Effects of COVID-19 infection on maximal oxygen consumption, gas exchange, and substrate oxidation in young adults who are overweight or obese

Efectos de la infección por COVID-19 en el consumo máximo de oxígeno, el intercambio gaseoso y la oxidación de sustratos en adultos jóvenes con sobrepeso u obesidad

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Abstract

Introduction: The impact of COVID-19 on maximal oxygen consumption ($\dot{V}O_2max$), gas exchange, and substrate oxidation in individuals who are overweight or obese remains uncertain and warrants investigation.
Objective: To investigate the effects of prior COVID-19 infection on $\dot{V}O_2max$, gas exchange, and substrate oxidation in overweight and obese young adults.
Methodology: Ninety young men and women who were overweight or obese were enrolled in the study and divided into two groups: those previously infected with COVID-19 (COVID) and those with no history of COVID-19 infection (NCOVID). Anthropometry, resting heart rate (RHR), blood pressure, and health questionnaire data were collected. $\dot{V}O_2max$, oxygen consumption ($\dot{V}O_2$), carbon dioxide production ($\dot{V}CO_2$), estimated fat oxidation (FO), carbohydrate oxidation (CHO), respiratory exchange ratio (RER), and minute ventilation ($\dot{V}E$) were assessed during an incremental treadmill $\dot{V}O_2max$ test. Differences between the groups were assessed using paired and independent sample t-tests. Associations between the parameters were examined using the Pearson product-moment correlation coefficient.
Results: Among the women, the $\dot{V}O_2$, $\dot{V}CO_2$, CHO, FO, and RER peaks were significantly different in the COVID group compared with the NCOVID group (all, $p < .05$). There was no statistically significant difference in $\dot{V}O_2max$ between the COVID and NCOVID groups. However, in both groups $\dot{V}O_2max$ differed significantly by sex, with higher values in the men than women. In the men, $\dot{V}O_2max$, $\dot{V}O_2$, and $\dot{V}CO_2$ were correlated with the participants' body mass, BMI, and exercise frequency. In the NCOVID group, RHR was found to be moderately correlated with $\dot{V}O_2max$, $\dot{V}O_2$, $\dot{V}CO_2$, and $\dot{V}E$ in the men, while in the NCOVID women, $\dot{V}CO_2$ was associated with the RHR, exercise frequency, and exercise duration.
Conclusion: Women who were overweight or obese and who had a history of COVID-19 infection exhibited altered gas exchange and substrate oxidation responses during maximal exercise compared with their never-infected peers, despite showing no difference in $\dot{V}O_2max$.

Keywords

COVID-19; overweight; $\dot{V}O_2max$; fat oxidation; carbohydrate oxidation.

Resumen

Introducción: El impacto de la COVID-19 en el consumo máximo de oxígeno ($\dot{V}O_2max$), el intercambio gaseoso y la oxidación de sustratos en personas con sobrepeso u obesidad sigue siendo incierto y requiere investigación.
Objetivo: Investigar los efectos de una infección previa por COVID-19 sobre el $\dot{V}O_2max$, el intercambio gaseoso y la oxidación de sustratos en adultos jóvenes con sobrepeso u obesidad.
Metodología: Noventa hombres y mujeres jóvenes con sobrepeso u obesidad participaron en el estudio y fueron divididos en dos grupos: aquellos con infección previa por COVID-19 (COVID) y aquellos sin antecedentes de infección por COVID-19 (NCOVID). Se recopilaron datos antropométricos, frecuencia cardíaca en reposo (FCR), presión arterial y respuestas a un cuestionario de salud. Se evaluaron el $\dot{V}O_2max$, el consumo de oxígeno ($\dot{V}O_2$), producción de dióxido de carbono ($\dot{V}CO_2$), la oxidación estimada de grasas (FO), la oxidación de carbohidratos (CHO), la razón de intercambio respiratorio (RER) y la ventilación por minuto ($\dot{V}E$) durante una prueba incremental de $\dot{V}O_2max$ en cinta rodante. Las diferencias entre los grupos se analizaron mediante pruebas t para muestras pareadas e independientes. Las asociaciones entre los parámetros se examinaron utilizando el coeficiente de correlación de momento-producto de Pearson.
Resultados: Entre las mujeres, los valores pico de $\dot{V}O_2$, $\dot{V}CO_2$, CHO, FO y RER fueron significativamente diferentes en el grupo COVID en comparación con el grupo NCOVID (todos, $p < .05$). No se encontró una diferencia estadísticamente significativa en el $\dot{V}O_2max$ entre los grupos COVID y NCOVID. Sin embargo, en ambos grupos el $\dot{V}O_2max$ difirió significativamente según el sexo, con valores más altos en los hombres que en las mujeres. En los hombres, el $\dot{V}O_2max$, el $\dot{V}O_2$ y el $\dot{V}CO_2$ se correlacionaron con la masa corporal, el IMC y la frecuencia de ejercicio de los participantes. En el grupo NCOVID, la FCR mostró una correlación moderada con el $\dot{V}O_2max$, el $\dot{V}O_2$, el $\dot{V}CO_2$ y el $\dot{V}E$ en los hombres, mientras que en las mujeres NCOVID, el $\dot{V}CO_2$ se asoció con la FCR, la frecuencia y la duración del ejercicio.
Conclusión: Las mujeres con sobrepeso u obesidad y con antecedentes de infección por COVID-19 mostraron respuestas alteradas en el intercambio gaseoso y en la oxidación de sustratos durante el ejercicio máximo, en comparación con sus pares que nunca se infectaron, a pesar de no presentar diferencias en el $\dot{V}O_2max$.

Palabras clave

COVID-19; sobrepeso; $\dot{V}O_2max$; oxidación de grasas; oxidación de carbohidratos.

Introduction

Coronavirus disease 2019 (COVID-19) is transmitted via body fluids, particularly saliva and mucus (Alsharif & Qurashi, 2021). COVID-19 infection primarily affects the respiratory system (Mihalick et al., 2021). The common symptoms of COVID-19 infection include fever, cough, sore throat, loss of taste, and loss of smell (Albashir, 2020). Management typically involves pharmacotherapy as indicated, adequate rest, and a temporary restriction of physical activity (Wells et al., 2021). Although significant progress has been made in understanding the acute clinical management of COVID-19, the longer-term consequences of infection, particularly regarding its impact on health-related fitness, remain under explored.

The COVID-19 pandemic that spread globally in 2020 led to widespread adverse changes in lifestyle and health-related behaviours with an aim to halt the spread of the virus. During this time, reductions in muscular endurance, muscle mass, physical activity, and sleep quality were widely reported (Ganesan et al., 2021; Musa et al., 2023), alongside increases in body fat, hypertension, and diabetes in many individuals (Dourado et al., 2025; Kumar et al., 2025; Musa et al., 2023). Among individuals with severe COVID-19 infection, cardiovascular fitness was significantly reduced and found to be correlated with the individuals' quality of life during the recovery period (Ekblom-Bak et al., 2021; Zavala Crichton et al., 2025). Alterations in exercise behaviour, along with the persistence of fatigue and exertional dyspnea, have been commonly reported following COVID-19 infection (Paneroni et al., 2021; Sawekchan & Silalertdetkul, 2024; Yaiyong et al., 2026). Collectively, these observations indicate that COVID-19 affected the health behaviours of individuals and multiple domains of physical fitness. Given this, it seems essential to gain further insights into the impact of long COVID-19 infection on physical fitness to more clearly understand how the pandemic has altered human health and behavior in the long term, and for developing effective strategies to restore and safeguard physical well-being in the future.

It has been reported that the prevalence of obesity increased during the COVID-19 pandemic (Garbsch et al., 2024; Guo et al., 2025). Obesity is well known to be associated with cardiovascular diseases, hypertension, and impaired cardiovascular function (Powell-Wiley et al., 2021), and has also been associated with a higher mortality risk among patients with COVID-19 (Albashir, 2020). Post-COVID-19, overweight women have been found to experience mild to moderate pain or discomfort, contributing to diminished health-related quality-of-life outcomes (Yaiyong et al., 2026). Body mass index (BMI) is associated with trunk fat mass, and a high BMI can negatively impact cardiovascular health and carry a higher risk of cardiovascular disease (Held et al., 2022; Silalertdetkul, 2024). Consequently, examining the impact of COVID-19 infection on individuals who are obese or overweight is essential to understand how COVID-19 infection has affected long-term health in this population and further to create effective strategies and guidance for personalised rehabilitation and recovery for such individuals following COVID-19 infection.

The maximal oxygen consumption ($\dot{V}O_2max$) is the highest amount of oxygen the body can utilise per minute (Heyward & Gibson, 2014). Cardiorespiratory fitness has been associated with the risk of mortality from COVID-19 infection (Christensen et al., 2021). Several studies have reported reductions in $\dot{V}O_2max$ in individuals following recovery from COVID-19 infection, including in professional football players (Parpa & Michaelides, 2022), and a lower $\dot{V}O_2max$ in normal-weight young men with prior COVID-19 infection compared with uninfected COVID-19 peers (Crameri et al., 2020). Conversely, one study found no significant difference in submaximal $\dot{V}O_2max$ between individuals with and without a history of COVID-19 infection among healthy college students (Alvaro et al., 2024). The $\dot{V}O_2max$ is associated with the BMI, body fat percentage, and blood pressure in healthy individuals (Kang & Ko, 2019; Mondal & Mishra, 2017). Additionally, a reduced cardiovascular capacity has been suggested to occur in obese individuals with COVID-19 infection (Rubio Herrera & Breton Lesmes, 2021). However, it remains unclear whether the $\dot{V}O_2max$ in young individuals who are overweight or obese is affected by COVID-19. Therefore, a focused investigation into the effects of COVID-19 infection on the $\dot{V}O_2max$ in young men and women who are overweight or obese is needed to better understand the interplay between COVID-19 infection, cardiorespiratory fitness, and body composition.

It has been reported that substrate metabolism during exercise may be altered following COVID-19 infection, potentially contributing to exercise limitations during recovery; for example, oxygen consumption and ventilatory efficiency during moderate-intensity exercise were reported to be lower in women recovering from COVID-19 compared with healthy controls (Pleguezuelos et al., 2022). Additionally, reduced fat oxidation during cardiopulmonary exercise testing has been observed in normal-weight individuals with post-acute COVID-19 infection, while lower fat oxidation than normative values has been reported in active men with long COVID-19 infection (de Boer et al., 2022; Meloni et al., 2023). It has been hypothesised that these reductions in fat oxidation reflect an underlying mitochondrial dysfunction (Guntur et al., 2022).

However, it remains unclear whether, and if so how, COVID-19 affects $\dot{V}O_2max$, oxygen consumption ($\dot{V}O_2$), and carbon dioxide production ($\dot{V}CO_2$), particularly among sedentary young adults who are overweight or obese. Moreover, the extent to which potential alterations in $\dot{V}O_2$ and $\dot{V}CO_2$ influence substrate utilisation, particularly the balance of carbohydrate and fat oxidation in this population, is not yet well understood. Further research is needed to clarify these relationships and their implications for long-term metabolic recovery following COVID-19 infection. Therefore, the objective of this research was to examine the impact of COVID-19 infection on $\dot{V}O_2max$, gas exchange, and substrate oxidation in young men and women who are overweight or obese.

Method

Study design

This cross-sectional study compared young adults who were overweight or obese and who had a prior history of COVID-19 infection (COVID) to age-matched counterparts who were also overweight or obese but who had no history of COVID-19 infection (NCOVID). The maximal oxygen consumption ($\dot{V}O_2max$) along with related gas-exchange and substrate-oxidation variables, were assessed in both groups. The study protocol was reviewed and approved by the Institutional Review Board (IRB) of Srinakharinwirot University, Ethics Committee No. SWUEC/E/G-135/2566, in accordance with ethical standards for research involving human participants. All individuals provided written informed consent before they participated in the study.

Participants

A total of 90 male and female participants classified as overweight or Class I obese, aged between 18 and 25 years old, were recruited for the study. Participants were divided into two groups: a COVID group and NCOVID group. The inclusion criteria were men or women, aged between 18 and 25 years old, with a BMI ranging from 25 to 35 kg/m^2, and without any injuries or underlying medical conditions that could contraindicate maximal exercise testing. The COVID group consisted of individuals with a documented history of mild-to-moderate acute COVID-19 infection who subsequently developed symptoms consistent with long COVID. Participants in this group had confirmed their infection using an Antigen Test Kit (ATK), with a time of diagnosis between one and twelve months before participation in the study. The NCOVID group consisted of individuals with no self-reported or documented history of COVID-19 infection. The exclusion criteria included current or unresolved COVID-19 infection, the presence of any injuries or medical conditions that would contraindicate maximal exercise testing, and a body mass index (BMI) of less than 25 or greater than 35 kg/m^2.

Preliminary assessment

Anthropometric measurements were taken, including height and body mass (OMRON, Japan), and were used to calculate the BMI (kg/m^2). Resting blood pressure and resting heart rate (RHR) were measured in a seated position following a minimum of five minutes of rest, using an automated oscillometric device (OMRON, Japan). Participants completed a general health questionnaire and the Physical Activity Readiness Questionnaire (PAR-Q) before undergoing a maximal oxygen consumption ($\dot{V}O_2max$) assessment (Venkataraman et al., 2024). Additional health-related information was obtained through a structured questionnaire, including the presence of any chronic conditions, smoking status, COVID-19 history for the COVID group, number of COVID-19 vaccine doses received, habitual exercise frequency (sessions/week), and typical exercise duration (minutes/session).

Experimental control

To ensure standardisation and minimise potential confounding factors, participants were instructed to adhere to the following pre-test guidelines. Participants were required to abstain from food consumption for at least 4 hours before $\dot{V}O_2max$ testing. They were also advised to avoid vigorous or high-intensity physical activity for 24 hours before testing. Additionally, the participants were requested to avoid the consumption of caffeine for at least 12 hours, nicotine for at least 3 hours, and alcohol for at least 24 hours before testing. Additionally, participants were advised to avoid any foods or medications that could influence their heart rate on the day of testing. Participants with any health conditions that might affect the test outcomes were instructed to inform the examiner beforehand. Before $\dot{V}O_2max$ testing, all the participants were screened for COVID-19 infection using an ATK.

Maximal oxygen consumption assessment

The maximal oxygen consumption ($\dot{V}O_2max$) was measured (CardioCoachCO$_2$, Korr Medical Technologies, USA) for the participants in the two groups. The $\dot{V}O_2max$ testing was performed on a treadmill (h/p/cosmos Mercury, Germany) using a graded exercise test until exhaustion. The workload was progressively increased every 2-3 minutes until the participants reached their maximum heart rate (220 - age), rating of perceived exertion (Borg, 1998) was equal to or above 17, and they could no longer run. The participants' heart rate was monitored continuously (Polar H10, Malaysia), and the rating of perceived exertion (RPE) levels was recorded throughout the test. The oxygen consumption ($\dot{V}O_2$), maximum carbon dioxide production ($\dot{V}CO_2max$), carbon dioxide production ($\dot{V}CO_2$), minute ventilation ($\dot{V}E$), respiratory exchange ratio (RER), maximum heart rate (MHR), test duration, and estimated carbohydrate oxidation (CHO), fat oxidation (FO), and total energy expenditure (EE) during the incremental $\dot{V}O_2max$ test were recorded. Here, RER is the ratio of carbon dioxide produced and total oxygen consumed. Carbohydrate and fat oxidation were estimated (Frayn, 1983) using the equation shown below.

$$\text{Carbohydrate oxidation (g/min)} = 4.55\dot{V}CO_2 - 3.21\dot{V}O_2$$

$$\text{Fat oxidation (g/min)} = 1.67\dot{V}O_2 - 1.67\dot{V}CO_2$$

Data analysis

Data were analysed using the SPSS software package (version 24; IBM, IL, USA). Descriptive statistics are presented as the mean and standard deviation (mean ± SD). Independent-samples and paired-samples t-tests were conducted to compare group differences in terms of the participants' characteristics and exercise variables, including $\dot{V}O_2max$, $\dot{V}O_2$, $\dot{V}CO_2$, MHR, test duration, CHO, FO, and EE. The relationships between $\dot{V}O_2max$, $\dot{V}O_2$, $\dot{V}CO_2$, and selected physiological variables were analysed using Pearson's correlation coefficient (r). A significance level of .05 was used to determine statistical significance. The sample size was calculated based on an assumed effect size (Cohen's d) of .61, a significance level (α) of .05, and a target statistical power of .80, in accordance with established guidelines (Kang, 2021; Parpa & Michaelides, 2022). Based on these input parameters, an estimated sample size of 43 participants per group, resulting in a total sample size of 86 participants, was estimated to be sufficient and appropriate to achieve a statistical power of at least 80%.

Results

General information

Among both the men and women, there were no significant between-group differences in age, height, body mass, BMI, blood pressure, resting heart rate, exercise duration, and exercise frequency (all, $p > .05$). However, among the women, the number of vaccine doses received was significantly lower in the NCOVID group compared with the COVID group ($p = .03$). In the COVID group, the men differed significantly from the women in term of body mass ($p < .001$), height ($p < .001$), SBP ($p = .001$), RHR ($p = .001$), and exercise frequency ($p = .02$). Similarly, in the NCOVID group, the men had a significantly higher body mass ($p = .001$), height ($p < .001$), and exercise frequency ($p = .02$) compared with the women. The data are presented in Table 1.

Table 1. Comparisons of the age, gender, height, body mass, body mass index (BMI), systolic blood pressure (SBP), diastolic blood pressure (DBP), resting heart rate (RHR), exercise frequency per week, exercise duration, number of COVID-19 vaccines received (No. vaccine), and time between acute COVID infection and the study between the COVID-19 infection group (COVID) and the non-COVID-19 infection group (NCOVID), N = 90.

General information	Men			Women		
	COVID N = 25	NCOVID N = 25	p-value	COVID N = 20	NCOVID N = 20	p-value
Age (year)	19.9 ± 1.2	20.1 ± 1.7	.59	20.5 ± 1.4	20.0 ± 1.5	.30
Gender						
Men	25	25	-	-	-	-
Women	-	-	-	20	20	-
Anthropometry						
Height (cm)	174.8 ± 4.6	174.0 ± 5.5	.66	160.6 ± 5.9#	162 ± 5.5	.20
Body mass (kg)	93.3 ± 16.5	96.6 ± 18.3	.57	76.2 ± 9.2#	79.0 ± 13.8	.46
BMI (kg/m^2)	30.6 ± 5.7	32.0 ± 7.0	.51	29.5 ± 2.8	29.6 ± 4.3	.95
Physiological parameters						
SBP (mmHg)	122.0 ± 12.0	122.9 ± 11.5	.81	108.6 ± 12.9#	117.0 ± 15.2	.07
DBP (mmHg)	65.3 ± 13.8	66.5 ± 10.5	.73	66.1 ± 9.9	67.7 ± 11.6	.62
RHR (bpm)	76.3 ± 10.7	80.3 ± 11.4	.16	83.6 ± 7.9#	82.5 ± 9.3	.71
Exercise behaviour						
Frequency (time/week)	3.2 ± 1.7	3.6 ± 1.6	.39	2.1 ± 1.3	2.5 ± 1.4#	.26
Duration (minutes)	59.6 ± 29.2	63.8 ± 35.8	.62	45.8 ± 27.8	46.8 ± 32.5#	.92
No.vaccine	2.8 ± 0.8	2.6 ± 0.8	.31	3.0 ± 0.6	2.5 ± 0.8*#	.03
COVID-19 (months)	10.3 ± 4.2	0	-	7.7 ± 4.7	0	-

Data are presented as the mean ± standard deviation (SD). *Significant difference between the COVID and NCOVID groups, p < .05.
#Significant difference between the men and women in the COVID or NCOVID groups, p < .05.

Oxygen consumption, carbon dioxide production, and substrate oxidation

In the women, significant differences were observed between the COVID and NCOVID groups in terms of the $\dot{V}O_2$ mean, $\dot{V}O_2$ last 15 seconds, $\dot{V}CO_2$ mean, $\dot{V}CO_2$ last 15 seconds, mean CO, mean FO, and RER peak (all, $p < .05$). Among the total participants in the COVID group, the men had significantly higher values than the women in terms of the $\dot{V}O_2$max ($p = .002$), $\dot{V}O_2$mean ($p = .004$), $\dot{V}O_2$ last 15 seconds ($p = .01$), $\dot{V}CO_2$max ($p = .01$), $\dot{V}CO_2$ mean ($p = .01$), $\dot{V}CO_2$ last 15 second ($p = .01$), total CHO ($p < .001$), mean CHO ($p = .04$), total FO ($p = .02$), mean FO ($p = .04$), total EE ($p < .001$), mean EE ($p < .001$), RER peak ($p = .001$), $\dot{V}E$ peak ($p < .001$), and $\dot{V}E$ last 15 seconds ($p < .001$). In the NCOVID group, the men demonstrated significantly higher values than the women for the $\dot{V}O_2$max, $\dot{V}O_2$ mean, $\dot{V}O_2$ last 15 seconds, $\dot{V}CO_2$ max, $\dot{V}CO_2$ mean, $\dot{V}CO_2$ last 15 seconds, total CHO, total fat oxidation, total EE, mean EE, $\dot{V}E$ peak, and $\dot{V}E$ last 15 seconds (all, $p < .001$). The comparative data are presented in Table 2.

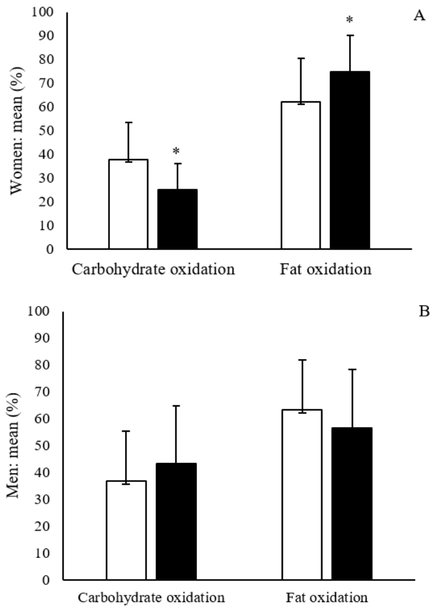
Table 2. Comparisons of the maximum oxygen consumption ($\dot{V}O_2$max), oxygen consumption ($\dot{V}O_2$), maximum carbon dioxide production ($\dot{V}CO_2$max), carbon dioxide production ($\dot{V}CO_2$), total carbohydrates oxidation (CO), mean carbohydrate oxidation (CO), fat oxidation (FO), mean fat oxidation, energy expenditure (EE), respiratory exchange ratio (RER), minute ventilation ($\dot{V}E$), maximum heart rate (MHR), and test duration during the $\dot{V}O_2$max test between the COVID-19 infection group (COVID) and the non-COVID-19 infection group (NCOVID), N = 90.

	Men			Women		
	COVID N = 25	NCOVID N = 25	p-value	COVID N = 20	NCOVID N = 20	p-value
$\dot{V}O_2$max (ml/kg/min)	33.8 ± 10.3	33.5 ± 9.8	.95	25.7 ± 5.9#	23.3 ± 4.7#	.20
$\dot{V}O_2$ mean (ml/kg/min)	20.3 ± 5.2	20.1 ± 4.7	.91	16.6 ± 2.5#	14.7 ± 2.8#*	.03
$\dot{V}O_2$ last 15 s (ml/kg/min)	32.5 ± 9.8	32.5 ± 9.6	.99	26.2 ± 5.8#	22.7 ± 4.7#*	.03
$\dot{V}CO_2$max (ml/kg/min)	35.0 ± 10.9	33.0 ± 8.7	.53	26.4 ± 7.6#	23.2 ± 5.4#	.12
$\dot{V}CO_2$ mean (ml/kg/min)	16.6 ± 4.2	16.0 ± 3.3	.60	13.8 ± 2.8#	11.8 ± 2.3#*	.02
$\dot{V}CO_2$ last 15 s (ml/kg/min)	33.9 ± 10.8	32.4 ± 8.7	.65	26.9 ± 7.3#	22.5 ± 5.4#*	.02
Total CHO (kcal)	48.6 ± 26.6	42.0 ± 14.0	.27	19.5 ± 7.3#	24.2 ± 9.2#	.10
Mean CHO (%)	41.7 ± 20.7	39.4 ± 15.0	.58	30.1 ± 14.2#	40.5 ± 12.8*	.04
Total FO (kcal)	68.5 ± 33.4	75.2 ± 33.1	.50	48.7 ± 17.4#	38.0 ± 15.5#	.07
Mean FO (%)	58.3 ± 20.7	60.6 ± 15.0	.57	69.9 ± 14.2#	59.5 ± 12.8*	.04
Total EE (kcal)	116.1 ± 38.4	114.4 ± 33.0	.88	68.1 ± 16.5#	61.7 ± 17.6#	.26
Mean EE (kcal/min)	8.9 ± 1.7	8.8 ± 2.0	.88	6.2 ± 1.1#	5.6 ± 1.2#	.07
RER peak	1.1 ± 0.2	1.0 ± 0.1	.15	0.9 ± 0.1#	1.0 ± 0.1*	.01
RER mean	0.8 ± 0.1	0.8 ± 0.1	.54	0.8 ± 0.1	0.8 ± 0.1	.14
RER last 15 s	1.0 ± 0.2	1.0 ± 0.1	.46	1.0 ± 0.1	1.0 ± 0.1	.16
$\dot{V}E$ peak (L/min)	124.6 ± 30.6	121.1 ± 29.5	.70	77.9 ± 16.1#	79.7 ± 20.4#	.74
$\dot{V}E$ last 15 s (L/min)	121.4 ± 30.8	118 ± 29.1	.78	80.2 ± 16.7#	78.5 ± 20.4#	.77
MHR (beats/min)	181.5 ± 16.2	184.1 ± 7.5	.47	171.2 ± 20.0	178.0 ± 13.2	.12
Test duration (min)	12.5 ± 2.5	12.0 ± 2.2	.46	10.2 ± 1.9	10.6 ± 1.7	.50

Data are presented as the mean ± standard deviation (SD). *Significant difference between the COVID and NCOVID group, p < .05. #Significant difference between the men and women in the COVID or NCOVID groups, p < .05.

Carbohydrate oxidation was significantly lower in the short-duration COVID group (COVID-S; N = 12) compared with the long-duration infection group (COVID-L; N = 8), while fat oxidation was significantly higher in the COVID-S group, particularly among the women (all, $p < .05$). Among men, no statistically significant differences in carbohydrate or fat oxidation were observed between the COVID-S group (N = 19) and the COVID-L group (N = 6).

Figure 1. Carbohydrate and fat oxidation in the COVID group who had recovered from COVID-19 infection less than 6 months (☐) and longer than 6 months (■) ago in the women (A) and men (B). *Significant difference between the two groups, $p < .05$.



Relationships between the study parameters

Table 3. Relationships between the maximal oxygen consumption ($\dot{V}O_2max$), oxygen consumption ($\dot{V}O_2$), carbon dioxide production ($\dot{V}CO_2$), and minute ventilation ($\dot{V}E$) with age, body mass (BM), height (H), body mass index (BMI), systolic blood pressure (SBP), diastolic blood pressure, (DBP), resting heart rate (RHR), number of vaccine received (VAC), exercise frequency (FRE), exercise duration (DU), time of recovery time from COVID-19 in the COVID-19 infection group (COVID) and the non-COVID-19 infection group (NCOVID), N = 90.

	Age	BM	H	BMI	SBP	DBP	RHR	VAC	FRE	DU	Time
$\dot{V}O_2max$											
Men											
COVID	-.06	-.61**	.01	-.59**	-.38	-.51**	-.15	.08	.66**	.33	.28
NCOVID	-.36	-.68**	.30	-.69**	-.20	-.50*	-.47*	-.12	.59**	.40*	-
Women											
COVID	.19	-.14	.17	-.31	.04	.22	-.15	-.08	.26	.47*	.17
NCOVID	-.09	-.12	.14	-.19	.02	-.12	-.48	.01	.54*	.48*	-
$\dot{V}O_2$											
Men											
COVID	-.08	-.54**	-.07	-.51**	-.33	-.46*	-.13	.10	.61**	.25	.29
NCOVID	-.39	-.59**	.30	-.60**	-.11	-.52**	-.53**	-.22	.61**	.45*	-
Women											
COVID	.22	.06	.22	-.10	.19	.29	.01	-.05	.05	.43	.22
NCOVID	-.21	-.13	.03	-.15	-.06	-.20	-.40	-.11	.48*	.33	
$\dot{V}CO_2$											
Men											
COVID	.08	-.55**	.02	-.54**	-.22	-.32	-.22	.08	.53**	.43*	.28
NCOVID	-.33	-.59**	.16	-.56**	-.11	-.38	-.42*	-.16	.60**	.43*	-
Women											
COVID	.09	-.08	.02	-.12	.07	-.01	-.18	.2	.09	.31	-.01
NCOVID	-.15	-.15	.07	-.18	-.06	-.28	-.48*	-.02	.56**	.47*	
$\dot{V}E$											
Men											
COVID	.12	-.11	.17	-.16	-.13	-.26	-.22	.17	.51**	.44*	.40*
NCOVID	-.55**	-.33	.24	-.36	.02	-.32	-.45*	-.26	.46*	.38	-
Women											
COVID	-.16	-.23	.14	-.40	.27	.33	-.24	-.13	.15	.32	.18
NCOVID	-.52*	.24	.39	.11	.12	-.10	-.24	-.42	.49*	.41	-

*Correlation is significant at the .05 level. **Correlation is significant at the .01 level.

In both the COVID and NCOVID groups, $\dot{V}O_2max$, $\dot{V}O_2$, and $\dot{V}CO_2$ were highly associated with body mass, BMI, and exercise frequency, particularly in the men. Among the NCOVID men, the resting heart rate was moderately correlated with $\dot{V}O_2max$, $\dot{V}O_2$, $\dot{V}CO_2$, and $\dot{V}E$. In the NCOVID women, $\dot{V}CO_2$ was associated with the RHR, exercise frequency, and exercise duration. In the NCOVID women, $\dot{V}E$ was moderately correlated with age and frequency of exercise. The $\dot{V}O_2max$ tended to be correlated with systolic blood pressure in the COVID-19 men ($p = .06$). The number of vaccines received tended to correlate with the $\dot{V}E$ in the NCOVID in NCOVID women ($p = .06$). The correlation data are presented in Table 3.

Discussion

This study aimed to compare the $\dot{V}O_2max$, $\dot{V}O_2$ and $\dot{V}CO_2$, and substrate oxidation during an incremental treadmill $\dot{V}O_2max$ test between young overweight and obese adults with a prior COVID-19 infection and their overweight and obese peers without a history of COVID-19 infection. Among the young women who were overweight or obese, significant differences were observed between the COVID and NCOVID groups in terms of $\dot{V}O_2$, $\dot{V}CO_2$, and estimated carbohydrate and fat oxidation during the incremental $\dot{V}O_2max$ test. However, the $\dot{V}O_2max$ did not differ significantly between the COVID and NCOVID groups in either the men or women. Additionally, the study found that associations between cardiorespiratory outcomes and anthropometric and behavioural variables varied according to sex and infection status.

Interestingly, substrate utilisation during the incremental $\dot{V}O_2max$ test differed in the participants with prior COVID-19 infection, particularly among the young women who were overweight or obese, in the present study. Differences in $\dot{V}O_2$ and $\dot{V}CO_2$ between the COVID and NCOVID groups were related to alterations of the estimated carbohydrate and fat oxidation, particularly in the young women who were overweight or obese. In particular, individuals with a shorter time gap since COVID-19 infection demonstrated greater carbohydrate metabolism and reduced fat oxidation during the incremental exercise test, indicating a time-dependent recovery of their metabolic flexibility. These findings align with previous research, which reported lower $\dot{V}O_2$ values in women recovering from COVID-19 compared to inhealthy controls (Pleguezuelos et al., 2022). Additionally, reduced fat oxidation during incremental ergometer $\dot{V}O_2max$ testing and exercise has been demonstrated in individuals with a history of COVID-19 infection (de Boer et al., 2022; Ramirez-Velez et al., 2023). It has been suggested that a persistent reduction in fat oxidation may reflect mitochondrial dysfunction (Guntur et al., 2022). It is important to note that estimates of fat and carbohydrate oxidation were derived from $\dot{V}O_2$ and $\dot{V}CO_2$ exchange measurements, as described in previous study (Frayn, 1983). The association of $\dot{V}CO_2$ with exercise frequency and duration in NCOVID women further indicated that habitual activity may modulate substrate selection. This observation was consistent with evidence that training status modulates FO in individuals with long COVID-19 infection (Meloni et al., 2023). Although the overall exercise frequency and duration did not differ between the two groups in the present study, the pattern of associations in the NCOVID cohort suggested that behavioural factors warrant closer examination in relation to post-infectious metabolic responses. Consequently, the energy derived from carbohydrates and fat varied according to an individual's infection status and time since infection, with metabolic alterations most pronounced in young women who were overweight or obese following COVID-19 infection.

Correlational analyses in the present study revealed differential determinants for performance and ventilatory variables according to sex and infection status. Among the NCOVID women, $\dot{V}CO_2$ was significantly associated with the RHR, exercise duration, and exercise frequency. In the NCOVID men, the RHR demonstrated moderate correlations with $\dot{V}O_2max$, $\dot{V}O_2$, and $\dot{V}E$, whereas $\dot{V}E$ was related to age and exercise frequency in the NCOVID women. However, in both the COVID and NCOVID men, $\dot{V}O_2max$ showed a significant association with body mass, BMI, and diastolic blood pressure. These findings are consistent with a previous study that demonstrated that $\dot{V}O_2max$ was associated with BMI both in previously COVID-19 infected and non-COVID-19 infected individuals (Sova et al., 2023). Moreover, $\dot{V}O_2max$ was correlated with BMI (Mondal & Mishra, 2017), systolic blood pressure, and diastolic blood pressure in non-COVID-19 infected individuals (Kang & Ko, 2019; Shin & Ha, 2016). The maximum systolic blood pressure, diastolic blood pressure, and RER during the exercise test were also reported to be different between previously COVID-19 infected and non-COVID-19 infected individuals (Keller et al., 2023; Sova et al., 2023). Consistent with these findings, our study observed that the maximum heart rate tended to be higher in the NCOVID group compared with the COVID group. This observation aligns with previous work indicating that there may be heart rate differences among patients based on the severity of COVID-19 illness, particularly between non-hospitalised individuals and those treated in intensive care units (Lemos et al., 2022), but there was no difference in the maximum heart rate during $\dot{V}O_2$max testing (Śliż et al., 2022). Overall, these findings highlight distinct patterns in the relationships between cardiorespiratory variables, such as $\dot{V}O_2$max, $\dot{V}O_2$, as well as $\dot{V}E$ and physiological parameters, depending on the COVID-19 infection status. However, the extent to which systolic blood pressure and the RHR influence $\dot{V}O_2$max, $\dot{V}O_2$, and $\dot{V}E$ in individuals with prior COVID-19 infection remains unclear and warrants further investigation. Future research should focus on long-term longitudinal studies aimed at evaluating the recovery trajectories of $\dot{V}O_2$max and cardiovascular markers, such as the RHR, following COVID-19 infection, to identify predictors of persistent functional impairment.

Despite observed group differences in gas-exchange variables and substrate oxidation, no significant differences in $\dot{V}O_2$max were found between the COVID and NCOVID groups in our study in either the men or women. This finding aligns with previous research demonstrating that $\dot{V}O_2$max did not differ significantly between previously COVID-19 infected and non-COVID-19 infected individuals, including overweight middle-aged and young healthy adults (Alvaro et al., 2024; Berg et al., 2025; Sova et al., 2023). By contrast, early post-infection reductions in $\dot{V}O_2$max have been reported in both elite and recreational athletes during the early stages of post-infection and after one year following recovery from mild to moderate COVID-19 infection (Crameri et al., 2020; Parpa & Michaelides, 2022; Stepanek et al., 2023). The timeline of post-infection recovery appears to be an important factor; for instance, one study reported that the 6-minute walk distance by individuals six months after recovery from COVID-19 infection was longer than at 3 months (Wu et al., 2021), suggesting progressive functional improvements over time. It is important to note that the majority of participants in the present study had recovered from COVID-19 infection more than six months before the assessment in this study, which may have allowed sufficient time for their cardiorespiratory function to return to baseline. Additionally, $\dot{V}O_2$max was found to be associated with exercise frequency and duration in the present study. Most of the participants in our COVID and NCOVID groups engaged in regular exercise with no difference in exercise frequency and duration between the two groups. Therefore, the lack of differences in $\dot{V}O_2$max between the COVID and COVID groups in this study may be attributed to the relatively long time gap since infection among the COVID-19 participants and the maintenance of regular exercise behaviours in both groups. These factors may have contributed to the preservation or normalisation of their aerobic capacity following infection.

Sex differences were evident across both groups in the present study; whereby the men exhibited higher $\dot{V}O_2$, $\dot{V}CO_2$, $\dot{V}E$, FO, CHO, and $\dot{V}O_2$max than the women. These findings are consistent with previous research findings of sex-related differences in $\dot{V}O_2$max following COVID-19 infection and non-COVID-19 infection (Mondal & Mishra, 2017; Sova et al., 2023). Compared to previous studies, the differences in the $\dot{V}O_2$max appear to be associated with body weight and physical activity levels, as the overweight young men and women exhibited lower values than their normal-weight and physically active counterparts (Namprai et al., 2019; Silalertdetkul, 2023). The alterations in body mass and exercise frequency between the men and women in this study likely contributed to the observed sex differences. Consequently, the $\dot{V}O_2$max is influenced by sex-specific physiological differences in body composition, hormone profiles, and cardiovascular responses. This suggests that individuals with excess body weight generally have a lower $\dot{V}O_2$max than other groups, likely due to a lack of regular exercise. This result could be due to the similar exercise frequency and duration between both groups, potentially minimising any impact of prior infection on their oxygen utilisation capacity.

There are several limitations of this study that should be noted. First, the cross-sectional design of the study restricted our ability to establish causal relationships between prior COVID-19 infection and the observed physiological differences. Second, exercise behaviour was assessed through self-reporting, which is subject to recall bias and potential inaccuracies. Third, assessments of substrate oxidation were conducted in a non-fasted state, potentially introducing variabilities due to recent dietary intake. Additionally, the imbalance in sex distribution may have influenced the generalizability of the sex-specific analyses. Another limitation is the variability in the time since infection among the participants in the COVID group, which was not experimentally controlled and may have affected the physiological recovery profiles. To address these limitations, future research should employ longitudinal designs to characterise $\dot{V}O_2$max, $\dot{V}O_2$, $\dot{V}CO_2$, RER, and RHR recovery; standardise pre-test nutritional status; and balance sex representation. Controlling for habitual physical activity and training status will also be essential to disentangle behavioural effects from pathophysiological effects.

Conclusions

In young adults who were overweight or obese, a history of COVID-19 infection was found to be associated with altered gas exchange and substrate utilisation during incremental exercise, particularly among women, without a concomitant reduction in $\dot{V}O_2max$. $\dot{V}O_2max$ remained strongly related to body mass, BMI, and diastolic blood pressure across the groups, while associations with the RHR and ventilatory responses varied by infection status and sex. Differences in CHO and FO between the groups, as well as their apparent dependence on time since infection, suggest potential persistent impairments in metabolic flexibility following COVID-19 infection. Longitudinal studies that rigorously control for exercise behaviour and pre-test conditions are needed to clarify the underlying mechanisms, identify predictors of persistent impairment, and guide tailored rehabilitation strategies for men and women who are overweight or obese following COVID-19 infection.

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Conflict of interest

The authors confirm that they have no conflicts of interest to declare.

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Author contributions

SS and ND conceptualised and designed the research; SS contributed to supervising the research, helped interpret the results and wrote the manuscript; ND performed data collection, analysed the data, interpreted the results, and wrote the first draft of the manuscript. WW, AA, and SSr helped to write the manuscript. All authors have read and approved the final version of the manuscript and agree with the order of presentation of the authors.

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