczecin, Poland), which is widely used to measure strength endurance in athletes (Alföldi *et al.*, 2021) and university students (Podstawski & Żurek, 2022; Podstawski *et al.*, 2022, 2024, 2025). The accuracy and reliability of the test were proven in a previous study by Podstawski *et al.* (2025). The following parameters were measured during the 12-MCTRE: maximum, average, and minimum heart rate ($HR_{\max, \text{avg}, \text{min}}$), total distance covered in 12 min, total power generated (W), mean time-to-500 m, calories burned per hour (kcal), and strokes per minute (S/M, stroke/min). Each participant wore a Polar H10 heart rate sensor (Polar Electro Oy, Kempele, Finland) on a chest strap. The ergometer was programmed and paired with the ErgData app (<https://www.concept2.com/support/erg-data>, accessed on 1 February 2024) and the HR sensor. The test was initiated by a verbal start cue. The test was conducted based on the procedures that had been programmed by Podstawski *et al.* (2024) and used in a study of male university students. The system is activated automatically when the participant engages the handle. It is deactivated automatically after 12 min, and data are logged in the app. The data from the ErgData app were recorded in an Excel spreadsheet. Before the test, the participants were instructed on how to correctly perform the 12-MCTRE, and they were allowed some time to practice. The test was preceded by an active warm-up (10 min). The warm-up routine included 5 min of rowing and stretching exercises (Shellock *et al.*, 1985).

2.3.3 12-MCTRE procedure for assessing $HR_{\max}$

The participants were characterized by varying PA levels (refer to Table 2 in subsection 3.2); therefore, their strength

endurance was also expected to differ. The following protocol was used to assess $HR_{\max}$ values during the test (Podstawski *et al.*, 2024).

- All subjects rowed at a damper setting of 10.
- During the first 6 min, the subjects modulated exercise intensity at own discretion to avoid excessive effort.
- Six minutes in, the subjects started to reduce their time-to-500 m by 5 s per minute, up to the 10-min mark.
- During the last 2 min, the subjects rowed at maximum intensity to achieve the highest possible HR displayed on the PM5 monitor.

2.4 Statistical analysis

Basic descriptive statistics (mean, SD, and range of variation) were calculated for each parameter. The normality of data distribution was verified with the Shapiro–Wilk test (skewness (As) was also examined). The values of all tested parameters were normally distributed. The examined variables were analyzed in three groups: (1) participants without a history of COVID-19 ($n = 40$), (2) participants who had a history of COVID-19 but had not been hospitalized ($n = 29$), and (3) participants who had been hospitalized due to COVID-19 ($n = 13$). The arithmetic means in groups were compared by one-way analysis of variance (ANOVA). If significant differences between group means were identified by ANOVA, pairwise differences were evaluated using Tukey's Honest significant difference test in the *post hoc* analysis. Data were processed in the Statistica 13 program at a significance level of $\alpha = 0.05$.

3. Results

The participants' performance in the 12-MCTRE, including their PA levels, as well as their anthropometric and physiological characteristics are presented in Table 2.

3.1 Physical activity and anthropometric characteristics of the study population

The average number of METs achieved during the test (1648 METs) suggests that the participants engaged in high-intensity exercise. However, moderate-intensity activity was noted in the majority of cases, and the students' PA level was regarded as an average. The mean BMI was within the normal range (23.1 kg/m^2); BFP was determined at 29.2%; BFM was 20.0 kg or higher, and fat-free mass (FFM) reached 45.5 kg. Based on these values, it was

Table 1. Descriptive statistics of the anthropometric and physiological characteristics of the study population

Parameter	Mean	SD	Min.	Max.	As
PA and anthropometric characteristics					
Age (years)	21.23	1.57	19.0	28.0	2.373
PA (METs/min/week)	1648.29	560.20	570.0	2950.0	-0.193
Body height (cm)	167.93	6.03	155.0	183.0	0.376
Body mass (kg)	65.49	13.98	40.8	107.4	1.205
Total body water (kg)	33.27	4.21	26.1	48.6	0.790
Proteins (kg)	8.93	1.15	7.0	13.1	0.774
Minerals (kg)	3.28	0.48	2.4	5.1	0.930
BFM (kg)	20.02	9.65	4.2	48.4	1.350
FFM (kg)	45.48	5.81	35.5	66.8	0.755
SMM (kg)	24.94	3.45	19.0	37.5	0.779
BMI (kg/m ²)	23.14	4.29	14.8	37.7	1.271
BFM% (%)	29.23	7.88	10.2	50.1	0.381
In body score	71.63	6.89	52.0	87.0	-0.892
Target weight (kg)	62.17	5.67	51.7	86.7	1.277
Weight control (kg)	-3.33	10.33	-34.0	18.5	-1.020
BFM control (kg)	-5.76	8.96	-34.0	9.5	-1.323
FFM control (kg)	2.43	2.47	0.0	10.5	0.863
BMR (Kcal)	1352.33	125.47	1137.0	1812.0	0.797
WHR	0.87	0.07	0.7	1.1	1.166
VFL	8.27	4.98	2.0	23.0	1.478
Physiological characteristics					
Distance (m)	2049.81	227.85	1664.0	2588.0	0.592
Power (W)	66.83	22.83	35.0	130.0	0.955
Energy expenditure (Kcal)	104.51	15.92	82.0	147.0	0.902
S/M (strokes/min)	25.73	3.93	20.0	42.0	1.687
Pace per 500 m (s)	174.10	23.09	115.0	216.0	-0.597
HR _{avg} (bpm)	152.42	19.13	97.0	193.0	-0.478
HR _{max} (bpm)	170.61	18.43	136.0	203.0	-0.274
Intensity of effort [s]					
Zone 1: < 90 (bpm)	45.31	115.19	0.0	714.0	3.767
Zone 2: 90 – 108 (bpm)	122.71	164.42	0.0	705.0	2.065
Zone 3: 108 – 124 (bpm)	205.65	180.05	0.0	660.0	0.963
Zone 4: 125 – 143 (bpm)	196.56	176.65	0.0	621.0	0.651

Table 1: Continued

Parameter	Mean	SD	Min.	Max.	As
Zone 5: 144 – 162 (bpm)	134.31	186.22	0.0	617.0	1.294
Zone 6: > 162 (bpm)	15.48	30.63	0.0	197.0	4.135

Notes: PA – physical activity, BFM – body fat mass, FFM – fat free mass, SMM – skeletal muscle mass, BMI – Body Mass Index, BFM % – body fat mass percent, BMR – basal metabolic rate, WHR – waist–hip ratio, VFL – visceral fat level, S/M – strokes per minute, HR – heart rate, HR_{avg} – average heart rate, HR_{max} – maximum heart rate, As – coefficient of skewness (asymmetry of distribution).

recommended that the participants should lose 3.3 kg to attain a target weight of 62.2 kg, but with an associated 5.8 kg decrease in BFM and a 2.4 kg increase in FFM. The mean waist-to-hip ratio (WHR) reached 0.9, which could be indicative of early gynoid obesity (WHR > 0.8).

3.2 Physiological characteristics of the study population

The average distance covered during the 12-MCTRE was 2049.1 m. The average generated power was 66.8 W, and the participants burned 104.5 kcal on average. The HR_{avg} and HR_{max} values were 152.4 and 170.6 bpm, respectively. An analysis of training intensity distribution revealed that the participants spent most of their exercise time (205.7 s on average) in HR (intensity) zone 3 (108–124 bpm) and somewhat less time (196.6 s) in zone 4 (124–143 bpm) (Table 1).

The PA levels and the anthropometric and physiological characteristics of the study population (groups G₁–G₃) are presented in Table 2. Most of the examined parameters differed significantly across groups.

3.3 Physical activity and anthropometric characteristics in groups

Healthy controls (G₁) as well as students who had been diagnosed with COVID-19 but had not been hospitalized (G₂) were characterized by significantly ($p < 0.001$) higher PA levels than hospitalized COVID-19 patients (G₃ – moderate). In addition, group G₁ students had significantly ($p < 0.001$) higher PA levels (2085 METs/min/week) than group

Table 2. Descriptive statistics of the anthropometric and physiological characteristics of the study population

Characteristic	Group*						Difference		
	G ₁ (n = 40)		G ₂ (n = 29)		G ₃ (n = 13)		F	p	Cohen's f
	Mean	SD	Mean	SD	Mean	SD			
	PA and anthropometric characteristics								
PA (METs/min/week)	2085.13 ^{2,3}	312.13	1439.66 ^{1,3}	293.33	769.62 ^{1,2}	152.51	115.26	<0.001	1.7082
Body height (cm)	167.44	5.15	167.43	5.96	170.54	8.09	2.11	ns	0.2311
Body mass (kg)	59.99 ³	5.56	63.16 ³	9.47	87.65 ^{1,2}	18.01	37.93	<0.001	0.9799
TBW (kg)	32.17 ³	3.47	32.97 ³	3.50	37.28 ^{1,2}	5.49	8.76	<0.001	0.4709
Proteins (kg)	8.65 ³	0.96	8.83 ³	0.94	9.98 ^{1,2}	1.51	7.97	<0.001	0.4492
Minerals (kg)	3.14 ³	0.34	3.25 ³	0.41	3.77 ^{1,2}	0.65	10.59	<0.001	0.5178
BFM (kg)	16.02 ³	3.50	18.10 ³	6.09	36.61 ^{1,2}	11.90	53.15	<0.001	1.16
FFM (kg)	43.97 ³	4.75	45.06 ³	4.84	51.05 ^{1,2}	7.64	8.83	<0.001	0.4728
SMM (kg)	24.07 ³	2.87	24.69 ³	2.83	28.18 ^{1,2}	4.55	8.35	<0.001	0.4598
BMI (kg/m ²)	21.37 ³	1.92	22.48 ³	2.76	30.06 ^{1,2}	5.60	17.69	<0.001	0.6692
BFM (%)	26.56 ³	4.27	27.98 ³	6.66	40.23 ^{1,2}	9.89	24.07	<0.001	0.7806
In body score	74.53 ³	4.55	72.66 ³	3.89	60.46 ^{1,2}	7.24	42.16	<0.001	1.0331
Target weight (kg)	61.07 ³	4.21	61.24 ³	4.78	67.62 ^{1,2}	8.25	8.47	<0.001	0.4631
Weight control (kg)	1.09 ³	4.56	−1.92 ³	6.79	−20.03 ^{1,2}	13.15	42.21	<0.001	1.0337
BFM control (kg)	−2.04 ³	3.36	−4.04 ³	5.71	−21.05 ^{1,2}	11.08	51.48	<0.001	1.1416
FFM control (kg)	3.13 ³	2.62	2.11	1.93	1.02 ¹	2.48	4.26	0.018	0.3284
BMR (Kcal)	1319.80 ³	102.59	1343.35 ³	104.61	1472.46 ^{1,2}	164.82	8.80	<0.001	0.472
WHR	0.85 ³	0.04	0.85 ³	0.05	0.97 ^{1,2}	0.10	26.76	<0.001	0.8231
VFL	6.13 ³	1.68	7.24 ³	3.09	17.15 ^{1,2}	5.73	63.53	<0.001	1.2682
	Physiological characteristics								
Distance (m)	2226.95 ^{2,3}	184.33	1928.69 ^{1,3}	73.40	1774.92 ^{1,2}	74.41	68.19	<0.001	1.3139
Power (W)	84.10 ^{2,3}	20.39	54.10 ¹	6.27	42.08 ¹	5.25	55.06	<0.001	1.1806
Energy expenditure (Kcal)	116.73 ^{2,3}	13.90	95.38 ¹	4.39	87.31 ¹	4.27	58.25	<0.001	1.2172
S/M (strokes/min)	26.85 ^{2,3}	4.63	24.93 ¹	2.56	24.08 ¹	3.25	3.59	0.032	0.3015
Pace per 500 m (s)	156.93 ^{2,3}	18.59	186.52 ¹	7.15	199.23 ¹	17.82	51.66	<0.001	1.1436
HR _{avg} (bpm)	157.85 ³	19.45	150.79	13.86	139.31 ¹	22.38	5.27	0.007	0.3653
HR _{max} (bpm)	175.35 ³	17.35	168.24	17.72	160.77 ¹	19.58	3.75	0.028	0.3081
	Intensity of effort [s]								
Zone 1: < 90 (bpm)	41.58	96.17	11.52 ³	16.39	132.15 ²	218.89	5.52	0.006	0.3738
Zone 2: 90 – 108 (bpm)	85.20	108.83	162.28	216.06	149.85	160.61	2.11	ns	0.2311
Zone 3: 108 – 124 (bpm)	183.25	157.48	231.76	209.95	216.31	178.68	0.63	ns	0.1263
Zone 4: 125 – 143 (bpm)	218.23	178.93	185.72	182.59	154.08	158.03	0.73	ns	0.1359
Zone 5: 144 – 162 (bpm)	169.05	202.22	118.76	181.86	62.08	117.33	1.18	ns	0.1728
Zone 6: > 162 (bpm)	22.70	40.73	9.97	13.49	5.54	12.65	2.34	ns	0.2434

Notes: * G₁ – women without a history of COVID-19; G₂ – women with a history of COVID-19 who had not been hospitalized; G₃ – women who had been hospitalized due to COVID-19, ns – not significant. Different superscript numbers represent significant differences between groups. Refer to Table 1 for a description of the remaining abbreviations.

G₂ subjects (1439 METs/min/week). Furthermore, the following parameters were significantly ($p < 0.001$) lower in groups G₁ and G₂: body mass, total body water (TBW), proteins, minerals, BFM, FFM, SMM, BMI, BFP, target weight, weight control, BFM control, FFM control (G₁ only, $p = 0.018$), basal metabolic rate (BMR), WHR, and VFL. Body height was the only parameter that did not differ significantly between groups (Table 2).

3.4 Physiological characteristics in groups

Healthy controls covered significantly ($p < 0.001$) longer distances in the 12-MCTRE than the remaining participants (groups G₂ and G₃). In turn, group G₂ subjects covered significantly ($p < 0.001$) longer distances than group G₃ participants. In addition, the following parameters were significantly ($p < 0.001$) higher in group G₁: power generated ($p < 0.001$), energy expenditure ($p < 0.001$), S/M ($p = 0.032$), and pace per 500 m ($p < 0.001$). HR_{avg} and HR_{max} values were significantly higher in healthy controls (G₁) than in students who had been hospitalized due to COVID-19 (G₃). The HR_{max} peaked in the healthy control group (G₁ – 175 bpm), and it was 7 bpm higher than in group G₂ and 15 bpm higher than in group G₃. No significant differences in physiological parameters were observed between group G₂ and group G₃ participants. In addition, group G₃ students remained in HR zone 1 over a significantly longer period of time than group G₂ females (132.2 and 11.5 s, respectively). No significant differences were noted in the times spent in the remaining HR zones (zone 2 to zone 6) (Table 2).

4. Discussion

This study was undertaken to examine the relationships between COVID-19, PA levels, and the anthropometric and physiological characteristics of female university students 10 months after the end of the pandemic in Poland. The students' performance was assessed during the 12-MCTRE, and special attention was paid to HR_{max} values during peak effort.

In the study population, the HR_{max} (171 bpm) was 49 bpm below the normal value calculated using the following formula: $HR_{max} = 220 - \text{age}$ (Fox et al., 1971). This parameter was also 16 bpm lower than that found in male university students ($HR_{max} = 187$ bpm) immediately after the end of the pandemic (Podstawski et al., 2024). The observed decrease in HR_{max} values probably could not result from the reduced PA levels of young women (1948 METs), compared with the PA levels of young men tested in the previous study (1975 METs) because the difference

between these groups (27 METs) was not significant. A more detailed analysis of group results revealed that students who had been hospitalized due to COVID-19 were characterized by the lowest values of HR_{max} (161 bpm), which were significantly ($p = 0.028$) lower than in healthy controls (by 15 bpm) and in subjects who had contracted COVID-19 but had not been hospitalized (by 7 bpm).

The differences between groups (G₁–G₃) shed more light on the relationships between COVID-19 and PA levels, physiological and anthropometric characteristics, and HR_{max}. For example, the PA levels of the study population approximated the lower limit of moderate intensity exercise (770 METs) in women who had been hospitalized due to COVID-19 (G₃) and the upper limit of moderate intensity exercise (1440 METs) in group G₂ students, whereas group G₁ participants were characterized by high PA levels (2090 METs). A systematic review of cross-sectional studies conducted by Oliveira et al. (2017) revealed that the autonomic control of cardiac function is significantly correlated with PA and cardiorespiratory fitness. In general, both older (Lester et al., 1968) and more recent research studies (Whyte et al., 2008) demonstrated that similarly aged and athletically trained individuals with high levels of motor fitness achieve slightly but significantly lower values of HR_{max} than untrained individuals in various modes of exercise. In contrast, in the present study, the lowest HR_{max} values were noted in the least physically active women who were also characterized by the least desirable anthropometric parameters. This discrepancy may be attributed to the fact that healthy controls were compared with COVID-19 patients. In this case, the group of COVID-19 patients comprised not only women who had been infected with SARS-CoV-2 and/or hospitalized but also students whose body composition parameters could be indicative of poor health. These parameters include BMI, and women with a history of COVID-19 and/or hospitalization had very high BMI values (>30 kg/m²) indicative of class 1 obesity. In group G₃ students, obesity was confirmed by the highest values of BFP ($>40\%$), VFL (17.2), and WHR (0.97). Obesity is not only a medical risk factor (Pi-Sunyer, 2009), and since 1998, it has been regarded as a serious disease that requires treatment (Rosen, 2014). Class 1 obesity induces changes in respiratory, cardiovascular, and renal physiology (Shashaty & Stapleton, 2014; Head, 2015), thereby considerably limiting exercise capacity (Gaul et al., 2016; Wang et al., 2016). Individuals with class 1 obesity are not able to achieve the HR_{max} values consistent with those of healthy persons (Oja, 1995; Podstawski et al., 2024; Tanaka et al., 2001). Reduced physical fitness is negatively correlated with susceptibility to infection, including COVID-19 (Larrateguy et al., 2023). Obese

individuals also exhibit adverse cardiometabolic profiles and suffer from additional chronic diseases (Kivimäki *et al.*, 2017; Nyberg *et al.*, 2018). The fatal impact of COVID-19 was particularly evident among individuals with adverse cardiometabolic profiles and coexisting chronic conditions (Barron *et al.*, 2020; Simonnet *et al.*, 2020; Zhou *et al.*, 2020).

Research studies have reported decreased HR_{max} values—consistent with chronotropic incompetence—in individuals with a history of SARS-CoV-2 infection, including both those diagnosed with the post-COVID-19 condition and athletes undergoing endurance tests after returning to training (Jimeno-Almazán *et al.*, 2021; Longobardi *et al.*, 2022; Stavrou *et al.*, 2023). These symptoms can prevent individuals from achieving the anticipated HR_{max} values during endurance tests, leading to a decline in physical performance and more rapid onset of fatigue. These observations can be largely attributed to dysautonomia, namely, an imbalance between sympathetic and parasympathetic systems, that can persist after infection. Chronic infections, microcirculation disorders, and deconditioning resulting from prolonged physical inactivity during illness and convalescence could also play a role. In turn, direct myocardial injury and post-inflammatory cardiomyopathy have been reported far less frequently (Durstfeld *et al.*, 2023). However, a reduction in HR_{max} values was not observed in all studies. In some subgroups, physical effort elicited an appropriate increase in HR_{max} values, whereas in athletes, only a transient decline was observed, with values returning to normal after several weeks or months—on average, around 60 days after infection (Hasler *et al.*, 2025). These variations could be attributed to differences in clinical progression of disease, level of training, and individual susceptibility to autonomic dysregulation. Therefore, it remains unclear whether the reduced HR_{max} observed in G_3 is a direct consequence of COVID-19 infection or an indirect effect mediated by obesity and reduced PA levels. Future longitudinal studies are needed to disentangle these factors. The present study revealed significant correlations between COVID-19 and negative outcomes, such as overweight/obesity and reduced PA and motor fitness levels, which persist over a prolonged period of time (approximately 10 months) after the end of the pandemic (Larrateguy *et al.*, 2023; Vélez-Santamaría *et al.*, 2023). In conclusion, the study provides new evidence on the long-term effects of COVID-19 on PA, motor fitness, and HR_{max} in female university students. The observed patterns closely mirror those previously reported in male cohorts, suggesting that the pandemic's impact on these physiological and performance-related parameters is similar for both sexes despite the fact that the males were assessed immediately after the pandemic. These findings highlight the lasting effects of

COVID-19 on the physical functioning of young adults and underscore the need for further research comparing long-term recovery trajectories across sexes. Furthermore, these results invite further investigation into the mechanisms underlying the observed sex similarities, as well as longitudinal studies exploring interventions to support the recovery of physical fitness in young adults after the pandemic.

5. Strengths and limitations

The main limitation of the study was the absence of pre-pandemic comparative data, which prevents a conclusive attribution of reduced PA levels and unfavorable changes in body composition or physiological parameters to SARS-CoV-2 infection. PA was self-reported using the IPAQ questionnaire, which may be subject to recall bias or overestimation/underestimation. Nevertheless, IPAQ remains a validated and widely applied tool for assessing PA in large-scale studies, where objective measurements are often not feasible. Due to the study design and participant selection, the direction of the observed relationships could not be clearly determined. It remains uncertain whether women with lower PA levels and less favorable body composition were more susceptible to infection, or whether SARS-CoV-2 infection led to a decline in PA and deterioration of these parameters. Both explanations are supported by previous research cited in Section 4. Another limitation was the inclusion of female participants only. Studies involving males were conducted immediately after the pandemic (Podstawski *et al.*, 2024), and logistical challenges led to the decision to examine females later and separately to ensure methodological consistency (Podstawski & Żurek, 2022). Despite these limitations, the study demonstrated that the new 12-MCTRE is an effective tool for assessing HR_{max} in less physically active young women. The rowing ergometer test also provides a reliable method for evaluating performance in overweight or obese participants, for whom running tests are not recommended.

6. Conclusion

The factors that were negatively associated with COVID-19 in young women and persisted nearly one year after the end of the pandemic were identified in the present study. The group of factors that were significantly correlated with a history of COVID-19 and severe complications (requiring hospitalization) included low PA levels, low motor fitness, and high values of BMI, WHR, VFL, and BFP. Female university students who had been

hospitalized due to COVID-19 met the aforementioned criteria around 10 months after the pandemic and were characterized by lower HR_{max} values than women without a history of COVID-19. The study underscores the need for longitudinal studies involving measurements of body composition and motor fitness and in-depth analyses of HR_{max} values in university students.

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Author contributions

Conceptualization: RP; data curation: RP; formal analysis: KB; funding acquisition: rp; investigation: RP, JS, PJ; methodology: RP, FI; validation: KB, RP; project administration: RP; software: KB; supervision: RP; writing – original draft: RP, KB, AS, FI; writing – review and editing: RP, KrB, AS; visualization: RP; resources: RP; all authors have read and agreed to the published version of the manuscript.

Conflict of interest statement

The authors declare no conflicts of interest.

Ethics approval and consent to participate

The research was conducted in accordance with the guidelines and policies of the Health Science Council and the Declaration of Helsinki, and it was approved by the Ethics Committee of the University of Warmia and Mazury in Olsztyn (37/2011). All female students gave their voluntary and informed consent to participate in the study by signing an informed consent form.

Data availability statement

The access to Excel data generated during this study has been restricted by the Ethics Committee of the UWM in Olsztyn to

protect the participants' privacy. Researchers who meet the criteria for access to confidential data can submit a data request by email to podstawski@robert@gmail.com.

Consent for publication

Consent was obtained from each participant for the publication of survey data.

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