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A longitudinal study to COVID-19 infection among university students: Physical fitness changes and psychological responses

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ABSTRACT

Background: The impact of COVID-19 infection on physical and mental health of young adults remains unclear. This study aimed to investigate the changes in the physical fitness three months after recovering from acute COVID-19 infection, and examine if the infection could also influence the mental health of university students.
Methods: A total of 460 university students (mean age 18.9 ± 1.3 years, with 30 males and 27 females uninfected with COVID-19) volunteered for the study. Participants underwent a fitness test initially, followed by another physical fitness test and a mental health assessment three months after the infection of COVID-19. Physical fitness tests included body composition, flexibility, cardiorespiratory fitness, muscle strength, and muscular endurance. Mental health was assessed using the Depression-Anxiety-Stress Self-Assessment Scale (DASS-21), the Pittsburgh Sleep Quality Inventory (PSQI), and the Post-Traumatic Stress Disorder Self-Assessment Scale (PTSD).
Results: Three months after acute COVID-19 infection, the physical performance of university students had decreased compared to pre-infection levels by approximate 3–15 % ($p < 0.05$). Regarding mental health, a notable difference was observed in sleep quality, with the positive group scoring 19 % higher than the negative group ($p < .05$, $d = .44$). Sex ($\beta = .164$, $p < .05$), previous infection ($\beta = .277$, $p = .019$) and anxiety ($\beta = .373$, $p = .002$) were predictive of PSQI scores, accounting for 37.5 % of the variance.
Conclusions: All participants experienced a decline in physical fitness compared to their pre-infection levels, regardless of infection status. Those who had been infected exhibited poorer sleep quality compared to their non-infected peers. Prior COVID-19 infection and higher anxiety levels may contribute to poorer sleep quality.

1. Introduction

The COVID-19 pandemic and its aftermath have had a profound global impact on all aspects of society. COVID-19 has been shown to significantly impact individuals' physical and mental health, accompanied by some short-term and long-term complications severely influencing their daily life, work, and social interactions. These sequelae including persistent malaise, respiratory distress, muscle pain or strength loss, cough, cognitive dysfunction, and mental health issues can persist 3–12 months after patients have recovered from the acute-phase symptoms of the infection.[1–4] For instance, previous studies suggest that the highest level of oxygen consumption and maximum power output decrease[5] in those infected decreased due to pulmonary damage[6] and cardiac injury[7] caused by COVID. What is worse, one-third of the patients still had residual lung function abnormalities at 12 months, despite significant improvement in exercise capacity observed between 3 and 6 months.[8] In terms of the influence of mental health caused by COVID-19, a range of issues including post-traumatic stress disorder (PTSD), depression, anxiety, obsessive-compulsive disorder,[9] and mild sleep disorders[10] can be observed, even 3-month after the infection.[4,11] Studies have shown that the prevalence of post-anxiety and depression at 3 months post-infection was slightly higher than pre-infection levels.[12] At 6 and 12 months post-infection, the prevalence of anxiety, depression, and PTSD was 13.31 % and 6.26 %; 20.35 % and 11.94 %; and 13.11 % and 6.07 %, respectively.[13]

Physical fitness is a comprehensive capability that encompasses several dimensions, including body composition, cardiorespiratory function, muscle strength and endurance, and flexibility.[14] College students form a unique group of young adults undergoing professional training, there is potential to develop health-related behaviors and habits that are likely to persist throughout life.[15,16] However, during the pandemic, strategies and measures implemented to limit the spread of

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the virus led to notable declines in strength endurance and aerobic capacity among uninfected college students as well as significant increase in body weight and body mass index (BMI).[17] Following the COVID-19 lockdown, a lack of training specificity resulted in notable increases in heart rate and lactate concentrations during the last stages of the submaximal shuttle run test. This observation indicates a decline in aerobic capacity.[18] Reduced physical fitness may be associated with prolonged recovery periods and increased susceptibility to infection and comorbidities related to COVID-19.[19,20] Young and healthy individuals may exhibit mild or no symptoms after infection, and children and adolescents have a relatively low risk of COVID-19 related mortality.[21]

Physical fitness testing may offer a valuable opportunity to serve as an educational tool in promoting physical activity and fitness.[15,22] The findings gathered from fitness tests may not only guide teaching methods but also play a crucial role in promoting healthy lifestyles (American Psychiatric Association & Association,[15,24]), despite ongoing debate on this topic.[23] It is critical to monitor the physical fitness levels and overall health outcomes of undergraduate students continuously. However, due to the sudden outbreak of COVID-19, obtaining baseline data for a pre-post study has become almost impossible. As a matter of fact, there is only one existing cohort study on children that demonstrates a decline in cardiopulmonary function indicators and an increase in BMI associated with measures to mitigate COVID-19, compared to baseline (Jarning et al., 2021). Therefore, there is a paucity of comparative data regarding the physical fitness performance of university students after recovery from COVID-19 acute infection.

It is worth noting that young people, who are relatively energetic and crave some extent of physical activities, have been particularly affected by the social needs, loneliness, detachment, boredom, and loss of freedom caused by COVID-19 outbreak related lockdowns.[24] As a result, they are among the most impacted groups, with heightened mental health problems,[25] and accounting for 70 % of those infected globally.[26] PTSD has been considered as one of the potential long-term consequences of COVID-19.[27] Additionally, an online Qualtrics survey indicated that poor sleep quality may enhance vulnerability to subsequent PTSD symptoms during the pandemic, especially for individuals who perceived the pandemic as threatening for their future.[28]

This study aimed to (1) primarily assess the differences in physical fitness parameters of students three months after recovering from COVID-19 infection in comparison to their uninfected state; and (2) investigate disparities in the impact of COVID-19 on physical fitness performance and mental health between those students who were infected and those who were not, as well as to infection. We hypothesize that 1) the physical fitness level of college students would be decreased due to limited physical activities regardless of infection status, 2) the infected individuals would have worse performance in physical and mental health outcomes than uninfected counterparts.

2. Materials and methods

2.1. Participants

A priori test was performed using the F test of repeated measures, between factors, with default moderate effect size (ES, $f = .25$), α error probability of .05, power of .80, and correlation among repeated measures of .50. The result indicated that the total sample size of 98 was required. Physical fitness testing is a routine component of our Physical Education (PE) classes. To account for the potential impact of COVID-19, three months before the sudden onset of a large-scale infection at the end of 2022, recruitment information was disseminated through an online questionnaire. This information was introduced and promoted by PE class instructors. Inclusion criteria for the study included: (a) receiving three doses of vaccine, (b) volunteering to participate in the research, (c) self-reported health; (d) being an undergraduate students in a mandatory PE class. Exclusion criteria were: (a) having a history of psychiatric illness, (b) currently having a medical condition that precluded safe exercise, and (c) incomplete participation in two tests. Physical fitness served as the primary outcome measure, consistent with its role as a standard monitoring indicator in PE classes. Survey data was gathered via online questionnaires, and participants provided informed consent prior to engagement. All procedures adhered to the guidelines set forth in the Helsinki legislation. This study received approval from the Ethics Review Board of the University of Macau (SSHRE23- APP117-FED).

A total of 620 participants initially took part in the study. Among them, 296 were males and 324 were females, and none of them tested positive in the first round. However, during the course of the study, 41 participants (5 males and 36 females) did not participate in the second fitness test, and 119 participants (61 males and 58 females) declined to complete the questionnaire, leading to their exclusion from the study. Consequently, the final cohort comprised 460 participants with a mean age of 18.90 ± 1.26 years. Of these, 403 were infected (POS, 200 males and 203 females), while 57 remained uninfected (NEG, 30 males and 27 females) (Fig. 1).

2.2. Study design and procedures

This study was initially intended to serve as a routine assessment of physical fitness among university students, but it later developed into a pre-post quasi-experimental study. Primary outcomes were collected before and after 3-month of COVID-19 infection. These outcomes included personal information (student number, e-mail address, sex, age, COVID-19 infection status), as well as the results of the physical fitness test. Taking into account the potential impact of COVID-19 on mental health, secondary outcomes were assessed after infection using scales such as the Depression-Anxiety-Stress Self-Assessment Scale (DASS-21), the Pittsburgh Sleep Quality Inventory (PSQI), and the Post-PTSD Scale. International Physical Activity Questionnaire (IPAQ) was employed to identify daily physical activity in participants.

This study was conducted between September 2022 (first physical fitness test), with an average outdoor temperature of 29.0 ± 1.0 °C, and March 2023 (second physical fitness test) with an average outdoor temperature of 18.5 ± 1.8 °C. Throughout this period, the indoor environment was maintained at a constant temperature of 22.2 ± 1.5 °C and relative humidity of 21.9 ± 5.8 %. The physical fitness test was conducted by PE teachers, with the assistance of PE teaching assistants. The team of PE teaching assistants are all graduate students majoring in physical education who have undergone systematic training and long-term experience in physical fitness testing. To conduct the test, we grouped the participants. There would be a 10-min interval break between each test item. The same participants were invited to participate in the second physical fitness test, where their identity was verified by matching their student numbers and names. Following the second fitness test, the participants were divided into negative and positive groups based on their infection status. Immediately following the completion of the second fitness test, participants were required to complete online questionnaires under the supervision of a PE teacher and teaching assistants in a computer room. Once their submitted questionnaires were checked on spot, they were allowed to leave.

Participants were required to avoid strenuous exercise 24 h before the fitness test, and to avoid eating, smoking, drinking alcohol, or consuming caffeinated beverages 2 h before the test. Experienced PE instructors and teaching assistants briefed participants on test procedures and safety measures beforehand. Demonstrations and instructions were provided before each test, and participants were allowed to make a trial attempt. Participants had the option to halt the test if they experienced any discomfort. A 10-min warm-up was required before testing to reduce the risk of sports injuries.

During physical fitness test indoors, students were asked to wear masks as much as possible, and maintain social distancing of at least 1 m. Indoor testing areas, lockers and changing rooms were cleaned and disinfected regularly, and equipment was properly cleaned and

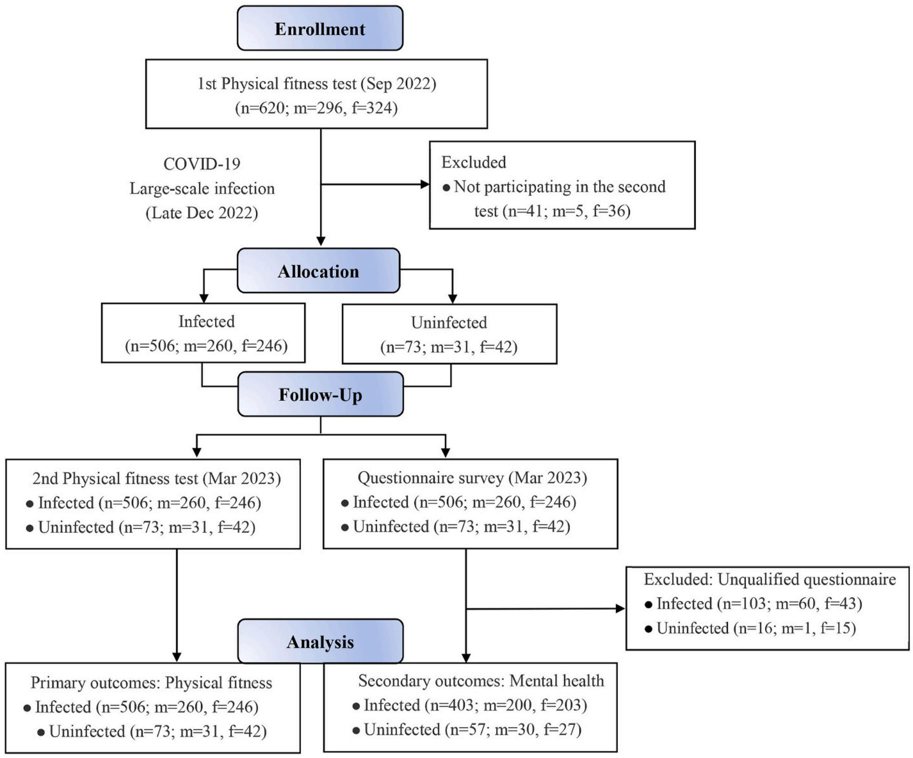

Fig. 1. Schematic diagram of the study protocol.

disinfected after each use. For test conducted outdoors where masks could not be tolerated, participants were instructed to maintain social distancing of at least 1.5 m.

2.3. Assessment of physical fitness

Physical fitness test was used to assess the physical fitness of the participants, encompassing body composition, flexibility, cardiorespiratory endurance, muscle strength, and muscular endurance.[29,30] The indoor and outdoor tests were spaced one week apart to ensure that participants could undergo both tests under consistent physical conditions.

Height was taken using a stadiometer in a standard manner. Weight data were obtained using the InBody 270 (Biospace, Tokyo, Japan). Body composition was assessed using BMI, which was calculated by dividing body weight in kilograms by the square of height in meters.

Flexibility was assessed through the sit and reach test,[31] with the best performance out of three attempts. Participants removed their shoes and placed their heels against the device's shield (Haidong, Ningde, China). With palms down, knees straight and upper body leaning forward, participants gently stretched fingertips forward. The test was repeated thrice, and the best result was recorded.

Cardiorespiratory fitness was assessed via the 3-min step test and the 800-m run (females)/1000-m run (males).[31,32] The step test is the last of all indoor tests. Participants stepped up and down at a pace of 120 beats per minute. Heart rate data were recorded at 1, 2, and 3 min via finger pulse oximeter (Yuwell - YX306, Singapore). The Step-test-index was calculated using a formula as: duration of step exercise (sec) $\times$ 100/2 $\times$ (sum of 3 heart rates during the rest and recovery period). In addition, the 800-m run (female)/1000-m run (male) was conducted in a standard 400-m track and field, with a standing start, immediately after the starting signal. The test results were recorded in minutes.

Muscle strength was determined by the hand grip strength (HS) and the standing long jump (SLJ).[31] For the HS, participants gripped the dynamometer (Camry, USA) with maximum force for three trials per hand. The SLJ was repeated 3 times, with the longest jump recorded.

Muscular endurance was assessed through the 1-min sit-up test (Sit-ups), and the push-up test (Push-ups).[31] In the 1-min sit-up test, the participant lay flat on a cushion with feet shoulder-width apart, knees bent and arms crossed in front of the chest. During the test, the elbows should touch the knees when sitting up and the shoulder blades should touch the mat when lying down. The test lasts for 1 min and the number of repetitions completed is recorded. The push-up test was gender-specific, with a standard version for males and a kneeling version for females. There was no time limit for the test, and the maximum number of repetitions completed at one time was recorded as the final test result.

2.4. Mental health assessment

The examination of PTSD and mental health in critical situations is a significant area for research. The DASS-21, PSQI, and PTSD self-assessment scales are valuable tools for investigating mental health concerns within university student populations.[33]

The DASS-21 is a reliable instrument to assess mood disorders such as depression, anxiety, and stress, and the scale is now widely used to measure hesitancy, anxiety, and stress states in university students.[34,35] With a Cronbach's α coefficient of .93, indicating good internal consistency,[36] the scale comprises seven questions per subscale, with scores categorized as normal, mild, moderate, severe, or very severe based on predetermined thresholds. In the present study, the Cronbach's α coefficient of the total scale was .94.

The PSQI assesses sleep quality across seven components using a 0–3 scoring system. A total score of $\leq$7 is indicative of "good sleep quality," while a score above 7 suggests "poor sleep quality".[37] Demonstrated as a reliable method for evaluating sleep quality, the PSQI is widely applied to identify sleep disorders in university settings.[38] With a Cronbach's α of .83, denoting good internal consistency.[37] In this study, the Cronbach α of the total scale was .78.

The PTSD Checklist is a self-assessment tool developed by Weathers et al.[39] based on the DSM-IV criteria (American Psychiatric Association & Association). This scale is commonly used to evaluate PTSD symptoms, measuring symptom severity on a 5-point scale that is widely utilized in various assessment contexts.[40] Scores are categorized into ranges indicating symptom presence and severity, potentially leading to a PTSD diagnosis. Notably, the scale demonstrates good internal consistency, with a Cronbach's α of .96.[39] In this study, the total scale showed a Cronbach's α coefficient of .95.

2.5. Measurement of daily physical activity

The IPAQ short form was used to measure daily physical activity.[41] The intensity of physical activity is described in terms of metabolic equivalents (MET). To calculate the number of MET minutes per week, multiply the given MET value (walking = 3.3, moderate activity = 4, vigorous activity = 8) by the number of minutes of activity and then multiply by the number of days of that activity. The sum of the weekly MET minutes for walking, moderate activity, and vigorous activity is calculated as the total MET minutes per week for physical activity, and the sum of the latter two is calculated as the MET minutes per week for moderate intensity physical activity. Physical activity intensities are categorized as "high", "moderate", or "low" based on criteria established by the IPAQ committee.[42]

2.6. Statistical analyses

SPSS 27.0 was used for data analysis (IBM SPSS Statistics for Windows, version 27.0. Armonk, NY, USA). Normality was assessed using the Kolmogorov-Smirnov test. Two-way repeated-measures ANOVA was used to determine the main effect (time) and interaction effect (between groups) of the data variables, and paired-sample t-tests were calculated to examine the differences between the pre-test and post-test. Two-way repeated-measures ANOVA was conducted to evaluate the differences in weight, BMI, DHS, NDHS, SLJ, Sit-ups, Push-ups, Sit and reach, Step-test index, and 800/1000m-Run across time points and groups. Bonferroni post hoc corrections were applied when significant interactions and main effects were identified. Partial eta squared (η_p^2) was used as the effect size measure for each main and interaction effect. Independent Samples t-tests were used to compare differences in mental health scale scores. Within- or between-group ES was revealed by calculating Cohen's *d* value. The inferences associated with ES are defined as trivial (< 0.20), small (0.20–0.59), moderate (0.60–1.19), large (1.2–1.9), very large (2.0–3.9), and extremely large (≥4.0),[43] while that associated with η_p^2 effect sizes are defined as negligible ($\eta_p^2 < .01$), small ($.01 \le \eta_p^2 < .06$), medium ($.06 \le \eta_p^2 < .14$), and large ($\eta_p^2 \ge .14$).[44] Based on the results of the existence of differences in mental health, regression analyses were conducted to examine whether there was an association between the relevant outcomes and physical fitness and other outcomes (anxiety, depression, stress and PTSD). $p < .05$ level of significance was considered statistically significant.

3. Results

3.1. Participant characteristics and daily physical activity

Out of the 460 participants, 77.4 % were infected while12.6 % were not infected (Table 1). There were no significant differences in vigorous intensity, moderate intensity, light intensity, IPAQ scores, and sitting time were not statistically significant ($p > .05$) between previously infected and uninfected groups (Table 2).

3.2. Changes in physical fitness

The study assessed the impact of time and group differences on various fitness performance indicators. The variations in fitness performance are shown in Table 1.

There were no significant time effects for NDHS and Sit and reach (*p*

Table 2
Daily activity and mental health.

		NEG	POS	*t*	*p*	*d*
Physical Activity	Vigorous intensity (MET/week)	1906 ± 2446	1908 ± 1912	−.006	.995	.00
	Moderate intensity (MET/week)	1087 ± 1000	1361 ± 1873	−1.301	.197	.18
	Light intensity (MET/week)	887 ± 1362	753 ± 1338	.550	.583	−.10
	IPAQ scores (MET/week)	3852 ± 3822	4026 ± 4047	−.238	.812	.04
	Sitting time (min/week)	426 ± 268	476 ± 261	−.1290	.198	.19
Mental Health	Depression-DASS	8.14 ± 8.01	9.83 ± 8.99	−1.347	.179	.20
	Anxiety-DASS	8.42 ± 7.28	9.94 ± 7.75	−.395	.164	.20
	Stress-DASS	11.19 ± 8.31	12.28 ± 9.13	−.849	.396	.12
	PSQI	5.88 ± 2.51	7.00 ± 2.62	−3.020	.003	.44
	PTSD	23.28 ± 15.30	23.40 ± 16.56	−.030	.976	.01

NEG: Negative group; POS: Positive group; MET: metabolic equivalents; IPAQ: International Physical Activity Questionnaire; DASS: Depression Anxiety Stress Scale, PSQI: Pittsburgh Sleep Quality Index Scale. PTSD: Post-Traumatic Stress Disorder Self-Assessment Scale.

Table 1
Comparison of physical fitness performance.

	NEG			POS			Time		Group		Interaction	
	PRE	POST	*d*	PRE	POST	*d*	*p*	η_p^2	*p*	η_p^2	*p*	η_p^2
Weight (kg)	58.48 ± 13.21	59.45 ± 13.02[a]	.07	60.12 ± 13.51	60.47 ± 13.48[a]	.03	.006	.020	.508	.001	.195	.004
BMI (kg·m^{-2})	20.65 ± 3.25	21.00 ± 3.27[a]	.11	21.13 ± 3.69	21.25 ± 3.66[a]	.03	.005	.021	.497	.001	.168	.005
DHS (kg)	33.41 ± 13.01	30.73 ± 9.78	−.23	31.12 ± 10.26	30.61 ± 10.96	−.05	.005	.020	.426	.002	.058	.009
NDHS (kg)	29.92 ± 11.63	28.36 ± 9.58	−.15	28.46 ± 9.09	28.37 ± 10.39	−.01	.128	.006	.601	.001	.176	.005
SLJ (cm)	182.17 ± 33.62	179.00 ± 33.70	−.09	178.45 ± 36.04	172.58 ± 36.34[b]	−.16	<.001	.042	.344	.002	.204	.004
Sit-ups (times)	36.02 ± 8.23	34.96 ± 7.41	−.14	36.01 ± 10.01	34.34 ± 10.01[b]	−.17	.011	.017	.821	<.001	.572	.001
Push-ups (times)	27.08 ± 10.17	22.67 ± 9.88[b]	−.44	24.94 ± 12.70	20.51 ± 11.18[b]	−.37	<.001	.074	.172	.005	.992	<.001
Sit and reach (cm)	10.43 ± 9.04	9.77 ± 7.95	−.08	11.23 ± 9.35	10.48 ± 8.77[a]	−.08	.087	.008	.557	<.001	.912	<.001
Step-test index	49.71 ± 7.29	48.04 ± 5.96[a]	−.25	49.79 ± 7.99	47.42 ± 6.61[b]	−.32	<.001	.037	.776	<.001	.516	.001
800/1000m-Run (min)	4.46 ± .71	4.97 ± .79[b]	.68	4.73 ± 1.11	5.12 ± .81[b]	.40	<.001	.097	.085	.008	.402	.002

NEG: Negative group; POS: Positive group; BMI: body mass index; 800/1000m-Run: 800 meter-run for female/1000 meter-run for male; DHS: dominant hand strength; NDHS: non-dominant hand Strength; SLJ: standing long jump. Significant difference from PRE at.

[a] $p < .05$.
[b] $p < .01$.

> .05). A small yet significant time effect ($p < .05$) was found for the weight ($\eta_\rho^2 = .020$), BMI ($\eta_\rho^2 = .021$), DHS ($\eta_\rho^2 = .020$), SLJ ($\eta_\rho^2 = .042$), and Sit-ups ($\eta_\rho^2 = .017$). A significant medium decrease was found in Push-ups ($p = .011$, $\eta_\rho^2 = .017$), with approximately 15 % decrease in the post-test compared to the pre-test. As for the within-group changes in NEG or POS, the effect sizes for the changes in these indicators (i.e., weight, BMI, SLJ, Sit-ups, Push-ups and Sit and reach) were small ($d =$ .03–.44), indicating trivial to small magnitudes of change. For cardiorespiratory fitness, both groups exhibited a significantly small or medium time effect on the Step-test index ($\eta_\rho^2 = .037$) and 800/1000-m run ($\eta_\rho^2 = .097$), with approximately a 10 % reduction ($p < .05$). However, no significant interaction or group effects were found between the infected (POS) and uninfected (NEG) groups for any of the physical fitness parameters.

3.3. Mental health performance

Table 2 displays the comparison of mental health between groups. There were no significant differences in depression, stress, anxiety, and PTSD between the positive and negative group. However, a significant increase of sleep quality index score was observed in the positive group when compared to the negative group ($t = -3.020$, $p < .05$, $d = .44$).

Table 3 displays the association between sleep quality and sex, previous infection, and anxiety outcomes. Using sex (female = 0, male = 1), infection status (negative = 0, positive = 1), physical activity levels, and physical and mental health indicators as predictor variables, a stepwise regression analysis was conducted to predict PSQI scores. The analysis indicated that sex ($\beta = .164$, $p < .05$), previous infection ($\beta = .140$, $p =$ .003), and anxiety ($\beta = .450$, $p < .05$), emerged as the significant predictors in the model, accounting for 37.5 % of the variance in PSQI scores.

4. Discussion

This study focused on assessing the disparities in physical performance of students three months post-acute COVID-19 infection compared to their pre-infection levels, and investigating the discrepancies in physical performance and mental health outcomes between students who contracted COVID-19 and those who did not. The findings revealed that all participants experienced a decline in cardiorespiratory performance compared to their pre-infection levels, and no difference was found between infected and non-infected groups. However, COVID-19 infected students reported poorer sleep quality.

Surprisingly, after three months of acute infection of COVID-19, we observed that COVID-19 strains did not affect the physical fitness level of the younger participants, which is contradictory to previous studies suggesting adverse effects caused by COVID-19.[7,45–47] This discrepancy may result from differences in age, physically active levels and physiological status. It has been reported that age-varying susceptibility to infection by COVID-19, where younger generations are less likely to be infected or able to recover faster after contact with an infectious person.[48] This reduced susceptibility or faster recovery may be the result of their stronger immune system, cross-protection from prior exposure to other coronaviruses, or non-specific protection immunity gained from recent infections with other respiratory viruses, facilitated by the socially active nature of younger generations as compared to their seniors.[24,48] Likewise, a study of clinical and CT features of the COVID-19 infection[49] shows that older people's lungs are more susceptible to viral infections, with the virus spreading more easily as indicated by the greater lung lobe involvement and interstitial changes. Elderly individuals, usually accompanied by multiple comorbidities (e.g., hypertension, type 2 diabetes, obesity, asthma, etc.), are more likely to impair body functions and weaken the immune systems, making them more susceptible to COVID-19.[45,49] Interestingly, despite a study finding no significant difference in cardiopulmonary fitness after 5 months of mild-to-moderate community infection in middle-aged, physically active patients compared to their uninfected counterparts, those who experienced symptoms and required hospitalization for recovery continued to exhibit persistent functional limitations.[50]

The type of virus variant is another possible reason that could explain our finding. Considering the circulating dominant strains circulating at the time of the sudden large-scale outbreak, it is plausible that the COVID-19 virus in this study was likely the Omicron variant https://ngdc.cncb.ac.cn/ncov/monitoring/country/China[51], though unconfirmed. Previous studies have shown that individuals infected during the Omicron waves (HR = 2–20; 95%CI: 1-96-2-48) or Delta (HR = 1–69; 95%CI: 1-43-2-01) recovered faster than those infected earlier, when SARS-CoV-2 was wild-type or Alpha-dominant.[46] The mutations in the Omicron variant, especially in the spike protein, enable it to evade antibodies, emphasizing the need for a stronger T-cell response.[52,53] Compared to the other variants, Omicron's spike mutations increase its ability to evade acquired immunity,[54] resulting in a milder acute course, shorter recovery time,[55] and a lower incidence of complex and prolonged COVID.[56] The relatively active physical levels and physiological health of the participants in our study may explain the minimal impact of COVID-19 on their physical fitness levels,[52] and may therefore play a key role in mitigating the impact of COVID-19, potentially accounting for the minimal effects observed on physical fitness observed in this study.

The general decrease in physical fitness observed in both groups during the second test can be attributed to reduced exercise opportunities during the epidemic, primarily due to quarantine and lockdown measures rather than the coronavirus itself. Both infected and non-infected individuals exhibited similar declines in weight, BMI, and DHS. This finding is consistent with several studies reporting health problems associated with the COVID-19 pandemic and the subsequent isolation measures. The closure of physical activity facilities and public spaces during the pandemic restricted opportunities for exercise, leading to a notable decline in all exercise intensities and an increase in sedentary behavior, which negatively impacted physical fitness.[5,57] Additionally, psychological factors, such as concerns about chronic fatigue and impaired cardiorespiratory fitness among those infected, and fear of contracting the virus among the uninfected, may have contributed to reduced physical activity, further exacerbating the decline in fitness levels. While there is no direct evidence linking these factors to reduced physical fitness, indirect indicators, such as decreased sleep quality evidenced by higher PSQI scores among infected individuals, support this hypothesis. This finding aligns with previous studies indicating that patients who had been infected with COVID-19 experienced poor sleep quality for up to 12 months.[58,59] Our further stepwise regression analysis revealed that sex, infection status, and anxiety explained 37.5 % of the variance in sleep quality, with infected males experiencing higher anxiety and poorer sleep quality. A study utilizing multimodal magnetic resonance imaging suggested that anxiety and depressive symptoms are more likely linked to Omicron-induced insomnia rather than the infection itself.[60] Compared to healthy controls, patients suffering from insomnia after infection showed reduced cortical thickness in pericalcarine regions and decreased proton density values, with cortical thickness demonstrating a negative correlation with anxiety and depression scores. Sleep is crucial for physical recovery

Table 3
Associations between sex, previous infection, and anxiety outcomes with sleep quality.

	β	p	95 % CI	
			Upper limit	Lower limit
Sex	.164	<.001	.387	1.344
Infection	.140	.003	.393	1.857
Anxiety	.450	<.001	.126	−.183

CI: confidence interval; Sex: female = 0, male = 1; Infection status: negative = 0, positive = 1.

and maintaining health, and COVID-19-related anxiety and stress can disrupt sleep, indirectly affecting fitness levels.[61,62] Exercise, which is an effective means of relieving anxiety and improving mental health, was limited during the pandemic,[20] potentially creating a vicious cycle between physical and mental symptoms. Although physical fitness indicators did not enter into the prediction of sleep quality, we hypothesize that this is due to the varying degrees of recovery of physical fitness from the viral infection. Future studies may investigate whether enhanced physical fitness training can improve factors such as anxiety, depression, and sleep quality.

Regarding mental health, our study found significant differences in sleep quality among COVID-19-positive individuals, however no significant differences in depression, anxiety, and PTSD compared to uninfected individuals after 3 months, contrary to other studies reporting such issues post-recovery.[58,63,] One of the potential reasons could be the youthfulness of our participants, as older, retired, non-single, and those with children may be more prone to PTSD due to increased physically and socioeconomically vulnerable.[64] Young people's sleep patter may be more susceptible to personal characteristics and external stressors associated with epidemics.[65] Internal resources such as personal, physical and psychological factors can be possessed and mobilized by individuals. These resources, including psychological resilience, self-efficacy, sense of control over one's life, and optimism, have been identified as key elements that can facilitate recovery from PTSD.[64,66] Studies have demonstrated that students who have recovered from infection may exhibit a potential psychological protective effect compared to uninfected students, which may positively impact the mental health outcomes,[67] and thus could contribute to the absence of significant differences in depression, anxiety, and PTSD observed in this study.

This study has several limitations. Firstly, the absence of pre-test mental health data restricts our deeper understanding of the impact of COVID-19 on mental health and its relationship with physical health. Secondly, the lack of a long-term continuous follow-up approach limits the precise assessment of the impact of COVID-19 on physical fitness over time.[56] Additionally, the sample size of this study is small, particularly in relation to the number of uninfected individuals. To ensure more representative results and improve the robustness of the analysis, it would be beneficial to increase the sample size and conduct a study with a balanced proportion of infected and uninfected individuals. Finally, due to the sudden outbreak of large-scale COVID-19 infection, the study was unable to consistently measure the physical activity levels during physical education classes and daily activities, as well as immediate physical and mental health indicators related to infections. Future research should incorporate comprehensive longitudinal studies that track and evaluate participants over time, especially in school populations during similar epidemics.

5. Conclusions

This study demonstrates the persistence of certain symptoms in individuals who have recovered from COVID-19 for over three months. Despite the ongoing issue of poor sleep quality three months after infection, the COVID-19 virus seems to have had minimal or mild impact on the physical fitness of young students. Previous COVID-19 infection and higher anxiety levels seem to result in poorer sleep quality.

Author statement

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Conflict of interest/competing interest

The authors declare that there is no conflict of interest and the outcomes are presented clearly, honestly, and without fabrication, falsification, or inappropriate data manipulation.

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