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# Respiratory complications following COVID-19 in athletic populations: A narrative review

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Athletes typically experience a mild-to-moderate, self-limiting illness following infection with the novel severe acute respiratory syndrome coronavirus 2. Some athletes, however, can develop prolonged symptoms, with breathlessness, cough, and chest tightness impacting return to training and competition. In athletes with persistent cardiopulmonary symptoms following COVID-19, focus is usually placed on the identification and characterization of cardiac complications, such as myocarditis. In this review, we focus on summarizing the literature assessing pulmonary complications and physiological consequences associated with COVID-19 illness in athletes. The review also provides recommendations for clinical assessment of the athlete with pulmonary issues following COVID-19 and directions for future research.

**KEYWORDS**
athlete, COVID-19, exercise test, persistent symptoms

## 1 | INTRODUCTION

In the general population, severe acute respiratory syndrome coronavirus 2 (SARS-CoV-2) infection results in protean manifestations, with the most prevalent sequalae and severe complications focused on the respiratory system.[1,2] Long-term pulmonary impairment is found in approximately 3%–5% of the population following COVID-19, predominantly in those aged over 50 years old.[3] Sonnweber et al.[4] reported that, at 100 days following COVID-19 diagnosis, almost a third of individuals continued to experience dyspnea and had impaired pulmonary function, and two-thirds had abnormal pulmonary imaging findings.[4] Moreover, in some series approximately one in five patients appear to develop pulmonary vascular abnormalities following COVID-19.

Over the course of the pandemic, it has become apparent that physical activity status appears to be relevant in modulating the risk of complications arising from COVID-19.[5] Several large epidemiological studies reveal a reduced risk of hospitalization, need for critical care support, and mortality, in physically active individuals; this may account for as much as 10% of the total attributable risk.[5] Accordingly, it may be expected that athletes, by virtue of their highly trained physical status, would be protected against the development of complications from COVID-19. A key concern in athlete health focused on the apparent risk of cardiac complications (e.g., myocarditis or peri-myocarditis) following COVID-19.[6] An alarmingly high prevalence was reported in early publications, with cardiac abnormalities reported in half of collegiate-level athletes[7] and a quarter of elite athletes.[8] This prompted conservative assessment strategies with the promotion of cardiac screening, prior to any return to play (RTP).[9] Later data challenged this, with most recent series indicating that the overall prevalence of cardiac complications is more

likely to be <2%.[10] Comparatively, one review reported over one in five individuals diagnosed with COVID-19, and one in two people hospitalized with COVID-19 presented with raised markers of cardiac dysfunction.[11]

COVID-19 results in a broad range of clinical manifestations, but by virtue of the nature of the initial infection, the respiratory system is the primary organ system affected in most individuals in the general population. Cough, dyspnea, and chest tightness are highly prevalent symptoms in the acute phase of the illness and respiratory symptomatology is common in the post-COVID-19 syndrome, with approximately one in eight individuals affected by ongoing, persistent symptoms.[12]

In athletes, the COVID-19 pandemic had an immediate impact on ability to train and undertake competitive sport with the majority of major sporting events cancelled.[13] The cessation of regular training and competition impacted not only impacts physical performance, with detraining effects on skeletal muscle mass and with alteration of mechanical tissue properties and structure[14] but also has deleterious effects on psychological well-being.[15]

Our understanding of how the pulmonary system is impacted in athletes with COVID-19 remains at a relatively embryonic stage. There is still very little published high-quality data providing insight regarding pulmonary physiology and imaging in this cohort of individuals. Regardless, the aim of this review is to provide an overview and summary of what is currently known regarding acute and persistent respiratory symptoms in athletic populations following COVID-19, with focus on findings from pulmonary function and cardiopulmonary exercise testing (CPET).

## 2 | METHODOLOGY

In this narrative review, we identified relevant research for the manuscript by searching two electronic databases (Google scholar and PubMed) from inception up to the period of August 2022. The search terms employed in both databases consisted of key words related to "COVID-19," "athletes," "pulmonary function," "respiratory," "cardiopulmonary," "CPET," "acute," "persistent," and "symptom." We identified relevant articles that present data on acute/persistent symptoms, pulmonary function testing and cardiopulmonary exercise tests, as well as respiratory sequalae following COVID-19 infection in athletes competing at an amateur, collegiate and/or elite or professional level.

### 2.1 | Respiratory symptoms in athletes in the acute phase of COVID-19

It is now well recognized that in the general population, acute COVID-19 (i.e., not asymptomatic SARS-CoV-2 infection), is associated with a broad range of clinical manifestations. In individuals with moderate-to-severe disease, respiratory symptoms are prominent; with acute breathing and cough difficulties present in 92% and 42%, respectively.[16]

As may be expected, athletic individuals appear to develop similar symptoms but that typically result in only a mild to moderate and self-limiting illness, that is, with the rare occurrence of hospital-based care reported.[17] Table 1 outlines symptom prevalence during the acute phase of COVID-19 in athletes, obtained from a review of 16 studies. In this analysis, the most prevalent acute symptoms reported in athletes were headache, anosmia, ageusia, fatigue, and fever. Respiratory symptoms, such as dyspnea, chest pain, and cough were apparent, but less frequently reported.

### 2.2 | Respiratory symptoms in athletes in the post/long-COVID Syndrome

Despite a low number of athletes requiring hospitalization (0.2%),[18] the development of persistent symptoms and presence of a protracted recovery period following COVID-19 is now recognized in both elite and sub-elite cohorts of athletes.[19] In the UK, the National Institute for Health and Care Excellence (NICE) define long COVID-19 as "signs and symptoms that continue or develop after the acute COVID-19 illness, including both ongoing symptomatic COVID-19 (four to twelve weeks) and post COVID syndrome (>12 weeks or more)".[20] Studies have indicated that "long" COVID-19 symptoms (>28 days) are present in approximately one in ten individuals in the general population, with a higher prevalence in those aged over 40 years old.[21]

In athletes, the majority of studies have defined persistent symptoms as those continuing >28 days from time of diagnosis.[22,23] The type of persistent symptoms reported in athletes with this issue are presented in Table 2, sampled from four studies. Figure 1 displays the prevalence of acute symptoms (16 studies) and persistent symptoms (four studies) reported by athletes following COVID-19 infection. In these studies, the timeframe of when the symptoms were reported ranged from the end of self-isolation up >28 days.

In the largest study to date evaluating this issue ($n$ = 3597 athletes), only 1.2% ($n$ = 44, 20 ± 2 years old, 36% female) experienced persistent symptoms (>28 days), with loss of taste and smell reported most commonly (63%), followed by dyspnea (20%), and then cough (15%). Of this cohort, 137 athletes reported exertional symptoms on their return to exercise, the most common symptom was dyspnea (58%), followed by chest pain (36%), and then exercise intolerance (23%).[24] In contrast, in a cohort of

**TABLE 1** Athlete acute symptoms prevalence

| | Athlete characteristics | Headache | Anosmia | Ageusia | Sore throat | Cough | Fatigue | SOB | Chest pain | Fever | Myalgia | Diarrhea |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Cavigli et al. ($n = 90$) | Professional and non-professional competitive athletes | 25 (36.2) | 35 (50.7) | 34 (49.3) | N/A | 20 (29.0) | N/A | 6 (8.7) | N/A | 50 (72.5) | N/A | 5 (7.3) |
| Moulson et al. ($n = 21$) | Competitive high school, collegiate, post-collegiate and recreational athletes | 17 (81.0) | 12 (57.0) | 11 (52.0) | 10 (48.0) | 8 (38.0) | 20 (95.0) | 9 (43.0) | 6 (29.0) | 11 (52.0) | 11 (52.0) | 6 (29.0) |
| Schwellnus et al. ($n = 45$) | Competitive athletes, 26% of cohort professional | 35 (77.8) | 31 (68.9) | 29 (64.4) | 23 (51.1) | 23 (51.1) | 35 (77.9) | 17 (37.8) | 14 (31.1) | 17 (37.8) | 24 (53.3) | 9 (20.0) |
| Erickson et al. ($n = 170$) | Collegiate athletes | 56 (32.9) | 66 (38.8) | 62 (36.5) | 36 (21.2) | 35 (20.6) | 43 (25.3) | 25 (14.7) | 12 (7.1) | 11 (6.5) | 23 (13.5) | 2 (1.2) |
| Hendrickson et al. ($n = 137$) | Collegiate athletes | 46 (41.0) | 65 (58.0) | 65 (58.0) | N/A | N/A | 45 (40.0) | 14 (12.0) | 13 (11.0) | 47 (42.0) | N/A | N/A |
| Moulson et al ($n = 1774$) | Collegiate athletes | 687 (39.0) | 712 (40.0) | 712 (40.0) | 547 (31.0) | 492 (28.0) | 434 (24.0) | 185 (10.0) | 88 (5.0) | 431 (24.0) | 501 (28.0) | 88 (5.0) |
| Petek et al. ($n = 3424$) | Collegiate athletes | 784 (39.0) | 753 (38.0) | 753 (38.0) | 629 (31.0) | 554 (28.0) | 502 (25.0) | 188 (9.0) | 99 (5.0) | 473 (24.0) | 563 (28.0) | 91 (5.0) |
| Hull et al. ($n = 126$) | UK Olympic and paralympic athletes | 57 (45.0) | 29 (23.0) | 29 (23.0) | 37 (29.0) | 61 (48.0) | 69 (55.0) | 18 (14.0) | 3 (2.0) | 51 (40.0) | 38 (30.0) | 5 (4.0) |
| Komici et al. ($n = 24$) | Competitive athletes | 3 (12.50) | 17 (70.8) | 15 (62.5) | 9 (37.5) | 11 (45.8) | 15 (62.5) | 5 (20.8) | N/A | 15 (50.0) | 16 (66.7) | 4 (16.7) |
| Csulak et al. ($n = 46$) | Elite level swimmers | 17 (36.0) | 10 (21.0) | 10 (21.0) | 10 (21.0) | 10 (21.0) | 29 (64.0) | 20 (43.0) | 3 (7.0) | 23 (50.0) | 20 (43.0) | N/A |
| Celik et al. ($n = 17$) | Volleyball players | N/A | 14 (82.4) | 14 (82.4) | N/A | 8 (47.1) | N/A | 7 (41.2) | N/A | 9 (52.5) | 9 (52.9) | N/A |
| Fikenzer et al. ($n = 8$) | Elite handball players | 5 (62.5) | 3 (37.5) | 3 (37.5) | 1 (12.5) | 1 (12.5) | N/A | 2 (25.0) | 2 (25.0) | N/A | 1 (12.5) | N/A |
| Gattoni et al. ($n = 13$) | Professional football players | 9 (69.0) | 8 (62.0) | 8 (62.0) | 6 (46.0) | 4 (31.0) | 13 (100.0) | 1 (8.0) | 3 (23.0) | 6 (46.0) | 11 (85.0) | 1 (9.0) |
| Gervasi et al. ($n = 18$) | Professional football players | 1 (5.6) | 3 (16.7) | 5 (27.8) | 1 (5.6) | 2 (11.1) | N/A | (N/A | N/A | 7 (38.9) | 2 (11.1) | N/A |
| Schuamacher et al. ($n = 15$) | Football players, staff, and referees | 9 (60.0) | 5 (33.3) | 4 (26.7) | 4 (26.7) | 1 (6.7) | 4 (26.7) | 1 (6.7) | N/A | 3 (20.0) | N/A | 2 (13.3) |
| Milovancev ($n = 16$) | First division volleyball players | 5 (31.0) | N/A | 10 (62.5) | 10 (62.5) | 5 (31.0) | 10 (62.5) | 1 (6.0) | 1 (6.0) | 12 (75.0) | 8 (50.0) | 3 (19.0) |
| Pooled prevalence (%) | | 29.63 | 29.74 | 29.68 | 23.21 | 21.13 | 20.98 | 8.42 | 4.22 | 19.64 | 21.52 | 3.78 |

*Note*: Data presented as total number of cases (% of the total population).

**TABLE 2** Athlete persistent symptoms prevalence (lasting >28 days)

| Study | Athlete characteristics | Headache | Anosmia | Ageusia | Sore throat | Cough | Fatigue | SOB | Chest Pain | Fever | Myalgia | Diarrhea |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Hull et al. ($n = 21$) | UK olympic and paralympic athletes | 11 (52) | 5 (24) | 5 (24) | 6 (29) | 12 (57) | 15 (71) | 8 (38) | 2 (10) | 9 (43) | 4 (19) | 1 (5) |
| Moulson et al. ($n = 14$) | Competitive high school, collegiate, post-collegiate, and recreational athletes | 6 (43) | 3 (24) | 2 (10) | 1 (5) | 2 (14) | 6 (43) | 11 (76) | 10 (71) | 0 (0) | 2 (14) | 1 (5) |
| Petek et al. ($n = 38$) | Collegiate athletes | 12 (32) | 30 (79) | 30 (79) | 7 (18) | 11 (29) | 15 (39) | 9 (24) | 6 (16) | 8 (21) | 8 (21) | 3 (8) |
| Gattoni et al. ($n = 13$) | Professional football players | 2 (15) | 3 (23) | 3 (23) | 1 (80 | 1 (8) | 10 (77) | 2 (15) | 0 (0) | 0 (0) | 3 (23) | 0 (0) |
| Pooled prevalence (%) | | 36 | 48 | 4 | 17 | 30 | 53 | 35 | 21 | 20 | 20 | 6 |

*Note*: Data presented as total number of cases (% of the total population).

Olympic and Paralympic athletes ($n = 147$), a higher prevalence of "long COVID" was reported with 14% reporting persistent symptoms at 28 days following initial diagnosis and 27% reporting an inability to return fully to their sport within this timescale. In this cohort, symptoms such as fatigue (71%), dry cough (57%), and headache (52%) were the most prevalent acute symptoms, but the presence of chest pain and dyspnea (i.e., lower chest-focused symptoms) appeared to be associated with a higher likelihood of delayed recovery and full return to sport.[23]

Schwellnus and colleagues[19] found athletes who reported chills, loss of smell, chest pain, and difficulty breathing had a lower chance of return to sport within 40 days compared to athletes without these symptoms. Moreover, in this cohort, excessive fatigue was found to be associated with a 75% lower probability of returning to sport within 40 days.[19] More recently, the same group[25] found that athletes who report a greater number of symptoms and fatigue were more likely to suffer a significant delay in their full return to sport.[25] In the general population, a similar finding is apparent with those reporting a greater number of symptoms at onset of illness more likely to suffer a protracted symptom course.[26]

Very few studies have objectively evaluated and investigated physiological findings in athletes with protracted COVID-19 symptoms. Moulson et al.[22] evaluated 21 athletes (22 ± 4 years old, 43% female) of whom over 70% reported persistent dyspnea, exercise intolerance, and chest pain. The prevalence of persistent symptoms was similar to that reported in the study by Petek et al.,[24] Athletes in their cohort all presented with at least one symptom during the acute phase of COVID-19 illness and 67% developed an additional late-onset symptom that was not present during the initial infection. All athletes reported at least one exertional cardiopulmonary symptom, the most common were dyspnea, chest pain, and exertional palpitations (76%, 57%, and 29%, respectively). The findings on subsequent lung function and CPET testing in this cohort are discussed below.

## 2.3 | Impact of COVID-19 on pulmonary function

Several studies have evaluated pulmonary physiology, predominantly using spirometry, in athletes following COVID-19. The majority of studies have found very little impact of COVID-19 infection on lung function, when compared to an individual's pre-COVID-19 values or when compared to the findings in a control group without COVID-19.[27-30] Specifically, Gattoni et al.[31] found no significant impairment in spirometry values assessed immediately after COVID-19 infection compared with pre-season

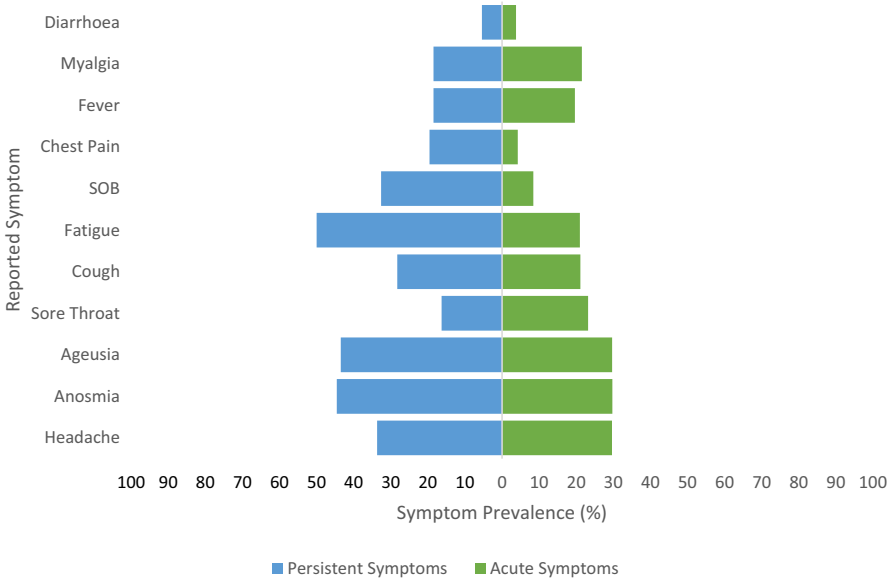


**FIGURE 1** Pooled acute (16 studies) and Persistent (4 studies) symptoms prevalence (%) reported by athletes following COVID-19 infection.

(i.e., pre-infection) baseline values in 13 male, professional football players (24 ± 4 years). Furthermore, there was no association found between forced vital capacity (FVC), forced expiratory volume in 1 second ($FEV_1$), and peak expiratory flow (PEF) and days positive with COVID-19 infection.[31] Milovancev et al.[32] also found minimal effect to spirometric data in athletes ($n = 16$, 24 ± 5 years old) following short duration, mild COVID-19 illness. $FEV_1$ and FVC were both within normal limits (>80% predicted), although athletes had returned to training for an average of 20 days prior to testing. Finally, Cafiero et al.[33] observed no abnormalities in either spirometry or diffusion capacity for carbon monoxide (DLCO) evaluations in pediatric athletes 30 days after COVID-19 infection.

In contrast, some studies have reported subtle findings of pulmonary dysfunction. Komici et al.[34] reported a decline in the mid-flow values of forced expiratory $flow_{75-25}$ ($FEF_{75-25}$) rates in a quarter of a cohort ($n = 24$) of athletes following COVID-19, but with the other parameters preserved. Similar findings were published by Moulson et al.,[22] (described above), who found that over 30% of athletes had an abnormal $FEV_1$% predicted and $FEV_1$/FVC ratio, indicative of airflow obstruction, when tested three to 6 months after COVID-19 infection. Furthermore, Gervasi et al.[28] reported declines of 5.4%, 6.3%, and 20.4% in FVC, $FEV_1$, and PEF, respectively, when an athlete's spirometry values were compared with their pre-infection baseline values. A similar finding was observed in an asymptomatic control group who had a 6% in $FEV_1$ from a pre-season value. The reason for these changes is unclear, given the fact that athletic status has limited impact on spirometric indices. Finally, one study assessed respiratory muscle strength and found a mean difference of −17% in maximal inspiratory pressure (MIP) and maximal expiratory pressure (MEP) values between a group of female athletes ($n = 17$) recovering from COVID-19 and a control group.[30] However, the lack of a longitudinal measurement perspective in this setting limits objective evaluation and comparison of results.

## 2.4 | Impact of COVID-19 on cardiopulmonary exercise performance

A number of studies have now utilized CPET to evaluate the cardiorespiratory impact of COVID-19 in athletes; a summary of findings can be viewed in Table 3. Results from these studies are somewhat conflicting but the majority showing that overall cardiorespiratory function appears to be relatively well preserved[31,32,34,35] and reveal no significant cardiopulmonary pathology.[22,34] Moulson and colleagues[22] used the findings from CPET to argue that the key value from this form of testing was to thus provide reassurance. In this study, 21 competitive athletes with protracted post-COVID-19 symptoms were evaluated. Of the 18 athletes with exertional symptoms during exercise, three athletes had an abnormal oxygen uptake, and three athletes achieved a peak oxygen uptake of ≥80% but ≤90% predicted. No dysrhythmia or gas exchange issue was identified. Some athletes in this cohort had a low breathing reserve at end exercise, occurring predominantly in participants in whom abnormal spirometry at rest was identified. A sub-group underwent a follow-up CPET at approximately 5 months, and there was evidence of an improvement in resting heart rate (HR) and peak exercise HR, with an accompanying 7% increase in peak oxygen consumption accompanied by improvements in exertional exercise symptoms such as dyspnea, chest pain, and cough.

A number of studies have reported impaired cardiopulmonary function following COVID-19. Anastasio et al.[29]

**TABLE 3** Studies reporting pulmonary symptoms and physiology following COVID-19 in athletes

| Author | Title | Population | Respiratory investigations | Measurements | Conclusions |
|---|---|---|---|---|---|
| Milovancev et al. (April 2021)[32] | Cardiorespiratory fitness in volleyball athletes following COVID-19 infection: a cross sectional study | 16 experience, male volleyball athletes (24 ± 4.5 years old) | PAR-Q spirometry CPET | Participants unable to train for 22 days. CPET parameters including $VO_{2peak}$ were typical of athletes this level. spirometry values >80% predicted | CPET results in keeping of athletes at similar level, with no change in spirometry |
| Komici et al. (July 2021)[34] | Clinical characteristics, Exercise Capacity and pulmonary Function in post-COVID-19 Competitive Athletes | Post-COVID-19 Soccer athletes mean age 23.5, range from 20–25.5 years old ($n = 24$), compared to healthy control mean age 21, range from 10 ($n = 11$) | Spirometry, CPET | $FEV_1$% predicted was significantly different with an 11% decrease in the post-COVID-19 group. No other spirometry parameters were statistically different. CPET parameters including peak $VO_2$, HR, peak RER, peak $V_E$ and $V_E/VCO_2$ slope were all similar between groups | Reduced exercise capacity cardiovascular complication and pulmonary function reductions or abnormalities were not seen. Apart from $FEV_1$% predicted |
| Fikenzer et al. (September 2021)[27] | SARS-CoV2 Infection: functional and morphological cardiopulmonary changes in elite handball players | 12 elite, male handball players, 8 $COVID^+$ (27 ± 3.5 years old) and 4 COVID- (22 ± 2.6 years old) | Spirometry CPET | Negligible decrements in mean spirometry values from preseason to post-COVID-19 baseline 5.2% drop in max power (W) 7.2% decline in $VO_{2peak}$ 3.8% higher peak HR (statistically different) 14.2% drop in minute ventilation | Post-COVID-19 athletes CPET performance dropped after infection. Lower work rates and peak oxygen uptake with an associated higher HR |
| Gervasi et al. (September 2021)[28] | Is extensive cardiopulmonary screening useful in athlete with previous asymptomatic or mild SARS-CoV2 infection? | Cohort Study of professional male soccer players $COVID\text{-}19^+$ group ($n = 18$): Mean age (Years): 22 IQR = 21–27 control group ($n = 12$): Mean age (years): 25 IQR = 19.5–26.5 | Spirometry | 15 participants from the $COVID\text{-}19^+$ group data was compared from pre-COVID-19 to post-COVID-19: spirometry parameters: 6% reduction in $FEV_1$ 5% reduction in FVC 20% reduction in PEF Results remained within theoretical % predicted norm (Excluded 2 PEF values) | Patient groups did not reveal adverse outcomes after clinical investigations. patient history. cardiac and hematological screening were also included. Chest CT is not necessary for patients with a mild reduction in spirometry values |
| Csulak et al. (September 2021)[36] | The impact of COVID-19 on the Preparation for the Tokyo olympics: a comprehensive Performance assessment of top swimmers | 14 post-COVID-19 swimmers (23 ± 3.8 years old, 50% female) compared with 32 control swimmers (24.2 ± 4.4 years old, 43.8%) | CPET Spirometry | No difference was seen in CPET parameters of post-COVID-19 athletes compared with control group. However, significant reduction in oxygen pulse was found when post-COVID-19 swimmers were compared with pre-season baseline tests. Athletes experienced higher HR at rest compared with pre-season baselines averages. One 27-year-old female swimmer was diagnosed with COVID-19 sequalae, ground glass opacity and reticulation on their CT scan. After 4 weeks, pulmonary infiltration regressed, and only discrete reticulation observed | Short term detraining and COVID-19 did not affect elite level swimmers and did not impair preparation for upcoming olympics. However, there was an isolated case of abnormal pulmonary imaging |

TABLE 3 (Continued)

| Author | Title | Population | Respiratory investigations | Measurements | Conclusions |
|---|---|---|---|---|---|
| Anastasio et al. (October 2021)[29] | Mid-term impact of mild–moderate COVID-19 on cardiorespiratory fitness in elite athletes | 13 post-COVID-19 elite cross-country skiers (21 ± 5 years old, 77% male) vs. 13 healthy elite cross-country skiers (20 ± 4 years old, 62% male) | Spirometry CPET | No significant impairment in cardiorespiratory parameters at peak exercise, except lower heart for post-COVID-19 athletes. At aerobic threshold, post-COVID-19 athletes demonstrate lower $VO_{2peak}$, minute ventilation, breathing reserve, oxygen pulse and lower heart rate compared with control group | Cardiorespiratory performance at aerobic threshold is significantly impaired following COVID-19 |
| Celik et al. (November 2021)[30] | Respiratory Muscle Strength in volleyball players suffered from COVID-19 | 17 female COVID-19-positive players (age: 23.47 ± 5.89 years old) and 25 non COVID-19 players (20.5 ± 5.1 years old) | Spirometry Maximal Inspiratory pressure (MIP) Maximal Expiratory Pressure (MEP) | Players reported cough, dyspnea, taste and smell loss, fever and myalgia as main symptoms. Spirometry values were within normal range, no significant difference between groups. Post-COVID-19 players −16.88% mean difference in MIP. Post-COVID-19 players −17.05% mean difference in MEP | Respiratory muscle strength indices were greatly affected following COVID-19, despite preserved spirometry values. However, caution warned due to findings related to technique discrepancies |
| Cafiero et al. (November 2021)[33] | Competitive Sport after SARS-CoV-2 infection in Children | 45, mean age: 13.97 ± 1.9 years old (13 male) | CPET spirometry | $FEV_1$, FVC, DLCO, $VO_{2\ peak}$ all within age predicted max (>80% predicted) | Following cases of mild COVID-19 infection there is minimal risk for pediatric athletes of developing cardio-respiratory complications |
| Moulson et al. (May 2022)[22] | Diagnostic evaluation and cardiopulmonary exercise test findings in young athletes with persistent symptoms following COVID-19 | Cohort study of high school, collegiate, post-collegiate and recreational athletes. Post-COVID-19 athletes ($n = 21$) Mean age (years): 21.9 ± 3.9 Sex: 43% female Control athletes ($n = 42$) Mean age (years): 21.9 ± 3.8 Sex: 43% female | Spirometry CPET | Post-COVID-19 athletes CPET Parameters: 14% with $VO_{2peak} < 80\%$ predicted. 14% had low-normal $VO_{2\ peak}$ (≥80% but <90%). Breathing reserve (%) statistically different between groups Spirometry Parameters: two athletes spirometry results excluded 42% had abnormal results in both $FEV_1$ (L) and $FEV_1$/FVC ratio (%) 5% had an abnormal $FEV_1$ 5% abnormal $FEV_1$/FVC ratio (%). 88% did not have current or previous childhood asthma | No athlete found to have active inflammatory cardiac disease. No significant ventilatory abnormalities despite the presence of persistent/late onset symptoms—including dyspnea, exercise intolerance and chest pain. Comparison of Initial CPET to F/U CPET Reduction in resting HR between initial CPET and F/U CPET. Improvement in $O_2$ pulse. No change in $VO_2$ peak |
| Gattoni et al.(May 2022)[31] | COVID-19 disease in professional football players: symptoms and impact on pulmonary function and metabolic power during matches | Retrospective study involving 13 male professional footballers (23.9 ± 4.0 years) within the same team | Spirometry CPET | No significant impairment in spirometry or CPET parameters following an average 15 ± 5-day positivity duration. In 10 matches following COVID-19, distance covered was 21.6% lower than before COVID-19. Metabolic power during match performance was 4.0% lower, statistically different | Spirometry and CPET were not significantly different post-infection. A reduction in match performance parameters may be seen after COVID-19 |

Abbreviations: CPET, Cardio-Pulmonary Exercise Test; $FEV_1$, Forced Expiratory Volume in 1 s; FVC, Forced Vital Capacity; PEF, Peak Expiratory Flow; $VO_{2\ peak}$, Peak Oxygen uptake; $V_E$, minute ventilation; $VCO_2$, Carbon dioxide output; RER, respiratory Exchange Ratio; HR, heart rate; PAR-Q, Physical Activity Readiness Questionnaire.

reported evidence of abnormal metabolic function on CPET, with an early onset of anaerobic metabolism (i.e., reduced threshold) in 13 elite cross-country skiers (mean age: 22 years, 77% male) recovering from COVID-19 when compared to 13 control athletes. Additionally, at aerobic threshold, the average $\dot{V}O_{2peak}$ was 27% lower in post-COVID-19 athletes, with an accompanying reduction in minute ventilation, oxygen pulse, and breathing reserve.[29] Fikenzer et al.[27] found that following COVID-19, athletes had a 5% decline in peak power output during incremental test, a 7% reduction in $\dot{V}O_{2peak}$ and 14% lower minute ventilation, all with a 4% higher peak HR.

### 2.5 | Pulmonary imaging following COVID-19

The literature evaluating pulmonary imaging in athletes following COVID-19 is currently sparse and confined to case reports and small case series$^{+/-}$cohorts. There are no systematic prospective studies evaluating pulmonary imaging in athletes following COVID-19.

In the report by Petek and colleagues[24] described above, of the 137 athletes who reported exertional cardiopulmonary symptoms, 16 athletes had pulmonary imaging. Of this sub-group pneumonia, pleural effusion and pulmonary embolism were identified in 3 individuals. Csulak and colleagues[36] presented a case study on a 27-year-old female elite swimmer, with ground glass opacities on CT imaging that resolved over 4 weeks.

## 3 | DISCUSSION

Persistent respiratory symptoms, such as breathlessness, can limit exercise performance following COVID-19. The physiological assessment of athletes with this issue typically focuses on the identification of cardiac issues. Our analysis of the published data indicates that the development of a pathological pulmonary disease process following COVID-19 in athletes is rare. Indeed, there are no published reports describing the development of pulmonary fibrotic complications in athletes and only isolated case reports of pulmonary vascular issues.[24] This aligns with findings reported in the general population, where young individuals appear to be protected against the development of interstitial related abnormalities following COVID-19 and generally have a mild self-limiting illness course, from a pulmonary perspective.

The presence of lower respiratory symptoms during the acute illness phase of COVID-19 appears to be associated with a higher chance of delayed sporting recovery and training time loss.[19] Specifically, one study reported athletes were nearly three times more likely to have prolonged time loss from sport if lower respiratory symptoms were present.[23] In support of these data, more recent findings by Snyders et al.,[25] reported athletes with an increased total number of symptoms and increased number of chest and neck symptoms can predict prolonged return to play. Furthermore, the prevalence of protracted COVID-19 symptoms has been associated with viral co-infections such as Epstein–Barr virus (EBV). Primary EBV infection is often asymptomatic and dormant in the majority of immunocompetent individuals; however, some reports indicate a proportion of patients with persistent COVID-19 symptoms and long-term sequalae may be the result of EBV reactivation and/or co-infection.[37]

Our review of the literature reveals that in some series, there does appear to be evidence of pulmonary physiological defect, in athletes following COVID-19.[22,34] The majority of publications, however, evaluating lung function indicate that generally there are minimal changes in lung function, as assessed by spirometry parameters, following COVID-19.[27,29] These findings are in keeping with those in the general population, which may be explained by the fact that the pulmonary sequalae of COVID-19 appear to cause the greatest physiological disruption to the interstitial compartment rather than the airways. Hence, generally only minor changes in spirometric indices are seen, but more marked reductions in more complex pulmonary function tests such as gas transfer (i.e., DLCO measurement) are more evident.[1] To assess this issue, more detailed pulmonary function testing is needed and to date, only one study has evaluated DLCO parameters following COVID-19 in pediatric athletes, which actually found values to reside within the normal predicted range. It would therefore be helpful for further prospective studies to include assessment of diffusion membrane capacity and capillary blood volume using measurements like DLCO and diffusion capacity for nitric oxide (DLNO). This acknowledged, some studies have, however, reported spirometric defects in athletes following COVID-19, indicative of evidence of airflow obstruction[22,28,34] and further assessment of airway inflammatory markers (e.g., with FeNO), bronchodilator reversibility testing$^{+/-}$ testing of airway hyper-responsiveness is needed to better characterize this issue.[38]

In the assessment of functional (i.e., exertional) breathlessness, CPET has provided insight regarding gas exchange, ventilatory capabilities, and measures the multi-system response when athletes are symptomatic.[22] Interpretation of findings must be considered with caution, given the potential confounding of a detraining effect, selection of an appropriate control group and whether the findings can be considered to be COVID-19 specific (i.e., there is little data comparing with other infections).

For one study cohort, athletes had a 20-day retraining period prior to CPET, whereby re-adaptation may have occurred, and detraining effects may have been mitigated.[32] Generally, the published reports to date have provided reassurance from CPET from the perspective of identification of cardiopulmonary pathology.[32,34] However, some reports found key physiological parameters at aerobic threshold to be reduced. Athletes reached aerobic threshold at a significantly earlier load, with a lower oxygen consumption, oxygen pulse, and minute ventilation.

Several CPET studies in post-COVID-19 cohorts in the general population have detailed a high prevalence of breathing pattern disorders$^{+/-}$ hyperventilation.[39] In this context, CPET was valuable in that it provides reassurance regarding the presence of a normal peak oxygen uptake, but simultaneously identifies features such as an abnormally high breathing frequency$^{+/-}$ erratic tidal volume for a given work rate.[39] This chaotic ventilation may be driven by chemoreceptor abnormalities or central control issues, which drives abnormalities in perception of breathing. However, the exact mechanism for persistent exertional dyspnea in the context of dysfunctional breathing following COVID-19 is currently unknown.[39] Therefore, to assess this issue, athletes reporting exertional dyspnea, persistent post-exercise cough, chest tightness, or abnormal spirometric indices, should be considered for investigations of a breathing pattern disorder, in addition to other tests of pulmonary physiology to identify reversible pathology such as exercise-induced bronchoconstriction (EIB).[40]

## 4 | LIMITATIONS

There are some limitations to this review that should be considered. With the emergence of new variants of SARS-CoV-2, there is potential that the presentation of post-COVID-19 sequalae and the influence on physiological parameters may differ. Varying definitions of symptom severity throughout the evaluated literature highlights the need for an individualized approach and management, which is further obscured by the introduction and effects of vaccines. The limitations of each individual study should be considered when interpreting results. A further key area is the heterogeneity of symptoms time course were reported, and physiological measurements taken. There is a range from immediately after COVID-19 infection up until three to 6 months which may lead to inaccuracies and difficulty generalizing results. Moreover, studies that used an observational research design without the comparison to pre-existing baseline measurements also make interpretation and the generalization of results difficult. Particularly as the declines observed may be attributed to detraining effects, periods of inadequate training instead of actual physiological change.

## 5 | PERSPECTIVE AND RECOMMENDATIONS

As studies continue to report findings in athletes recovering from COVID-19, further details regarding pulmonary function and imaging will undoubdetly emerge. The literature included in this review has predominantly identified findings in young, adult white patients and thus the generalizability of the published findings is limited. Future studies should aim to recruit more diverse, heterogenous sample populations that lead to more robust and complete datasets.

The papers assessing symptom clusters and prevalence should state the sporting level of athletes, the training experience, occurrence of comorbidities and some a breakdown of ethnicity demographics. Furthermore, prospective work should evaluate training time out, detraining and compare with other non-SARS-CoV-2 infections, to determine whether findings are COVID-19 specific.

In the meantime, it is recommended that any athlete with breathlessness undergoes a detailed clinical review to identify clinical features that may identify pulmonary vascular issues (e.g., pleuritic chest pain) or airway centric symptoms to help direct investigations.[9] Features of cardiac concern (e.g., chest pain, palpitations) should prompt cardiology assessment, with minimum recommendation that any individual with ongoing breathlessness has a chest x-ray, full blood count and spirometry$^{+/-}$ measurement of airway inflammation with possible assessment of gas transfer. A CPET test provides useful insight and may reassure individuals with ongoing exertional symptoms.

In conclusion, the vast majority of athletes with COVID-19 appear to develop a self-limiting, mild disease and do not require targeted treatment of hospital-based care. Persistent respiratory symptoms and an initial presentation with lower respiratory-focused symptoms appear to be associated with longer recovery and extended return to play. In this setting, it is still rare to identify a protracted pulmonary pathological process secondary to SARS-CoV-2 but serious pulmonary conditions (e.g., PE) should be identified with a robust clinical-investigation algorithm. The use of CPET and pulmonary function testing appear to be valuable in providing reassurance of the lack of cardiopulmonary pathology and in the identification of airway disease$^{+/-}$ a breathing pattern disorder. Although breathlessness may be a relevant clinical issue in a proportion of athletes recovering from COVID-19, both may identify other issues by evaluating cardiopulmonary performance under physiological

stress and identify features such as autonomic dysfunction or breathing pattern dysfunction. Future research should focus on evaluating gas exchange indices and pulmonary imaging in athletes with persistent dyspnea with an inclusive perspective.

## CONFLICT OF INTEREST

The authors declare no conflict of interest.

## DATA AVAILABILITY STATEMENT

The data that support the findings of this study are available in Google Scholar at https://scholar.google.com/. These data were derived from the following resources available in the public domain: Google Scholar, https://scholar.google.com/; Pubmed, https://pubmed.ncbi.nlm.nih.gov/.

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## REFERENCES

1. Thomas M, Price OJ, Hull JH. Pulmonary function and COVID-19. *Curr Opin Physiol*. 2021;21:29-35.
2. Fernández-de-las-Peñas C, Palacios-Ceña D, Gómez-Mayordomo V, et al. Prevalence of post-COVID-19 symptoms in hospitalized and non-hospitalized COVID-19 survivors: a systematic review and meta-analysis. *Eur J Intern Med*. 2021;92:55-70.
3. Biswas M, Rahaman S, Biswas TK, Haque Z, Ibrahim B. Association of sex, age, and comorbidities with mortality in covid-19 patients: a systematic review and meta-analysis. *Intervirology*. 2021;64:36-47.
4. Sonnweber T, Sahanic S, Pizzini A, et al. Cardiopulmonary recovery after COVID-19: an observational prospective multicentre trial. *Eur Respir J*. 2021;57(4):2003481.
5. Hamer M, Kivimäki M, Gale CR, Batty GD. Lifestyle risk factors, inflammatory mechanisms, and COVID-19 hospitalization: a community-based cohort study of 387,109 adults in UK. *Brain Behav Immun*. 2020;87:184-187.
6. Alosaimi B, AlFayyad I, Alshuaibi S, et al. Cardiovascular complications and outcomes among athletes with COVID-19 disease: a systematic review. *BMC Sports Sci Med Rehabil*. 2022;14(1):74.
7. Brito D, Meester S, Yanamala N, et al. High prevalence of pericardial involvement in college student athletes recovering from COVID-19. *JACC Cardiovasc Imaging*. 2021;14(3):541-555.
8. Małek ŁA, Marczak M, Miłosz-Wieczorek B, et al. Cardiac involvement in consecutive elite athletes recovered from Covid-19: a magnetic resonance study. *J Magn Reson Imaging*. 2021;53(6):1723-1729.
9. Wilson MG, Hull JH, Rogers J, et al. Cardiorespiratory considerations for return-to-play in elite athletes after COVID-19 infection: a practical guide for sport and exercise medicine physicians. *Br J Sports Med*. 2020;54:1157-1161.
10. van Hattum JC, Spies JL, Verwijs SM, et al. Cardiac abnormalities in athletes after SARS-CoV-2 infection: a systematic review. *BMJ Open Sport Exerc Med*. 2021;7:1164.
11. Cheng MP, Cau A, Lee TC, et al. Acute cardiac injury in coronavirus disease 2019 and other viral infections-a systematic review and meta-analysis. *Crit Care Med*. 2021;49:1558-1566.
12. Ballering AV, van Zon SKR, Olde Hartman TC, JGM R, Lifelines Corona Research Initiative. Persistence of somatic symptoms after COVID-19 in The Netherlands: an observational cohort study. *Lancet*. 2022;400(10350):452-461.
13. Hull JH, Loosemore M, Schwellnus M. Respiratory health in athletes: facing the COVID-19 challenge. *Lancet Respir Med*. 2020;8(6):557-558.
14. Paoli A, Musumeci G. Elite athletes and covid-19 lockdown: future health concerns for an entire sector. *J Funct Morphol Kinesiol*. 2020;5:30.
15. Facer-Childs ER, Hoffman D, Tran JN, Drummond SPA, Rajaratnam SMW. Sleep and mental health in athletes during COVID-19 lockdown. *Sleep*. 2021;44(5):zsaa261.
16. Hopkinson NS, Buttery S, Philip KEJ, et al. Patient symptoms and experience following COVID-19: results from a UK-wide survey. *BMJ Open Respir Res*. 2021;8:e001075.
17. Lemes IR, Smaira FI, Ribeiro WJD, et al. Acute and post-acute COVID-19 presentations in athletes: a systematic review and meta-analysis. *Br J Sports Med*. 2022;56:941-947.
18. Moulson N, Petek BJ, Drezner JA, et al. SARS-CoV-2 cardiac involvement in young competitive athletes. *Circulation*. 2021;144:256-266.
19. Schwellnus M, Sewry N, Snyders C, et al. Symptom cluster is associated with prolonged return-to-play in symptomatic athletes with acute respiratory illness (including COVID-19): a cross-sectional study-AWARE study I. *Br J Sports Med*. 2021;55(20):1144-1152.
20. National Institute for Health and Care Excellence. *COVID-19 Rapid Guideline: Managing the Long-Term Effects of COVID-19*. NICE; 2022.
21. Sudre CH, Murray B, Varsavsky T, et al. Attributes and predictors of long COVID. *Nat Med*. 2021;27:626-631. doi:10.1038/s41591-021-01292-y
22. Moulson N, Gustus SK, Scirica C, et al. Diagnostic evaluation and cardiopulmonary exercise test findings in young athletes with persistent symptoms following COVID-19. *Br J Sports Med*. 2022;56:927-932. doi:10.1136/bjsports-2021-105157
23. Hull JH, Wootten M, Moghal M, et al. Clinical patterns, recovery time and prolonged impact of COVID-19 illness in international athletes: the UK experience. *Br J Sports Med*. 2022;56(1):4-11.
24. Petek BJ, Moulson N, Baggish AL, et al. Prevalence and clinical implications of persistent or exertional cardiopulmonary symptoms following SARS-CoV-2 infection in 3597 collegiate athletes: a study from the outcomes registry for cardiac conditions in athletes (ORCCA). *Br J Sports Med*. 2021;56:913-918.
25. Snyders C, Schwellnus M, Sewry N, et al. Symptom number and reduced pre-infection training predict prolonged return to training after SARS-CoV-2 in athletes: a ware IV. *Med Sci Sports Exerc*. 2022;Publish Ahead of Print. doi:10.1249/MSS.0000000000003027
26. Nalbandian A, Sehgal K, Gupta A, et al. Post-acute COVID-19 syndrome. *Nat Med Nat Res*. 2021;27:601-615.

27. Fikenzer S, Kogel A, Pietsch C, et al. SARS-CoV2 infection: functional and morphological cardiopulmonary changes in elite handball players. *Sci Rep*. 2021;11(1):17798.
28. 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.
29. Anastasio F, Rossi G, D'Abbondanza M, Curcio R, Vaudo G, Pucci G. Mid term impact of mil-moderate COVID-19 on cardiorespiratory fitness in elite athletes. *J Sports Med Phys Fitness*. 2021;62:1383-1390.
30. Çelik Z, Güzel NA, Kafa N, Köktürk N. Respiratory muscle strength in volleyball players suffered from COVID-19. *Ir J Med Sci*. 2021;191:1959-1965.
31. Gattoni C, Conti E, Casolo A, et al. COVID-19 disease in professional football players: symptoms and impact on pulmonary function and metabolic power during matches. *Physiol Rep*. 2022;10(11):e15337.
32. Milovancev A, Avakumovic J, Lakicevic N, et al. Cardiorespiratory fitness in volleyball athletes following a covid-19 infection: a cross-sectional study. *Int J Environ Res Public Health*. 2021;18(8):4059.
33. Cafiero G, Passi F, Calo' Carducci FI, et al. Competitive sport after SARS-CoV-2 infection in children. *Ital J Pediatr*. 2021;47(1):221.
34. 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.
35. Cavigli L, Frascaro F, Turchini F, et al. A prospective study on the consequences of SARS-CoV-2 infection on the heart of young adult competitive athletes: implications for a safe return-to-play. *Int J Cardiol*. 2021;336:130-136.
36. Csulak E, Petrov Á, Kováts T, et al. The impact of COVID-19 on the preparation for the Tokyo Olympics: a comprehensive performance assessment of top swimmers. *Int J Environ Res Public Health*. 2021;18:9770. doi:10.3390/ijerph18189770
37. Gold JE, Okyay RA, Licht WE, Hurley DJ. Investigation of long covid prevalence and its relationship to epstein-barr virus reactivation. *Pathogens*. 2021;10(6):763.
38. Hull JH. Persistent symptoms in athletes following COVID-19: time to take a breath in the search for answers? *Br J Sports Med*. 2022;56:952-953. doi:10.1136/bjsports-2022-105889
39. Frésard I, Genecand L, Altarelli M, et al. Dysfunctional breathing diagnosed by cardiopulmonary exercise testing in "long COVID" patients with persistent dyspnoea. *BMJ Open Respir Res*. 2022;9(1):e001126.
40. Couto M, Kurowski M, Moreira A, et al. Mechanisms of exercise-induced bronchoconstriction in athletes: current perspectives and future challenges. *Allergy*. 2018;73:8-16.

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