Original article

Impact of Covid-19 on maximal oxygen uptake, physical activity, and fatigue in Saudi recreational athletes: A cross-sectional study

Hind Alshuael Aldossari[1], *Mohammed Essa Alsubaiei*[2], *Shoug Yousif Al Humoud*[3], *Hail Alshuael Aldossari*[4], *Alsayed Abdelhameed Shanb*[2]

[1]Department of Physical Therapy, Medical Polyclinics, King Faisal University, Al-Ahsa, Saudi Arabia; [2]Department of Physical Therapy, College of Applied Medical Sciences, Imam Abdulrahman Bin Faisal University, Al-Khobar, Saudi Arabia; [3]Department of Respiratory Care, College of Applied Medical Sciences, Imam Abdulrahman Bin Faisal University, Al-Khobar, Saudi Arabia; [4]Regional laboratory, Hafr Albatin Health Cluster, Ministry of Health, Saudi Arabia

Abstract. *Background:* Coronavirus is a novel viral infection that emerged in late 2019. The World Health Organisation declared it a pandemic and life-threatening illness due to its detrimental impacts on multiple organ systems. *Objective:* The aim of this study was to investigate the long-term impact of Covid-19 on maximal oxygen uptake (VO_2 max), physical activity, and fatigue in Saudi recreational athletes. *Methods:* A total of 42 Saudi male and female recreational athletes participated in a cross-sectional study. They were equally and non-randomly assigned to either an experimental group (21 athletes with a history of Covid-19 infection) or a matched control group (21 healthy athletes). VO_2 max, physical activity, and fatigue were measured using the COSMED Quark cardiopulmonary exercise test (CPET) system, the International Physical Activity Questionnaire (IPAQ), and a hand-held blood analyser, respectively. Independent t-tests and Mann-Whitney tests were used to assess significant differences between the two groups. *Results:* Significant reductions were observed in mean values of $\dot{V}O_2$ max (40.88 ± 12.94 & 50.16 ± 1.72; d = 0.75; p = 0.019), physical activity (6.81 ± 1.36&7.90 ± 0.89; d = 0.49; p = 0.006), and metabolic equivalents (12.19 ± 3.01&14.5 ± 3.39; d = 0.36; p = 0.025), in contrast, no significant differences were found in mean values for lactic acid (13.91 ± 7.44 &16.33 ± 5.44 ; d = - 0.37; p = 0.473) or respiratory quotient (1.01 ± 0.15&0.95 ± 0.07; d = - 0.27; p = 0.512) in the Covid-19 & matched control groups respectively. *Conclusion:* Covid-19 was associated with significant reductions in VO_2 max, physical activity, and metabolic equivalents among Saudi recreational athletes compared to healthy controls. However, no significant differences were found in mean values of lactic acid or respiratory quotient. Health care providers are advised to prescribe individualised rehabilitative tailored programmes for recreational athletes with Covid-19, regardless of the time since infection. (www.actabiomedica.it)

Key words: athletes, covid-19, aerobic capacity, exercise capacity, fatigue, physical activities

Introduction

Coronavirus disease 2019 (Covid-19) is a viral infection that affects multiple organs, causing a range of systemic and physical impairments, resulting in a series of consequences, including neurological, musculoskeletal, and psychological disturbances (1-3). The pandemic originated in Wuhan, China, and was declared a global health emergency by the World Health Organisation (WHO) due to its high mortality rate and economic impact (3,4). Covid-19 is caused by the severe acute respiratory syndrome coronavirus

(SARS-CoV-2), as the diseases share similar symptoms and consequences (5). The incidence of Covid-19 among athletes remains unclear, although recent findings indicate a higher prevalence among swimmers (9.6%), cyclists (8.0%), triathletes (6.0%), and runners (4.1%) (6). Recreational athletes, who engage in sport primarily for enjoyment rather than competition, do not follow systematic training regimens and typically compete at lower levels (2). These individuals were significantly affected by lockdown restrictions, virus infections, and the suspension of sporting events, leading to declines in motivation and training consistency (7). Consequently, their focus shifted further from competition to the intrinsic pleasure of participation (2). Reductions in physical performance may stem from decreased aerobic capacity, myalgia, fatigue, and breathing difficulties (8). Elevated C-reactive protein and polymerase chain reaction (PCR) levels are markers of Covid-19 infection and associated with inflammatory conditions (9). Covid-19 may cause pulmonary complications such as pulmonary fibrosis, interstitial lung fibrosis (10), and pulmonary embolism (11), alongside cardiac involvement. This may result in anaemia of inflammation (AI) or functional iron deficiency (FID). AI was present in 24.7% of patients with Covid-19 on admission and 68.8% after hospitalisation (11,12). FID, secondary to impaired iron regulation and absorption, that leads to insufficient circulating iron for haemoglobin production, causing tissue damage, poor outcomes, and compromised oxygenation (13). Covid-19 patients may also experience reduced respiratory functions (14), impaired aerobic performance, general wellness, muscular strength and endurance, particularly among athletes. One study found a 95% reduction in exercise capacity among athletes with Covid-19 (12) and a 39% reduction in the general Covid-19 patient population (8,15). Lung dysfunction is typically indicated by a reduced VO_2 max, which reflects the efficiency of the cardiopulmonary system in supplying the muscles with oxygen and exporting waste from active muscles (16). Genetic and environmental factors, such as age and sex, also influence VO_2 responses to exercise training (17). VO_2 max is further determined by cardiac output, blood oxygen-carrying capacity, and muscular oxidative efficiency (17). Hence, it serves as a valuable metric for evaluating muscular oxidative function, training programme effectiveness, fatigue thresholds, and cardiopulmonary dysfunctions (18-20). A diagnosis of long Covid-19 is made when symptoms persist for more than 12 weeks following initial infection, as defined by the United Kingdom, National Institute for Health and Care (21). Approximately 10% of patients are suspected of developing long Covid, although the prevalence may reach 70% in some SARS-CoV-2 cases (21). Fatigue is characterised by a reduced ability of muscles to maintain required force , it is a common symptom of viral and bacterial infections and leads to decreased physical performance, altered joint sense, impaired balance, and increased fall risk (22). Fatigue was the most reported symptom in Covid-19 cases, with prevalence rates reaching up to 64% (23). Pictogram fatigue scales showed that 19.3% and 32% of patients with long Covid reported mild and moderate fatigue, respectively (24), while another study reported fatigue in 80% of Covid-19 patients (25). Maintaining optimal physical performance is critical for athletes to prevent premature fatigue (26). Cardiopulmonary fitness, evaluated by VO_2 max and lactate threshold, is the gold standard method for assessing performance capacity (27). To sustain cardiopulmonary efficiency, athletes must maintain adequate levels of physical activity and VO_2 max (27). After Covid-19, levels of VO_2 max fell from superior to good categories among athletes (28), and they dropped by more than 10% within 45 days of infection (19). Full recovery from Covid-19 may occur within three months (29,30), and six-week rehabilitation programmes have shown significant improvements in respiratory muscular strength, pulmonary function, and general muscle endurance (24). Physical capacity is an early predictor of disease progression (31). Post-lockdown studies reported reduced endurance capacity in elite handball players despite home-based training (32), alongside declines in cardiopulmonary function (33,34) and endurance capacities even among athletes without Covid-19 histories (35). Moreover, the pandemic significantly disrupted sporting events worldwide (36). To the best of our knowledge, previous studies (24,32-35) have reported wide variability in Covid-19 outcomes. Some patients recover spontaneously (29,30), others benefit from therapeutic interventions (24), and some experience prolonged impairments (32-35). Long Covid has been defined as a distinct condition, and current guidelines call for translational research (37), a nuanced understanding of its diverse manifestations (38), and large-scale trials (37,38). However, protection strategies, therapeutic outcomes, and recovery trajectories vary widely by country and population. While many patients seek symptom relief, the long-term impact on aerobic capacity and cardiopulmonary fitness remains critical especially for athletes. Yet, this topic has not been examined in Saudi population particularly recreational athletes. Accordingly, the aim of this study was to investigate the impact of long Covid on VO_2 max, physical activity, fatigue, and metabolic equivalents in Saudi recreational athletes.

Materials and Methods

Study design

This was a cross-sectional study.

Sample size

The sample size was calculated using an online tool (http://www.stat.ubc.ca/~rollin/stats/ssize/n2a.html) and based on the mean and standard deviation (SD) of the VO_2 max variable from a previous study (28): μ1 = 51.97, μ2 = 123.3, sigma/SD = 81.97. The significance level was set at 0.05 with a power of 0.80. The total required sample size was 42 athletic participants, with 21 in each group.

Participants

Forty-two athletic participants were screened and recruited from various sports clubs in the Eastern region, specifically in the cities of Dammam and Al-Khobar. They were non-randomly assigned into two groups:

- *Experimental group:* Twenty-one male and female recreational athletes who had been diagnosed with Covid-19 (37) at least 12 months prior to the time of study participation. Recovery was defined as being free from fever and respiratory symptoms for at least three days.
- *Control group:* Twenty-one male and female healthy matched athletes with no history or signs of Covid-19 infection, confirmed by absence of symptoms suggestive of acute infection (39).

Inclusion criteria

Male and female Saudi recreational athletes aged 18 to 35 years were included in this study. For the experimental group, a positive PCR test for Covid-19 recorded in the Tawakkalna application one year prior to data collection was required. For the control group, a negative PCR test for Covid-19 was required, with no reported symptoms of infection.

Exclusion criteria

Participants were excluded if they were non-Saudi recreational athletes; smokers; had acute infections, recent surgeries, unstable cardiovascular conditions, chronic respiratory or neurological diseases, or mental illness; were unable to walk; or had any other condition that contraindicated participation in the study (40,41).

Procedure of the study

After informed consent was obtained, demographic data were collected, including age, body weight, body mass index (BMI), oxygen saturation, heart rate, and blood pressure. The following assessments were then conducted for all participants:

a. *Chest X-ray*: As one of the most cost-effective and accurate diagnostic imaging tools, chest X-ray was used to detect lung infection or any tissue abnormalities (42-44). All images were evaluated by specialised radiologists for potential abnormalities secondary to Covid-19.
b. *Physical activity*: This was assessed using the valid International Physical Activity Questionnaire (IPAQ) Arabic version (45), which measures physical activity over the previous seven days across five domains: work-related activities, transportation, domestic, sports, and

leisure time each day (45). Results were classified into three categories based on MET (metabolic equivalent) minutes per week: low (3.3 METs), moderate (4 METs), and high or vigorous activity (8 METs). MET is a standard measure of energy expenditure during physical activity. These values were calculated by multiplying the MET value by the duration of the activity in minutes and the number of days per week. One MET is equal 3.5 millilitres of oxygen consumed per kilogram (kg) of body weight per minute at rest (44,46). Each participant completed all items of the IPAQ, and their total score and activity level were recorded.

c. *Fatigue level:* Fatigue was assessed using a portable handheld blood analyser, which is considered the gold standard for fatigue estimation via blood lactate concentration (47). With the participant in a seated and relaxed position, a fingertip was pricked using a lancet, and a drop of blood was placed on a test strip, which was then inserted into the Lactate Pro device. The resulting lactate level was recorded from the device screen.

d. *Cardiopulmonary functions*: They were measured using the COSMED Quark CPET system, it is a valid and reliable method for determining maximal oxygen consumption (VO_2 max), heart rate, and respiratory rate (48). Participants attended the physiological lab wearing their appropriate sports attire and footwear. Chest hair was shaved, and electrocardiograph leads were applied. An oxygen exchange mask was fitted securely to avoid leakage. After a detailed explanation of the procedure, the Bruce treadmill protocol was followed, involving four progressive stages of increasing speed and incline. Participants were encouraged to exert a maximal effort. Upon completion, a gradual cool-down was conducted. VO_2 max, METs, and respiratory quotient were recorded during this test (49).

Statistical analysis

Data were analysed using SPSS statistical software (version 25). Normality was tested using the Kolmogorov-Smirnov test. Independent t-test and Mann-Whitney test were used for comparisons between groups for normally and non-normally distributed variables, respectively. Cohen's d was used to determine effect sizes, while Chi-squared tests were used to compare categorical variables. Statistical significance was set at $p < 0.05$, with a 95% confidence interval.

Results

Out of 80 recreational athletes screened, 42 were recruited into the study. Twenty-one were assigned to the Covid-19 group (positive PCR at least 12 months prior) 21 to the healthy matched control group (negative PCR). Demographic characteristics (age, gender, BMI, resting and maximal heart rate, types of sports activities (football, basketball, running) and physical activity levels (moderate, and high) did not differ significantly between groups ($p > 0.05$) (Table 1). Most participants were male (81% in the Covid-19 group and 85% in the control group), with football and basketball as the most common sports (52% and 28% in the Covid-19 group; 42% and 28% in controls). All images of chest X-ray were not included in the analysis as they did not show any tissue abnormalities for all participants. High physical activity levels were reported by the majority of our participants (90% and 71%), and similar proportions were classified as overweight (28% and 27%) in the Covid-19 and control groups respectively (Table 1).

Mann-Whitney and independent t-tests revealed significant differences in mean values of the IPAQ scores, VO2 max, METS, and exercise breathing rates between the Covid-19 and healthy matched control groups ($p < 0.05$), (Figure 1 ,Table 2). However, no statistically significant differences were obtained in mean values of the respiratory quotient, lactic acid, VE (Minute volume), or VE/VCO2 (Validation of carbon dioxide production) between groups ($p > 0.05$). There was no statistically significant difference in mean values of lactic acid between groups, although values were slightly lower in the Covid-19 group (Table 2, Figure 2).

Results of Pearson correlation analysis show positive correlations between lactic acid and respiratory

Table 1. Demographic data of recruited participants.

Variables	Covid -19 athletes Mean ± SD	Effect sizes Cohen's d	Matched athletes Mean ± SD	Confidence interval at 95% (Lower; upper)	p-values
Age in years	24.05 ± 1.91	-0.31	23.24 ± 3.46	(-2.55;0.93)	†0.134 [M]
BMI in kg/m²	28.27 ± 2.65	-0.20	27.74 ± 2.55	(-2.15;1.09)	† 0.512[I]
Resting HR	78.0 ± 2.93	0.21	78.71 ± 3.72	(-1.37;2.80)	†0.598 [M]
Resting HR_{max}	195.95 ± 1.91	0.30	196.76 ± 3.46	(-0.93;2.55)	†0.134 [M]
Gender (N)%	male (17) 81%, female (4) 19%		male (18) 85.7%, female (3) 14.3%		† 0.679[C]
Types of sports activities (N)%	running (4) 19%, football (11) 52.4%, basketball (6) 28.6%		running (6) 28.6%, football (9) 42.8 %, basketball (6) 28.6%		† 0.183[C]
Physical activities categories (N)%	moderate (2) 9.5 %, high (19) 90.5 %		moderate (6)28.6%, high (15) 71.4%		† 0.116[C]

[C]: Chi-square test was used to compare categorical variables between groups, [I]: Independent -t test was used to compare between two groups for normal distributed variables, [M]: Mann-Whitney test was used to compare between two groups for non-normal distributed variables, CI at 95%: Confidence interval of the difference at 95%. Abbreviations: BMI: body mass index in kilogram/meter squared, HR: heart rate in beats / minute, HR max: maximal heart rate in beats/minute. †: non-significant differences as p- value > 0.05.

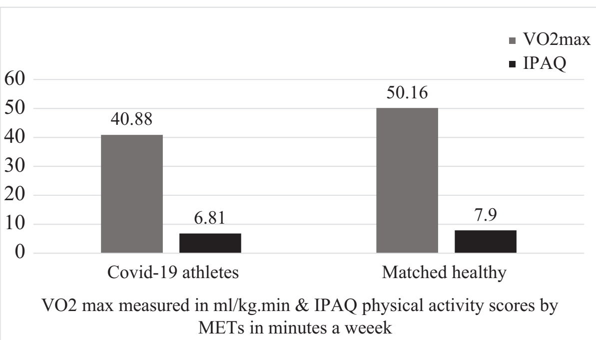

Figure 1. Mean values of VO2max and IPAQ physical activity scores of athletes with Covid-19 and healthy matched athletes. Covid-19: Coronavirus disease 2019. *Abbreviations:* IPAQ: International physical activity questionnaire; VO2 max: the maximum rate of oxygen consumption measured during incremental exercise. MET: is a way to measure body's expenditure of energy it is equal to 3.5 ml O2 per kg body weight x min.

quotient (r = 0.399, p = 0.009) and between IPAQ scores and exercise breathing rate (r = 0.343, p = 0.026). Spearman correlations revealed significant positive associations between VO2 max and METs (r = 0.941, p = 0.00), VO2 max and minute volume (r = 0.676, p = 0.000), and VO2 max and IPAQ scores (r = 0.417, p = 0.006).

Discussion

This study aimed to investigate the long-term impact of Covid-19 on aerobic capacity, physical activity, fatigue, and metabolic equivalents in Saudi recreational athletes. The current results show significant reductions in mean values of aerobic capacity, physical activity, and metabolic equivalents in Saudi recreational athletes with a history of Covid-19 on comparison with healthy matched athletes. Our findings indicate negative impact of Covid-19 on cardiopulmonary functions, physical activity levels, and METs, while no significant differences were gained in mean values of lactic acid and respiratory quotient between the two groups. Other meaning, individuals with a history of Covid-19 consistently exhibited higher albeit non-significant mean values of respiratory quotient than those matched healthy athletes. Our findings agree with the results of Barbagelata et al., Beyer et al., and Baratto et al., who detected significant negative impacts of viral infection on aerobic capacity (50), physical performance (51), oxygen contents and endurance performance (12) in patients with Covid-19. Similarly, our results are supported by Alshammari and López-Bueno et al., they detected significant reductions in exercise capacity in both non-athletes (52)

Table 2. Mean values of the IPAQ, METs, lactic acid and respiratory measures of athletic Covid-19 and healthy matched athletes.

Variables	Covid-19 athletes Mean ± SD	Healthy matched athletes Mean ± SD	Effect sizes Cohen's d	CI at (95%) (Lower; upper)	p-values
IPAQ Score of physical activity	6.81 ± 1.36	7.90 ± 0.89	0.49	(0.38;1.81)	* 0.006^{M}
Maximal oxygen consumption (Vo2 max) in (ml/kg.min)	40.88 ± 12.94	50.16 ± 1.72	0.75	(1.58;16.97)	* 0.019^{I}
Metabolic equivalent METs	12.19 ± 3.01	14.5 ± 3.39	0.36	(0.31;4.30)	* 0.025^{I}
Exercise breathing rate	57.48 ± 19.08	44.01 ± 18.06	-0.72	(-24.97; -1.97)	* 0.025^{I}
Respiratory quotient (RQ)	1.01 ± 0.15	0.95 ± 0.07	-0.27	(-0.13; -0.01)	† 0.512^{I}
Lactic acid	13.91 ± 7.44	16.33 ± 5.44	-0.37	(-1.65;6.48)	† 0.473^{M}
Minute volume (VE)	79.46 ± 29.9	91.67 ± 32.15	0.39	(-7.16;31.57)	† 0.210^{I}
VE / Vco2 slope	26.54 ± 6.81	30.19 ± 5.12	0.61	(-0.11;7.40)	† 0.057^{I}

^{M}: Mann-Whitney test was used to compare between two groups for non-normal distributed variables, ^{I}: Independent -t test was used to compare between two groups for normal variables. *Abbreviations:* IPAQ: International physical activity questionnaire; VO2 max: the maximum rate of oxygen consumption measured during incremental exercise; it is the gold standard measure of aerobic fitness. MET: is a way to measure body's expenditure of energy it is equal to 3.5 ml O2 per kg body weight x min. VE: Minute volume = tidal volume/ respiratory rate its increases mean increases work of breathing, VE / Vco2 slope is an index of ventilatory response to exercise, Respiratory quotient: >1.0 might suggest excessive carbohydrate or calorie provision that can result in increased CO2 production. CI at 95%: Confidence interval of the difference at 95%. †: non-significant differences as p-value > 0.05, *: non-significant differences as p-value < 0.05

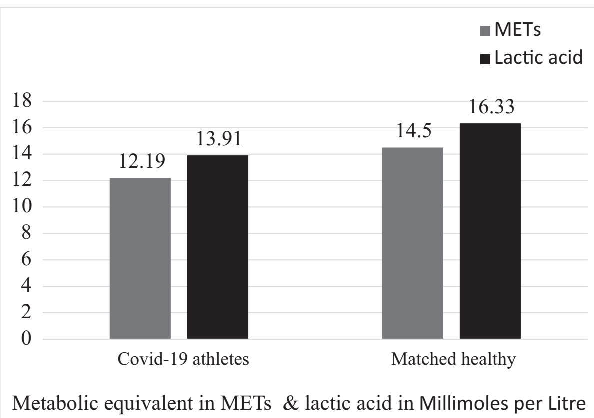

Figure 2. Mean values of metabolic equivalents in METs & lactic acid in mmol/L of athletes with Covid-19 and healthy matched athletes. Covid-19: Coronavirus disease 2019. *Abbreviations:* VO2 max: the maximum rate of oxygen consumption measured during incremental exercise. METs: means metabolic equivalent, it is a way to measure body's expenditure of energy, one MET is equal to 3.5 ml O2 per kg body weight x min.

and adolescents with Covid-19 (53). In contrast, Komici et al. they found that patients with Covid-19 exhibited optimal exercise capacity and no impairments in pulmonary or cardiovascular functions (54). Likewise, studies by Gervasi et al., Savicevic et al., and Ceglie et al. who determined no significant differences in athletes' performance before and after Covid-19 infection, including minutes played, rebounds, turnovers, and field goals (55-57). Gervasi et al. found no significant differences in cardiovascular functions between Covid-19 and non-Covid-19 groups, nor within the Covid-19 group pre- and post-infection in players from an Italian soccer team (55). Furthermore, no significant changes were reported in performance among National Basketball Association players before and after Covid-19 infection (58). Savicevic et al. also they found no significant differences in professional Croatian soccer players post-infection, which reflects preserved anaerobic endurance (59). Several previous studies explored the effect of time on disease progression and patients' recovery (29,30). Their results indicate improvements in impairments and consequences of Covid-19 over time. They attributed these improvements to various mechanisms for example, cardiopulmonary function may improve naturally due to normalisation of myocardial extracellular proteins and reduction of the inflammatory cytokines within six months of infection (59), also their findings have shown non-significant differences in cardiopulmonary function between groups (60), further, exercise interventions may improve immune response and functional outcomes via increasing stress hormones, reducing of local inflammatory changes (61), and enhancing respiratory and physical status in recovered patients (62). Some authors found intact of cardiopulmonary functions with good exercise capacity post-infection (63), which appears to contradict our findings, however, those authors assessed athletes within 30 days of the first negative PCR test. In contrast, the current study involved participants who were assessed at least one year after infection, a period generally considered sufficient for complete recovery (64). Post-infection improvements which may appear significant over time, on comparison of them with healthy matched controls still reveals persistent differences. Moreover, despite physiological recovery, the time lost from sports participation has markedly decreased (from 27 days to 10 days), indicating a safe return to activity (63,66). This recovery may be due to widespread vaccination, spontaneous healing, greater pandemic awareness, a healthy diet, physical activity, and compliance with health guidelines (63,65,66). While the majority of participants from both groups in the current study were categorised as highly active, the findings reveal significantly reductions in mean values of the IPAQ scores and VO_2 max among athletes with prior Covid-19 infection on comparison with matched healthy controls. This discrepancy may help to explain the observed differences in aerobic capacity. This highlights the need for individualised rehabilitation tailored programmes for previously infected individuals, regardless of the duration since infection or their general physical activity. These conclusions align with WHO recommendations and previous studies, which have advocated physical activity since the beginning of the pandemic and promoted home-based exercise to mitigate adverse effects of the viral outbreak (67,68). Similar recommendations include the promotion of healthy behaviours, physical activity participations, and increases of global awareness (53). It is also widely acknowledged that physically active individuals are less vulnerable to Covid-19 complications and hospitalisation (69). Pulmonary recovery of participants may be delayed as a result of comorbidities, advanced age, severe viral infection (70), and smoking (71). VO_2 max values reduces significantly in smoker athletes than in non-smokers (72). Fortunately, all participants in the current study were non-smokers, had no comorbidities, and had normal chest X-rays. which might be a solid aspect to eliminate pulmonary consequences. Smoking is significantly associated with Covid-19 progression, and it has a detrimental effect on cardiopulmonary function (73). Vaccination also played a major role in mitigating the long-term consequences of Covid-19 infection (74). Two doses of mRNA vaccine were associated with significant reductions in long-term symptoms (75,76), earlier return to work (75), and improvement in aerobic capacity compared to unvaccinated patients (74). All Covid-19 participants of the current study received three doses of the vaccine, both before and after infection. This may explain the similarities in some outcome measures e.g., lactic acid, minute volume, and respiratory quotient in both groups. Our findings show no significant differences in mean values of lactic acid between athletes with and without prior Covid-19, suggesting a comparable fatigue threshold. Physiologically, as exercise intensity increases, glycolysis intensifies, resulting in greater lactate utilisation in the mitochondria, particularly within adjacent slow-twitch muscle fibres, alongside fat oxidation. The ability to clear blood lactate is a useful indicator of mitochondrial function (77-79). While evidence on Covid-19's impact on mitochondrial metabolism remains limited, our findings contrast with the previous results showing impairment in fat oxidation and increases in accumulation of blood lactate during exercise in non-athletic patients with Covid-19 (77-79). These earlier findings were linked to risk factors such as age over 60, being female, admission at the onset of infection in intensive care unit, breathing difficulties, and pre-existing health conditions (80). Physically fit individuals generally have better mitochondrial function and higher fat oxidation rates during exercise. Well-conditioned athletes exhibit superior mitochondrial function, demonstrating enhanced capacity to oxidize both fatty acids and carbohydrates (81). For instance, cycling at 70% to 90% of VO_2 max significantly improves oxidative and glycolytic capacity (82), while 12 weeks of endurance training can double mitochondrial enzyme levels and increase total protein content by 60% (83). Our findings on mitochondrial function are consistent with the physical condition of our study population and support the 'open window' theory, which suggests that moderate-intensity exercise best enhances immunity by reducing inflammation, preserving thymic mass, and boosting immunosurveillance (84). Finally, the current results show positive correlations between lactic acid and respiratory quotient, indicating that increases in lactic acid levels may be associated with increases in respiratory quotient. This may suggest that excessive carbohydrate or calorie provision results in increased CO_2 production and greater lactic acid accumulation. However, there is a lack of evidence supporting this explanation. The observed positive correlation between physical activity and breathing rate during exercise is consistent with findings reported by Biernat et al., who stated that vigorous activities involve breathing much harder than normal and may include heavy lifting, digging, aerobics, or fast bicycling (85). The positive correlation observed between VO2 max and METs supports the use of METs in estimating VO_2 max and aligns with Paterson et al., who reported that increases in VO_2 max correspond with increases in METs (86). These correlations among different outcome measures facilitate interpretation of the current results although, overall, there remains a shortage of evidence in this area.

Conclusion

Mean values of VO_2 max, physical activity, and metabolic equivalent reduced significantly in Saudi recreational athletes with Covid-19 on comparison with healthy matched controls. In contrast, non-significant differences were found in mean values of lactic acid and respiratory quotient. Health care providers are advised to prescribe individualised rehabilitative training programmes for recreational athletes with Covid-19, regardless of the time since infection.

Strengths of the study

The use of the Cosmed Quark CPET ensured accurate determination of VO_2 max, and blood analysis enabled reliable detection of lactic acid concentrations. The Saudi athletic population warrants investigation due to lack of evidence regarding the impact of long Covid-19 on the sports sector in the Middle East.

Limitations

The small sample size and predominance of male participants may limit the generalisability of the findings. Additionally, the non-randomised recruitment of participants may have introduced bias to the current results.

Recommendations

Individualised rehabilitative training programmes should be prescribed by health care providers for recreational athletes with prior Covid-19, regardless of the time since infection. Further research is needed with a larger, randomly selected sample, focusing on a single sport and gender pattern to enhance the generalisability of the results.

Ethical Approval: All study procedures were approved by the Ethics Research Committee of the Institutional Review Board of Imam Abdualrahman bin Faisal University (IRB-PGS-2022-03-312). The study was conducted in accordance with the Declaration of Helsinki at the physiological laboratory of the physical therapy department, College of Applied Medical Sciences, Imam Abdualrahman bin Faisal University, between December 2022 and June 2023. Written informed consent was obtained from all participants, who were informed that the data collected would be used for publication.

Conflict of Interest: Each author declares that he or she has no commercial associations (e.g. consultancies, stock ownership, equity interests, patent/licensing arrangements, etc.) that might give rise to a conflict of interest with respect to the submitted article.

Availability of Data and Materials: All materials and data used for analysis are available from the corresponding author on any reasonable request.

Authors' Contributions: made a substantial contribution to the concept, design of the article, the acquisition, analysis, and interpretation of data: Ha A, AS. Drafted the article, revised it critically for important intellectual content: HA, AS. Approved the version to be published: AS, MS. Agreed to be accountable for all aspects of the work in ensuring that questions related to the accuracy or integrity of any part of the work are appropriately investigated and resolved : HA, AS&MS.

Acknowledgement: The authors would like to thank Dean of scientific research in Imam Abdulrahman bin Faisal University, King Faisal University, Dr Belal shanb, Medical Bachelor student Rawda Alsayed Shanb for cooperation and assistance in conducting this research.

Funding: All authors reported non-funding or any financial support from anybody or agencies.

References

1. South AM, Diz DI, Chappell MC. COVID-19, ACE2, and the cardiovascular consequences. Am J Physiol Heart Circ Physiol. 2020;318(5):H1084-90. doi: 10.1152/ajpheart.00217.2020
2. McKinney J, Velghe J, Fee J, et al. Defining athletes and exercisers. Am J Cardiol. 2019;123(3):532-5. doi: 10.1016/j.amjcard.2018.11.001
3. Kwok KO, Wong VW, Wei WI, et al. Epidemiological characteristics of the first 53 laboratory-confirmed cases of COVID-19 epidemic in Hong Kong, 13 February 2020. Euro Surveill. 2020;25(16):2000155. doi: 10.2807/1560-7917.ES.2020.25.16.2000155
4. Li Q, Guan X, Wu P, et al. Early transmission dynamics in Wuhan, China, of novel coronavirus-infected pneumonia. N Engl J Med. 2020;382(13):1199-1207. doi: 10.1056/NEJMoa2001316
5. Petrosillo N, Viceconte G, Ergonul O, et al. COVID-19, SARS and MERS: are they closely related? Clin Microbiol Infect. 2020;26(6):729-34. doi: 10.1016/j.cmi.2020.03.026
6. Silva FB, Fonseca B, Domecg F, et al. Athletes health during pandemic times: hospitalization rates and variables related to COVID-19 prevalence among endurance athletes. Int J Cardiovasc Sci. 2021;34(3):274-83. doi: 10.36660/ijcs.20200208
7. Peña J, Altarriba-Bartés A, Vicens-Bordas J, et al. Sports in time of COVID-19: impact of the lockdown on team activity. Apunts Sports Med. 2020;56(209):100340. doi: 10.1016/j.apunsm.2020.100340
8. Halpin SJ, McIvor C, Whyatt G, et al. Post-discharge symptoms and rehabilitation needs in survivors of COVID-19 infections: a cross-sectional evaluation. J Med Virol. 2021; 93(2):1013-22. doi: 10.1002/jmv.26368
9. Husain I, Bauddha S. The outbreak, epidemic and pandemic of coronavirus disease (COVID-19). Int J Adv Res Biol Sci. 2021;8(8):80-8. doi: 10.22192/ijarbs
10. Raghu G, Collard HR, Egan JJ, et al. An official ATS/ERS/JRS/ALAT statement: idiopathic pulmonary fibrosis evidence-based guidelines for diagnosis and management. Am J Respir Crit Care Med. 2011;183(6):788-824. doi: 10.1164/rccm.2009-040GL
11. Lazar M, Barbu EC, Chitu CE, et al. Interstitial lung fibrosis following COVID-19 pneumonia. Diagnostics (Basel). 2022;12(8):2028. doi: 10.3390/diagnostics12082028
12. Baratto C, Caravita S, Faini A, et al. Impact of COVID-19 on exercise pathophysiology: a combined cardiopulmonary and echocardiographic exercise study. J Appl Physiol (1985). 2021;130(5):1470-8. doi: 10.1152/japplphysiol.00710.2020
13. Bellmann-Weiler R, Lanser L, Barket R, et al. Prevalence and predictive value of anemia and dysregulated iron homeostasis in patients with COVID-19 infection. J Clin Med. 2020;9(8):2429. doi: 10.3390/jcm9082429
14. Chun HJ, Coutavas E, Pine AB, et al. Immuno-fibrotic drivers of impaired lung function in post-acute sequelae of SARS-CoV-2 infection. JCI Insight. 2021;6(14): e148476. doi: 10.1172/jci.insight.148476
15. Zhu Y, Sharma L, Chang D. Pathophysiology and clinical management of coronavirus disease (COVID-19): a mini-review. Front Immunol. 2023; 14:1116131. doi: 10.3389/fimmu.2023.1116131
16. Strasser B, Burtscher M. Survival of the fittest: VO2max, a key predictor of longevity? Front Biosci (Landmark Ed). 2018;23(8):1505-16. doi: 10.2741/4657
17. Meyler S, Bottoms L, Muniz-Pumares D. Biological and methodological factors affecting response variability to endurance training and the influence of exercise intensity prescription. Exp Physiol. 2021;106(7):1410-24. doi: 10.1113/EP089565
18. Amirudin A, Abdillah S. Analysis of physical conditions of aerobic endurance or VO2Max. In: Proceedings of the 1st South Borneo International Conference on Sport Science and Education; 2019; Banjarmasin, Indonesia. Paris: Atlantis Press; 2019. p.117-9. doi: 10.2991/assehr.k.200219.033
19. Crameri GG, Bielecki M, Züst R, et al. Reduced maximal aerobic capacity after COVID-19 in young adult recruits, Switzerland, May 2020. Euro Surveill. 2020;25(36):2001542. doi: 10.2807/1560-7917.ES.2020.25.36.2001542
20. Poole DC, Jones AM. Measurement of the maximum oxygen uptake VO2max: VO2peak is no longer acceptable. J Appl Physiol (1985). 2017;122(4):997-1002. doi: 10.1152/japplphysiol.01063.2016
21. Davis HE, McCorkell L, Vogel JM, et al. Long COVID: major findings, mechanisms and recommendations. Nat Rev Microbiol. 2023;21(3):133-46. doi: 10.1038/s41579-022-00846-2
22. Abd-Elfattah HM, Abdelazeim FH, Elshennawy S. Physical and cognitive consequences of fatigue: a review. J Adv Res. 2015;6(3):351-8. doi: 10.1016/j.jare.2015.01.011
23. Joli J, Buck P, Zipfel S, et al. Post-COVID-19 fatigue: systematic review. Front Psychiatry. 2022; 13:947973. doi: 10.3389/fpsyt.2022.947973
24. Araújo BS, Barros A, Nunes DX, et al. Effects of continuous aerobic training associated with resistance training on maximal and submaximal exercise tolerance, fatigue, and quality of life of patients post-COVID-19. Physiother Res Int. 2023;28(1):e1972. doi: 10.1002/pri.1972
25. Nalbandian A, Desai AD, Wan EY. Post-COVID-19 Condition. Annu Rev Med.2023; 74, 55-64. doi:10.1146/annurev-med-043021-030635.
26. Billaut F, Gore CJ, Aughey RJ. Enhancing team-sport athlete performance: is altitude training relevant? Sports Med. 2012;42(9):751-67. doi: 10.1007/BF03262293

27. Beattie K, Kenny IC, Lyons M, et al. The effect of strength training on performance in endurance athletes. Sports Med. 2014;44(6):845-65. doi: 10.1007/s40279-014-0157-y
28. Ariestika E, Widiyanto W, Nanda FA. Physical activities and VO2 max: Indonesian national team, is there a difference before and after COVID-19? J Sportif. 2020;6(3):763-78
29. Fumagalli A, Misuraca C, Bianchi A, et al. Pulmonary function in patients surviving to COVID-19 pneumonia. Infection. 2021;49(1):153-7. doi: 10.1007/s15010-020-01474-9
30. Nopp S, Moik F, Klok FA, et al. Outpatient pulmonary rehabilitation in patients with long COVID improves exercise capacity, functional status, dyspnea, fatigue, and quality of life. Respiration. 2022;101(6):593-601. doi: 10.1159/000522118
31. Brawner CA, Ehrman JK, Bole S, et al. Inverse relationship of maximal exercise capacity to hospitalization secondary to coronavirus disease 2019. Mayo Clin Proc. 2021;96(1): 32-9. doi: 10.1016/j.mayocp.2020.10.003
32. Fikenzer S, Fikenzer K, Laufs U, et al. Impact of COVID-19 lockdown on endurance capacity of elite handball players. J Sports Med Phys Fitness. 2021;61(7):977-82. doi: 10.23736/S0022-4707.20.11501-9
33. Fikenzer S, Kogel A, Pietsch C, et al. SARS-CoV-2 infection: functional and morphological cardiopulmonary changes in elite handball players. Sci Rep. 2021;11(1):17798. doi: 10.1038/s41598-021-97120-x.
34. Moulson N, Petek BJ, Drezner JA, et al. SARS-CoV-2 cardiac involvement in young competitive athletes. Circulation. 2021;144(4):256-66. doi: 10.1161/CIRCULATION AHA.121.054824
35. Kalinowski P, Myszkowski J, Marynowicz J. Effect of online training during the COVID-19 quarantine on the aerobic capacity of youth soccer players. Int J Environ Res Public Health. 2021;18(12):6195. doi: 10.3390/ijerph18126195
36. Scheer D, Laubenstein D. The impact of COVID-19 on mental health: psychosocial conditions of students with and without special educational needs. Soc Sci. 2021;10(11):405. doi: 10.3390/socsci10110405
37. Ewing AG, Joffe D, Blitshteyn S, et al. Long COVID clinical evaluation, research and impact on society: a global expert consensus. Ann Clin Microbiol Antimicrob. 2025; 24:27. doi: 10.1186/s12941-025-00793-9
38. Negrut N, Menegas G, Kampioti S, et al. The multisystem impact of long COVID: a comprehensive review. Diagnostics (Basel). 2024;14(3):244. doi: 10.3390/diagnostics14030244
39. Bhimraj A, Morgan RL, Shumaker AH, et al. Infectious Diseases Society of America guidelines on the treatment and management of patients with COVID-19. Clin Infect Dis. 2020;27(10). doi: 10.1093/cid/ciaa478
40. Giannitsi S, Bougiakli M, Bechlioulis A, et al. 6-minute walking test: a useful tool in the management of heart failure patients. Ther Adv Cardiovasc Dis. 2019; 13:1753944719870084. doi: 10.1177/1753944719870084
41. Talaminos Barroso A, Márquez Martín E, Roa Romero LM, et al. Factors affecting lung function: a review of literature. Arch Bronconeumol Engl Ed. 2018;54(6):327-32. doi: 10.1016/j.arbr.2018.04.003
42. Majrashi NA. The value of chest X-ray and CT severity scoring systems in the diagnosis of COVID-19: a review. Front Med (Lausanne). 2022; 9:1076184. doi: 10.3389 /fmed.2022.1076184
43. Mohammd AH, Said AF, Esmaeel TE, et al. Chest imaging's diagnostic and prognostic relevance in COVID-19; a review article. MJMR. 2022;33(3): 37-5. doi: 10.21608 /mjmr.2022.126641.1062
44. Omar S., Motawea AM., Yasin R. High-resolution CT features of COVID-19 pneumonia in confirmed cases. Egyptian Journal of Radiology and Nuclear Medicine.2020; 51, 1-9. doi:10.1186/s43055-020-00236-9
45. Helou K, ElHelou N, Mahfouz M, et al. Validity and reliability of an adapted Arabic version of the long international physical activity questionnaire. BMC Public Health. 2018;18(49):1-8. doi:10.1186/s12889-017-4599-7
46. Craig CL, Marshall AL, Sjöström M, et al. International physical activity questionnaire: 12-country reliability and validity. Med Sci Sports Exerc. 2003;35(8):1381-95. doi: 10.1249/01.MSS.0000078924.61453.FB
47. Tanner RK, Fuller KL, Ross ML. Evaluation of three portable blood lactate analysers: Lactate Pro, Lactate Scout and Lactate Plus. Eur J Appl Physiol. 2010;109(3):551-9. doi: 10.1007/s00421-010-1379-9
48. Brooks KA, Carter JG, Dawes JJ. A comparison of VO2 measurement obtained by a physiological monitoring device and the Cosmed Quark CPET. J Nov Physiother. 2013; 3:1000126. doi: 10.4172/2165-7025.1000126
49. Sierra AR, Lima GO, da Silva ED, et al. Angiotensin-converting enzyme related-polymorphisms on inflammation, muscle and myocardial damage after a marathon race. Front Genet. 2019; 10:984. doi: 10.3389/fgene.2019.00984
50. Barbagelata L, Masson W, Iglesias D, et al. Cardiopulmonary exercise testing in patients with post-COVID-19 syndrome. Med Clin (Barc). 2022;159(1):6-11. doi: 10.1016 /j.medcli.2021.07.007
51. Beyer S, Haufe S, Dirks M, et al. Post-COVID-19 syndrome: physical capacity, fatigue and quality of life. PLoS One. 2023;18(10):e0292928. doi: 10.1371/journal.pone.0292928
52. Alshammari M, Shanb A, Alsubaiei M. Long-term effect of non-severe COVID-19 on pulmonary function, exercise capacities and physical activities: a cross-sectional study in Sakaka Aljouf. F1000Res. 2024; 12:809. doi: 10.12688 /f1000research.133516.3
53. López-Bueno R, Calatayud J, Andersen LL, et al. Cardiorespiratory fitness in adolescents before and after the COVID-19 confinement: a prospective cohort study. Eur J Pediatr. 2021;180(7):2287-93. doi: 10.1007/s00431 -021-04029-8
54. Komici K, Bianco A, Perrotta F, et al. Clinical characteristics, exercise capacity and pulmonary function in post-COVID-19 competitive athletes. J Clin Med. 2021; 10(14):3053. doi: 10.3390/jcm10143053
55. Gervasi SF, Pengue L, Damato L, et al. Is extensive cardiopulmonary screening useful in athletes with

previous asymptomatic or mild SARS-CoV-2 infection? Br J Sports Med. 2021;55(1):54-61. doi: 10.1136/bjsports-2020-102789
56. Savicevic AJ, Nincevic J, Versic S, et al. Performance of professional soccer players before and after COVID-19 infection: observational study with an emphasis on graduated return to play. Int J Environ Res Public Health. 2021;18(21):11688. doi: 10.3390/ijerph182111688
57. Ceglie N, Petito A, Cibelli G. Return to play of young and adult professional athletes after COVID-19: a scoping review. J Exerc Sci Fit. 2024;22(3):208-20. doi: 10.1016/j.jesf.2024.03.005
58. Vaudreuil NJ, Kennedy AJ, Lombardo SJ, et al. Impact of COVID-19 on recovered athletes returning to competitive play in the NBA "Bubble". Orthop J Sports Med. 2021;9(3):23259671211004531. doi: 10.1177/23259671211004531
59. Sonnweber T, Sahanic S, Pizzini A, et al. Cardiopulmonary recovery after COVID-19: an observational prospective multi-centre trial. Eur Respir J. 2021;57(4):2003481. doi: 10.1183/13993003.03481-2020
60. Cassar MP, Tunnicliffe EM, Petousi N, et al. Symptom persistence despite improvement in cardiopulmonary health: insights from longitudinal CMR, CPET and lung function testing post-COVID-19. EClinicalMedicine. 2021; 41:101159. doi: 10.1016/j.eclinm.2021.101159
61. Martin SA, Pence BD, Woods JA. Exercise and respiratory tract viral infections. Exerc Sport Sci Rev. 2009;37(4): 157-64. doi: 10.1097/JES.0b013e3181b7b57b
62. Rodriguez-Blanco C, Bernal-Utrera C, Anarte-Lazo E, et al. A 14-day therapeutic exercise tele-rehabilitation protocol of physiotherapy is effective in non-hospitalized post-COVID-19 conditions: a randomized controlled trial. J Clin Med. 2023;12(3):776. doi: 10.3390/jcm12030776
63. Maestrini V, Penza M, Filomena D, et al. Low prevalence of cardiac abnormalities in competitive athletes at return-to-play after COVID-19. J Sci Med Sport. 2023;26(1):8-13. doi: 10.1016/j.jsams.2022.10.015
64. Walque JM, Terwangne C, Jungers R, et al. Potential for recovery after extremely prolonged VV-ECMO support in well-selected severe COVID-19 patients: a retrospective cohort study. BMC Pulm Med. 2024; 24:19. doi: 10.1186/s12890-023-02836-3
65. Aldhahri M, Alghamdi R. Awareness of COVID-19 before and after quarantine based on crowdsourced data from Rabigh City, Saudi Arabia: a cross-sectional and comparative study. Front Public Health. 2021; 9:632024. doi: 10.3389/fpubh.2021.632024
66. Hull JH, Williams Z, Wootten M, et al. Recovery from COVID-19 in athletes and impact on sporting participation. J Sci Med Sport. 2023;26(10):528-9. doi: 10.1016/j.jsams.2023.07.011
67. Araújo C, Scharhag J. Athlete: a working definition for medical and health science. Scand J Med Sci Sports. 2016; 26(1):4-7. doi: 10.1111/sms.12632
68. Araújo CG. Physical activity, exercise and sports and COVID-19: what really matters. Int J Cardiovasc Sci. 2021; 34(2):113-5. doi: 10.36660/ijcs.20210003
69. Smer A, Squires RW, Bonikowske AR, et al. Cardiac complications of COVID-19 infection and the role of physical activity. J Cardiopulm Rehabil Prev. 2023;43(1):8-14. doi: 10.1097/hcr.0000000000000701
70. Van Willigen HD, Wynberg E, Verveen A, et al. One-fourth of COVID-19 patients have an impaired pulmonary function after 12 months of disease onset. PLoS One. 2023;18(9):e0290893. doi: 10.1371/journal.pone.0290893
71. Almohannadi MS, Alyafei A. Aerobic capacity and regular physical exercise among tobacco smokers. Rea Int J Community Med Public Health. 2021;2(1):1-4. doi: 10.37179/rijcmph.000010
72. Tchissambou BP, Massamba A, Babela JR, et al. The effects of smoking and the degree of nicotine dependence on aerobic capacity in sportsmen. Rev Mal Respir. 2004;21(1): 59-66. doi: 10.1016/s0761-8425(04)71236-x
73. Patanavanich R, Glantz SA. Smoking is associated with COVID-19 progression: a meta-analysis. Nicotine Tob Res. 2020;22(9):1653-6. doi: 10.1093/ntr/ntaa082
74. Blumberg Y, Edelstein M, Abu Jabal K, et al. Protective effects of BNT162b2 vaccination on aerobic capacity following mild to moderate SARS-CoV-2 infection: a cross-sectional study. J Clin Med. 2022;11(15):4420. doi: 10.3390/jcm11154420
75. Nicholas MM, Ian DP, Kari KH, et al. Presence of symptoms 6 weeks after COVID-19 among vaccinated and unvaccinated US healthcare personnel: a prospective cohort study. BMJ Open. 2023;13(2):e063141. doi: 10.1136/bmjopen-2022-063141
76. Antonelli M, Penfold RS, Merino J, et al. Risk factors and disease profile of post-vaccination SARS-CoV-2 infection in UK users of the COVID Symptom Study app: a prospective, community-based, nested, case-control study. Lancet Infect Dis. 2022;22(1):43-55
77. De Boer E, Petrache I, Goldstein NM, et al. Decreased fatty acid oxidation and altered lactate production during exercise in patients with post-acute COVID-19 syndrome. Am J Respir Crit Care Med. 2022;205(1):126-9. doi: 10.1164/rccm.202108-1903LE
78. Laguarta-Val S, Varillas-Delgado D, Lizcano-Álvarez Á, et al. Effects of aerobic exercise therapy through Nordic walking program in lactate concentrations, fatigue and quality of life in patients with long-COVID syndrome: a non-randomized parallel controlled trial. J Clin Med. 2024;13(4):1035. doi: 10.3390/jcm13041035
79. Pleguezuelos E, Del Carmen A, Llorensi G, et al. Severe loss of mechanical efficiency in COVID-19 patients. J Cachexia Sarcopenia Muscle. 2021;12(4):1056-63. doi: 10.1002/jcsm.12739
80. Poole-Wright K, Guennouni I, Sterry O, et al. Fatigue outcomes following COVID-19: a systematic review and meta-analysis. BMJ Open. 2023;13(4): e063969. doi: 10.1136/bmjopen-2022-063969

81. San-Millán I. The key role of mitochondrial function in health and disease. Antioxidants (Basel). 2023;12(4):782. doi: 10.3390/antiox12040782
82. Gollnick PD, Armstrong RB, Saltin B, et al. Effect of training on enzyme activity and fiber composition of human skeletal muscle. J Appl Physiol. 1973;34(1):107-11. doi: 10.1152/jappl.1973.34.1.107
83. Holloszy JO. Biochemical adaptations in muscle: effects of exercise on mitochondrial oxygen uptake and respiratory enzyme activity in skeletal muscle. J Biol Chem. 1967; 242(9):2278-82. PMID: 4290225
84. Baskerville R, Castell L, Bermon S. Sports and immunity, from the recreational to the elite athlete. Infect Dis Now. 2024;54(4S):104893. doi: 10.1016/j.idnow.2024.104893
85. Biernat E, Stupnicki R, Lebiedziński B. Assessment of physical activity by applying IPAQ questionnaire. Phys Educ Sport. 2008; 52:46-52. doi: 10.2478/v10030-008-0019-1
86. Paterson DH, Jones GR, Rice CL. Aging and physical activity: data on which to base recommendations for exercise in older adults. Appl Physiol Nutr Metab. 2007;32 (Suppl 2F): S75-171. doi: 10.1139/H07-165.

Correspondence:
Received: 28 April 2025
Accepted: 5 June 2025
Alsayed Abdelhameed Shanb. Associate professor,
Department of Physical Therapy, College of Applied Medical Sciences, Imam Abdulrahman Bin Faisal University, King Fahd Street, Al-Khobar, Dammam, Saudi Arabia. E-mail: aashanb@iau.edu.sa , ORCID: 0000-0002-4878-5025