The effects of acute respiratory illness on exercise and sports performance outcomes in athletes – a systematic review by a subgroup of the IOC consensus group on "Acute respiratory illness in the athlete"

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Abstract:

Acute respiratory infections (ARinf) are common in athletes, but their effects on exercise and sports performance remain unclear. This systematic review aimed to determine the acute (short-term) and longer-term effects of ARinf, including SARS-CoV-2 infection, on exercise and sports performance outcomes in athletes. Data sources searched included PubMed, Web of Science, and EBSCOhost, from January 1990–31 December 2021. Eligibility criteria included original research studies published in English, measuring exercise and/or sports performance outcomes in athletes/physically active/military aged 15-65years with ARinf. Information regarding the study cohort, diagnostic criteria, illness classification, and quantitative data on the effect on exercise/sports performance were extracted. Database searches identified 1707 studies. After full text screening, 17 studies were included (n=7793). Outcomes were acute or longer-term effects on exercise (cardiovascular or pulmonary responses), or sports performance (training modifications, change in standardised point scoring systems, running biomechanics, match performance or ability to start/finish an event). There was substantial methodological heterogeneity between studies. ARinf was associated with acute decrements in sports performance outcomes (4 studies) and pulmonary function (3 studies), but minimal effects on cardiorespiratory endurance (7 studies in mild ARinf). Longer-term detrimental effects of ARinf on sports performance (6 studies) were divided. Training mileage, overall training load, standardised sports performance-dependent points and match play can be affected over time.

Despite few studies, there is a trend towards impairment in acute and longer-term exercise and sports outcomes after ARinf in athletes. Future research should consider a uniform approach to explore relationships between ARinf and exercise/sports performance.

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(254 words)

Highlights:

- Cardiorespiratory endurance is largely unaffected by recent mild SARS-CoV-2 infection and upper ARinf (rhinovirus) infection, however more severe ARinf is associated with a negative impact on exercise and sports performance.
- An upper ARinf (rhinovirus) and SARS-CoV-2 infection caused marked reductions in pulmonary function tests ($FEV_{1.0}$/FVC), with greater reductions observed in more severe ARinf. However, the results remained within normal ranges.
- Self-reported training ability and training capacity can be reduced during an upper ARinf, and an ARinf with fever could alter running kinematics.
- Training mileage and overall training load can be impaired over time post-ARinf. Analysis of initial studies indicates a trend for a reduction in standardised sports performance-dependent points in athletes with respiratory infection.

Key words:
athlete, sport, training, competition, infection, SARS-CoV-2, COVID-19, coronavirus

Introduction

Acute respiratory illness (ARill) can be classified as infective or non-infective in origin. Acute respiratory infections (ARinf) are reported as the most common acute illness experienced by athletes,[1-3] responsible for ~50% of all illness episodes in athletes[2-5] with more than 75% of all cases presenting with predominantly upper respiratory tract symptoms and signs.[6, 7] ARinf can disrupt an athlete's training and competition by a) affecting the normal response of the body to an acute exercise (training) session, and b) affecting the body's adaptation to regular exercise training.

The emergence of coronavirus disease 2019 (COVID-19), caused by SARS-CoV-2 infection, has added a novel complexity to the understanding of ARinf. Athletes experience predominantly mild illness during episodes of ARinf, including SARS-CoV-2 infection,[8, 9] with common symptoms of excessive fatigue, headache, blocked/plugged nose, and sore/scratchy throat.[6, 10, 11] ARinf in athletes has a mean symptom duration of 7 days[12] however SARS-CoV-2 infection can manifest with a greater number and more severe symptoms, as well as a longer return to sport (±30 days vs. ±10 days) compared to other ARinf.[11, 13] Therefore, understanding the effects of a recent ARinf, including SARS-CoV-2 infection, on responses during an exercise session, and the longer-term effects of ARinf on adaptation to training, are crucial in the medical care and practical management of athletes returning to sport after an ARinf.

There are two terms that describe aspects of the effect of ARinf on an athlete's response to exercise and participation in sport: "exercise performance" and "sports performance". Exercise performance is the result of an integrated physiological response of the body to an acute exercise session and to repeated sessions over time (training). Exercise performance has underlying primary factors including endurance, strength, and power,[14, 15] and requires the interaction of various organ systems such as the cardiovascular, pulmonary, musculoskeletal, neuromuscular and nervous system.[14] In this review, "exercise performance" includes measurable physiological responses (changes) during exercise in the abovementioned organ systems. Examination of the effects of ARinf on exercise and sports performance should be considered alongside clinical considerations related to ARinf in the athletic population.[16]

The term "sports performance" refers to highly variable demands during different types of exercise that require skill, intense training, and are often of a competitive, structured nature.[14, 17] Endogenous and exogenous variables (physical, technical, mental and tactical) interact to form the construct of sports performance.[17] This multifactorial construct can be reduced to measurable components such as time, speed, and distance.[18] Thus, sports performance outcomes differ from exercise performance outcomes because they refer to measurements (variables) of sporting success and include competition results, improvements in time, standardised points or ranking systems, changes in biomechanics, and the ability to train and compete without modification or interruption.

The acute and longer-term effects of ARinf on an athlete's capacity to respond during a training session, adapt to regular training sessions over time, compete, and ultimately achieve in sport are currently unclear. Despite many reports detailing the epidemiology of acute respiratory illness in athletes, there are very few studies that describe the acute and longer-term effects of ARinf on exercise and/or sports performance. There is evidence that general acute illness, including ARinf, may impair the function of several organ systems as evidenced by recent data from SARS-CoV-2 infection.[19-21] Specifically, there is evidence that ARinf can impair muscle function, cardiorespiratory capacity and nervous system function.[22-24] Effects on these systems can alter measures of exercise and sports performance,[22] including coordination ability, and mechanical and functional aspects of performance which may also increase the risk of musculoskeletal injuries.[2, 6, 23, 25] Regardless of impairments in performance outcomes, loss of training time due to ARinf is a major determinant of sports performance of athletes in high-level competition and thus warrants further understanding.[26]

The aim of this systematic review was to determine the effects of an ARinf, including SARS-CoV-2 infection on acute (short-term) and longer-term exercise and sports performance parameters in athletes.

Methods

Protocol and registration

This systematic review was performed in accordance with the Preferred Reporting for Systematic Reviews and Meta-analyses (PRISMA) guidelines[27] (Supplementary File 1). The review was registered prospectively with PROSPERO (CRD42020159259).

Study selection and eligibility criteria

The PICO (Participants Intervention Comparison Outcome) scheme was followed where applicable ('Intervention' was omitted given that our focus was observational rather than experimental studies) and formed the basis of the inclusion criteria as follows:

- Participants: athletes/physically active individuals/military personnel, aged 15 to 65 years, who had an ARinf (suspected or confirmed),
- Outcome: studies which reported any measures and/or outcomes of exercise performance or sports performance,
- Comparison: results of the performance measurement compared within-subjects to a baseline measurement or to a healthy control group,
- Original full-text studies of observational, prospective, retrospective, cross-sectional, longitudinal or intervention design, written in English, and published between January 1990 and 31 December 2021.

We excluded animal/non-human studies, participants with an underlying chronic respiratory illness i.e., patients who had an acute exacerbation (of either infective or non-infective origin) of chronic obstructive pulmonary disease, a hospital-acquired ARill, or illness acquired by other injury or complication. Studies that only included non-infective ARill were excluded (e.g., asthma). Studies were also excluded if it was a single case-report or laboratory-based basic science, review article, expert opinion or position statement.

Studies were screened independently by two reviewers (KK, DP) first by title/abstract and then full text, and any conflicts resolved through discussion or via a third researcher (NS).

Search strategy

PubMed, EbscoHost and Web of Science (core collection) databases were used to search for published studies between 1990 and 31 December 2021. A combination of search terms was used relating to ARill and exercise or sports performance (acute respiratory illness AND athletes AND performance) and relevant exclusions (for full search string see Supplementary File 2). The results of these searches were combined, and duplicate studies removed. Any additional studies the authors identified relating to the topic, or sourced from the reference list of identified studies, were added to the list. All study screening and selection was undertaken using the online tool CADIMA.[17]

Data extraction

Three clusters were determined for reporting the extracted data: a) descriptive characteristics of the studies (study design, surveillance period (days), cohort number, sex, age (years), sport, and level of participation), b) outcome measures of exercise performance, and c) outcome measures of sports performance. Data related to outcome measures of exercise or sports performance were classified as acute effects (e.g., during an exercise bout, training session or a match/race/competition) or longer-term effects (e.g., an effect over time or on the inability to adapt to regular training sessions). The following information was used to classify the ARinf: method of diagnosis, pathological classification, and anatomical classification. Study results were extracted, and clinical/practical comments added. Where the study was an intervention, only data from the control group(s) was extracted.

Definitions and classification of ARill subgroups

The categorisation of respiratory illness was aligned to a standardised classification as defined by other subgroups of the IOC consensus group for "Acute respiratory illness in athletes". This group established methods to diagnose ARill in each study as follows: (1) self-reported symptoms of ARill only, (2) self-reported symptoms but with an algorithm partially validated for ARill, (3) self-reported symptoms of an ARill reviewed by a physician, but without clinical or laboratory evaluation, (4) clinical diagnosis of an ARill by a physician, based on history and clinical examination, (5) diagnosis of ARill by a physician that was confirmed by laboratory investigation to identify a specific pathogen as follows: polymerase chain reaction (PCR) testing on specimens, culture of an organism from specimens, or serology (e.g. increase in antibody titres). Using the methods of diagnosis of ARill as the primary category, studies were differentiated based on a pathological classification into two main groups: Undiagnosed Acute Respiratory Illness (ARill) and Acute Respiratory Infection (ARinf). All ARinf were classified into two subgroups as follows: suspected ARinf and confirmed ARinf. (Supplementary Table S1)

Finally, studies were classified according to the predominant anatomical region affected by ARill or ARinf. This classification was previously described in detail,[12] but is summarized as follows:

- *Upper (ARill or ARinf)*: Studies where the predominant symptoms, signs, or confirmed pathology was clearly related to the upper respiratory tract (i.e., above the larynx), or if the study specifically referred to athletes with upper ARill (including 'flu', 'flu-like', and influenza).
- *Lower (ARill or ARinf)*: Studies where the predominant symptoms or signs were below the larynx (including chest symptoms i.e., cough, chest pain), or if a confirmed diagnosis specifically referred to athletes with lower respiratory illness (tracheal, bronchial or lung pathology e.g., pneumonia).
- *General (upper/lower) (ARill or ARinf)*: Studies where there were no data to clearly distinguish between predominantly upper/lower respiratory ARill. These studies could include upper, lower or both.

Measures of outcome

The primary study outcomes were allocated to one of two categories: a) measures of exercise performance, or b) sports performance outcomes, and the direction of change was indicated.

Exercise performance outcomes:

Exercise performance outcomes included measurable physiological parameters as follows:

- Cardiovascular response to exercise, including heart rate (HR), blood pressure (BP), VO_2max, and rating of perceived exertion (RPE).
- Pulmonary function, including forced vital capacity (FVC), forced expiratory volume in the first second ($FEV_{1.0}$), $FEV_{1.0}$ as a percentage of FVC (FEV_1/FVC), peak expiratory flow (PEF), and rating of perceived breathlessness (RPB).
- Muscle strength measured in newtons (N), distance thrown (m) or jumped (cm), and time to fatigue (s).

Sports performance outcomes:

Sports performance outcomes included race or event time, a change in standardised points or ranking as a result of ARinf, the ability to participate (start or finish) in a race or event, match performance (statistics and global positioning system (GPS) data), change in running biomechanics, and training-related modifications.

Acute or longer-term effect of exercise or sports performance outcomes:
This parameter indicated if an outcome was affected acutely (e.g. during an exercise bout, single training session or a match, race or competition) or if there was a longer-term effect (e.g. inability to adapt to regular training sessions).

Direction of change of exercise or sports performance outcome:
The direction of change indicated *how* performance has been affected; either a negative effect, no effect, or a positive effect on performance.

Quality assessment and risk of bias

A modified Downs and Black checklist[28] was used to determine the quality of the studies (see Supplementary File 3). Two reviewers (KK, DP) scored the studies independently and reached consensus on the final score after discussion. A third reviewer (NS) resolved any disputes. The Downs and Black checklist was adjusted to remove questions pertaining to randomised controlled trials. The modified checklist included components of reporting, external and internal validity (bias and selection bias) and yielded a final score for each study out of a possible 13 points. The quality assessment score of each study was determined against the following criteria: excellent (11-13 points), good (9-10), fair (7-8), and poor (<6).

The level of evidence was also determined using the Oxford Centre for Evidence Based Medicine Levels of Evidence (OCEBM, 2009).[29]

Data synthesis

The large heterogeneity in the reporting of outcomes in the included studies precluded meta-analysis. A qualitative synthesis was used to present the data on the effects of ARinf on various measures of exercise and sports performance.

Results

Included studies

All search strategies employed identified a total of 1707 studies. Duplicate studies were removed, and further studies were excluded based on established exclusion criteria. This process yielded a final total of 58 full-text studies, of which 17 were included. Figure 1 depicts the flowchart of the selection process of the studies.

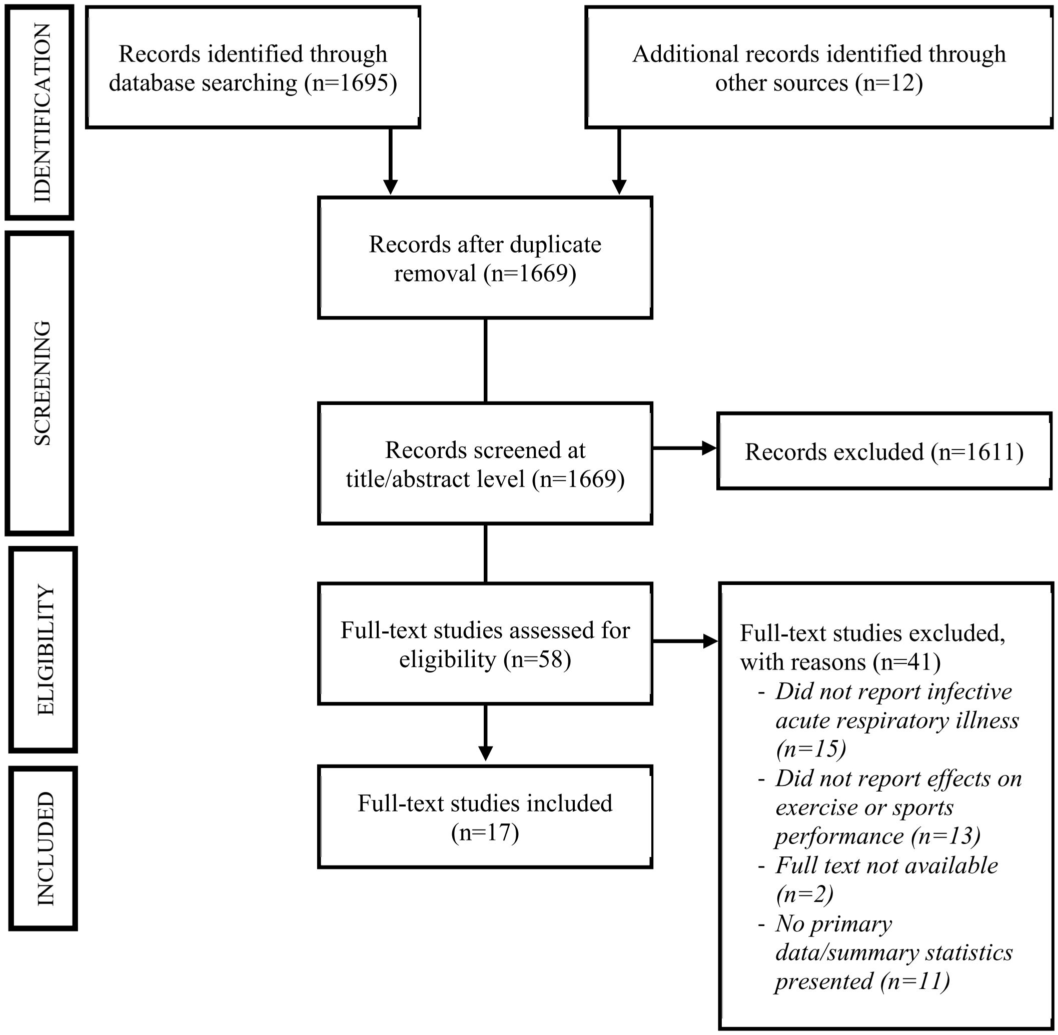

Figure 1: PRISMA flowchart of the selection of studies investigating the effects of infective acute respiratory illness on exercise and/or sports performance.

The included studies were assigned to appropriate main and subgroups, including anatomical and pathological classification (Supplementary Table S2).

Quality assessment of the studies

Table 1 shows the Oxford Level of Evidence as well as the results of the modified Downs & Black quality assessment for each study. The level of evidence of the 17 studies ranged from 1b to 4, with experimental designs including a randomized double-blinded placebo-controlled trial, prospective cohort and experimental studies, and case series. Quality assessment scores ranged from 9 to 12 points, out of a possible 13 points. Eleven of the 17 included studies were rated as excellent, with the other six studies rated as good.

Descriptive characteristics of the studies

The 17 studies included full-text articles conducted between 1997 – 2021, in athletic cohorts (n=7793) (all levels of athletes including amateur, elite and professional), across a variety of sports ranging from endurance-based activities to rugby union, and badminton in cohorts of 8 to 7031 athletes. Half of the studies had comparable proportions of male (range 51-56%) and female (range 44-49%) participants in the study cohort, while the other half of the studies were predominantly males (range 70-100%). Two studies did not report the sex of the participants. Most participants were aged between their late teenage years and thirties. Table 1 details the descriptive characteristics of the studies.

Methodological heterogeneity was prominent in the 17 selected studies, particularly the measurement of exercise and sports performance outcomes. Methods to diagnose ARinf included symptom checklist with algorithm/scoring system (three studies), self-reported symptoms with physician check (no examination) (one study), physician-diagnosed by history and clinical exam (two studies), or physician-diagnosed including confirmation of pathology (PCR or culture) for the infecting pathogen (11 studies). Seven studies reported on upper ARinf specifically, and the other 10 studies reported general (upper/lower) ARinf (Table 2 and Table 3). The full details of the results can be found in Supplementary Tables S3 and S4.

Table 1: Descriptive characteristics, level of evidence and quality of the studies examining the effect of acute respiratory infection on exercise and sports performance outcomes

Study	Title	Study Design	Level of Evidence (OCEBM)[1]	Quality assessment score[2]	Cohort number	Sex	Age (y) mean ± SD or range	Sport	Level of participation
Anastasio et al. 2021[(30)]	Mid-term impact of mild-moderate COVID-19 on cardiorespiratory fitness in élite athletes	Retrospective case-control study	4	11	13	10 males; 3 females	21 ± 5	Cross-country skiers	Elite / prof. / international / national
Costello et al. 2021[(31)]	Athletes with mild COVID-19 illness demonstrate subtle imaging abnormalities without exercise impairment or arrhythmias	Case-control study	4	12	16	12 males; 4 females	25 ± 6	Basketball	Elite / professional / international / national
Csulak et al. 2021[(32)]	The Impact of COVID-19 on the Preparation for the Tokyo Olympics: A Comprehensive Performance Assessment of Top Swimmers	Prospective observational study	2b	12	14	7 males; 7 females	23 ± 3.8	Swimming	Elite / professional / international / national
Fikenzer et al. 2021[(33)]	SARS-CoV2 infection: functional and morphological cardiopulmonary changes in elite handball players	Retrospective case-control study	4	11	8	8 males	27 ± 3.5	Handball	Elite / professional / international / national
Komici et al. 2021[(34)]	Clinical Characteristics, Exercise Capacity and Pulmonary Function in Post-COVID-19 Competitive Athletes	Case-control study	4	9	24	Not reported	23.5 (20-25.5)	Football	Recreational / amateur / military
Savicevic et al. 2021[(35)]	Performance of Professional Soccer Players before and after COVID-19 Infection; Observational Study with an Emphasis on Graduated Return to Play	Prospective observational study	1b	12	31	Not reported	21.6	Football	Elite / professional / international / national
Vaudreuil et al. 2021[(36)]	Impact of COVID-19 on Recovered Athletes Returning to Competitive Play in the NBA "Bubble"	Case series	4	9	20	20 males	26.7	Basketball	Elite / professional / international / national
Wagemans et al. 2021[(37)]	The Impact of COVID-19 on Physical Performance and Mental Health—A Retrospective Case Series of Belgian Male Professional Football Players	Retrospective case series	4	12	11	11 males	25.34 ± 4.61	Football	Elite / professional / international / national
Crameri et al. 2020[(38)]	Reduced maximal aerobic capacity after COVID-19 in young adult recruits, Switzerland, May 2020	Retrospective observational study	2b	11	199	173 males; 26 females	21 (18–27)	Swiss army recruits	Recreational / amateur / military
Marinkovic et al. 2016[(39)]	Lactobacillus helveticus Lafti® L10 supplementation reduces respiratory infection duration in a cohort of elite athletes: a randomized double-blind placebo-controlled trial	Randomized double-blind placebo-controlled trial	1b	12	50	36 males; 14 females	18-28	Badminton, triathlon, cycling, alpinism, athletics, karate, kayak, judo, tennis and swimming	Elite / prof. / international / national
Van Tonder et al. 2016[(40)]	Prospective cohort study where 1 in 13 report systemic symptoms in the 8–12-day period before a race, increasing their risk of not finishing the race 1.9 times	Prospective cohort study	1b	12	7031	3952 males; 3079 females	>15	Running	All levels

He et al. 2013(41)	Influence of CMV/EBV serostatus on respiratory infection incidence during 4 months of winter training in a student cohort of endurance athletes	Prospective cohort study	1b	12	239	169 males; 70 females	21 ± 2	Endurance-based activities (running, cycling, swimming, triathlon, team games and racquet sports)	All levels
Cunniffe et al. 2011(42)	Mucosal immunity and illness incidence in elite Rugby Union players across a season	Prospective longitudinal observational study	1b	12	31	31 males	26.8 ± 0.9 (forwards) and 25.9 ± 0.9 (backs)	Rugby Union	Elite / prof. / international / national
Fricker et al. 2005(43)	Influence of training loads on patterns of illness in elite distance runners	Prospective observational study	2b	10	20	20 males	24.2 ± 3.1	Running	Elite / prof. / international / national
Pyne et al. 2000(44)	Mucosal immunity, respiratory illness, and competitive performance in elite swimmers	Prospective cohort study	1b	10	41	21 males; 20 females	15-27	Swimming	Elite / prof. / international / national
Weidner et al. 1997(45)	Effect of a rhinovirus-caused upper respiratory illness on pulmonary function test and exercise responses	Prospective cohort experimental study	2b	9	45	24 males; 21 females	18-29	Physically fit students	Recreational / amateur / military
Weidner, Anderson et al. 1997(23)	Effects of viral upper respiratory illness on running gait	Prospective cohort experimental study	2b	10	18	13 males; 5 females	20.4 ± 2.4	Physically fit students	Recreational / amateur / military

**prof. = professional*

[1]***Level of Evidence:*** *1b – individual Randomised Controlled Trial with narrow confidence limits; individual cohort study with good follow-up or prospective cohort study with good follow-up; 2b – individual Randomised Controlled Trial with smaller follow-up, exploratory cohort study, retrospective cohort study; 4 – case series or case-control study*

[2]***Quality assessment score:*** *11-13: Excellent | 9-10: Good | 7-8: Fair | ≤6: Poor*

Acute effects of ARinf on exercise performance outcomes

There were nine studies reporting acute (short-term) effects of acute respiratory infection (ARinf) on exercise performance outcomes (Table 2). In these studies, outcome variables were determined immediately after the ARinf (< 2 days)[45] within 10 days of the ARinf,[43] <30 days[31-35, 37] or >30 days[30, 37, 38] in the studies investigating SARS-CoV-2 infection specifically. In one study, it was not reported how long after the ARinf episode the data were collected.[36] In another study, testing was conducted after inoculation with a specific pathogen (rhinovirus), and in another study the diagnosis of ARinf was suspected and the pathogen/s was not identified. In the other six studies SARS-CoV-2 infection was confirmed by PCR analysis. Exercise performance parameters included laboratory measurements at rest (pulmonary function tests)[30, 33, 34, 45] and during submaximal[45] or maximal exercise testing,[30-34, 38, 43, 45] and measures of muscle strength.[38] Specific exercise performance outcomes included measures of upper extremity (seated shot put test) and trunk (prone bridge test) muscle strength, cardiorespiratory endurance (heart rate, VO_2max, ventilation (VE), respiratory exchange ratio (RER), rating of perceived exertion (RPE), blood lactate response and treadmill time), and pulmonary function testing (PFT) at rest (FVC, $FEV_{1.0}$, and PEF).

The main findings from individual studies on the acute effects of ARinf on cardiorespiratory endurance were a) the aerobic threshold is reached sooner in athletes post-SARS-CoV-2 infection with lower oxygen consumption and HR ($p<0.01$) and higher breathing reserve and heart rate reserve ($p<0.05$) than controls,[30] b) there is more evidence of unchanged VO_2max in the presence of mild upper ARinf[43, 45] and post-SARS-CoV-2 infection[30-32, 34] than for significant reductions in VO_2max post-infection,[32, 33, 38] c) expired ventilation (VE) between ARinf and healthy groups was not different in some studies[31, 33, 34, 43] but was higher in ARinf athletes post-infection compared to pre-infection[32] d) respiratory exchange ratio (RER), maximum blood lactate, time to exhaustion, and maximum workload during a treadmill running test were similar between healthy athletes and ARinf athletes,[30-34, 43] and e) there was little effect of ARinf on muscle strength.[38]

Post-SARS-CoV-2 infection pulmonary function testing (PFT), FVC, FEV_1%, or PEF values remained unchanged at rest[30, 33] except for one study where FEV_1% was lower [97.5 (91.5–108)] than controls [109 (106–116)] ($p=0.007$) but also within the normal range.[34] In another study where the infecting pathogen was rhinovirus, values at rest were not significantly affected by ARinf[45] However, significant differences were observed when the severity of the illness was considered. There was a marked difference between groups in their $FEV_{1.0}$/FVC measures between pre- and post-illness assessment, with the severe group (84.2 ± 2.3%) lower than the mild group (88.9 ± 2.6%) which in turn was lower than the control group (92.7 ± 2.2%).[45] However, all pre- and post-illness $FEV_{1.0}$/FVC values were within the normal range.

Acute effects of ARinf on sports performance outcomes

There were four studies reporting acute (short term) effects of ARinf on sport performance outcomes (Table 2). In these studies, outcome variables were determined during an ARinf[23, 39, 42] or within 12 days of the ARinf.[40] In one study, testing was conducted after inoculation with a specific pathogen (rhinovirus) while in the other three studies the diagnosis of ARinf was suspected and the pathogen/s not identified. Sports performance parameters included not starting or not completing an event, acute training modifications, and laboratory measurements of running kinematic variables (stride length, stride frequency, and ankle, knee and hip joint angles). The main findings from single studies on the acute effects of an ARinf on sporting performance variables were that: a) an athlete is significantly less likely (risk ratio = 1.15) to start an event if they have a recent ARinf (8-12 days prior to a race),[40] b) during an upper ARinf there is a negative effect on training, impairing self-reported training ability and capacity,[39, 42] and c) during an ARinf with fever there are alterations in running kinematics (measured stride length, stride frequency and joint angles).[23]

Longer-term effects of acute respiratory infection on sports and exercise performance outcomes

There was one study that reported changes in exercise performance variables over time; specifically muscle strength in athletes post-SARS-CoV-2 infection (Table 3).[37] The outcome variables in this study were counter movement jump (cm), bilateral hip abduction (N), hip adduction (N) and Nordic hamstring strength (N) measured at regular 2-week intervals, and compared to measurements taken 1 week prior to infection. There were no substantial changes in these measurements.

The longer-term effects of acute respiratory infection on sports performance were reported in six studies (Table 3). In these studies, outcome variables were determined over a number of weeks, months, or between two seasons. In three of these studies the diagnosis of ARinf was suspected and the pathogen/s not identified, while in the other three studies SARS-CoV-2 infection was confirmed. The sports performance outcome variables were training modifications,[32, 43, 46] match performance,[35, 36] or a change in standardised points.[32, 44] The main findings are conflicting. There is evidence that ARinf episodes impair training mileage[43] and overall training load[41-43] over a 4-5 month period, but there is also evidence that training hours/week post-SARS-CoV-2 infection are not affected.[32] Similarly, there was a trend for reduced match performance[35, 36] and standardised performance-dependent points in athletes who had been ill compared to those who remained healthy between two major competitions/seasons[44] as well as evidence of similar improvement in standardised performance-dependent points over two seasons between infected and non-infected athletes.[32] In summary, It is currently inconclusive whether training, match performance, or standardised performance points over time are affected or not post-ARinf.

Table 2: Acute (short term) effects of acute respiratory infection on exercise and sports performance outcomes

Study	Illness classification	Diagnostic method	Study design / flow / testing	Timing of measurements in relation to ARinf	Summary effect of ARinf on exercise / sports performance outcome variable/s
Anastasio et al. 2021[30]	Confirmed general (upper/lower)	Physician diagnosis including pathology confirmed (PCR or culture) for pathogen	• Elite cross-country skiers with previous SARS-CoV-2 infection • CPET and pulmonary function testing before resuming seasonal training • Retrospectively selected and compared to a detrained, similar control group	• 4-6 weeks after SARS-CoV-2 positive test	Cardiorespiratory endurance • Aerobic threshold (blood lactate 2mmol/L) reached earlier in ARinf athletes (4:48 mins) than controls (6:28 mins) (R^2=0.15; F=4.37; $p<0.05$) • Compared to controls at the aerobic threshold, ARinf athletes had *lower:* o Oxygen consumption (VO_2/kg 28.6 mL/min vs. 38.9 mL/min, R^2=0.39; F=15.34; $p<0.01$) o Average values of VE (50 L/min vs. 61 L/min, R^2=0.22, F=6.64; p=0.01) o HR (136 bpm vs. 50 bpm, R^2=0.29, F=9.90; $p<0.01$) o Oxygen pulse (VO_2/kg/HR 0.16 vs. 0.19, R^2=0.22; F=6.79; p=0.01) • Compared to controls at the aerobic threshold, ARinf athletes had *higher:* o BR (71% vs. 57%, R^2=0.15, F=4.36; $p<0.05$) o HRR (26% vs. 22%, R^2=0.16, F=4.11; $p<0.05$) Pulmonary function • Similar levels of pulmonary function (at rest) [FVC (l), FVC (%), FEV1 (l), FEV1 (%), FEV1/FVC, PEF (l), PEF (%), MVV (l), MVV (%)]
Costello et al. 2021[31]	Confirmed general (upper/lower)	Physician diagnosis including pathology confirmed (PCR or culture) for pathogen	• Professional basketball players who tested positive for SARS-CoV-2 were compared to teammates who tested negative • Assessment included CPET on return to training	• 10-21 days after SARS-CoV-2 positive test	Cardiorespiratory endurance • Similar levels of cardiorespiratory endurance [peak exercise HR (bpm), peak RER, peak VO_2 (L/min), peak VO_2 (mL/kg/min), VE/VCO_2] between ARinf and control athletes
Csulak et al. 2021[32]	Confirmed general (upper/lower)	Physician diagnosis including pathology confirmed (PCR or culture) for pathogen	• Hungarian Swimmers preparing for the Olympics were prospectively assessed on their return to training post-SARS-CoV-2 infection • Experimental group CPET results compared to their own baseline measurements pre-SARS-CoV-2 infection and to non-infected controls	• 10-14 days after SARS-CoV-2 positive test	Cardiorespiratory endurance • Higher resting HR (bpm) post-SARS-CoV-2 in ARinf (72.4 ± 17) athletes compared to controls (62.0 ± 11) (p=0.024) • Higher VE (l/min) during maximal exercise post-SARS-CoV-2 (2021) (178.0 ± 16.6) compared to pre-SARS-CoV-2 (2019) (153.0 ± 9.5) in ARinf athletes (p=0.03) • Similar levels of peak HR (bpm), HR recovery (1/min), RER, VO_2max (l/min), VO_2max (l/min/kg), VE/VCO_2, peak lactate (mmol/L)] between ARinf and control athletes between 2019 and 2021
Fikenzer et al. 2021[33]	Confirmed general (upper/lower)	Physician diagnosis including pathology confirmed (PCR or culture) for pathogen	• Elite handball players who tested positive for SARS-CoV-2 were compared to teammates who tested negative • Assessment included CPET and pulmonary function on return to training	• 19 ±7 days after SARS-CoV-2 positive test	Cardiorespiratory endurance • Lower VO_2max (− 292 ml/min, − 7.0%), oxygen pulse (− 2.4 ml/beat, − 10.4%), and respiratory minute volume (− 18.9 l/min, − 13.8%) in athletes with a history of SARS-CoV-2 infection ($p < 0.05$) compared to controls • No significant differences in pulmonary function (at rest) [FVC (l), FEV1 (l), PEF (l/s), MEF_{25} (l/s)]
Komici et al. 2021[34]	Confirmed general (upper/lower)	Physician diagnosis including pathology confirmed (PCR or culture) for pathogen	• Competitive athletes with recent SARS-CoV-2 infection underwent CPET and pulmonary function testing • Experimental group was compared to a non-infected control group	• ≤30 days after SARS-CoV-2 positive test	Cardiorespiratory endurance • Similar levels of cardiorespiratory endurance [peak HR (bpm), peak SBP (mmHg), peak VO_2 (ml/kg/min), peak VE (l/min), Peak RER, peak SpO_2 (%), peak VCO_2 (l/min), VE/VCO_2 slope, lowest VE/VCO_2, 1stVT VO_2 (ml/kg/min), 1stVT% peak VO_2, peak O_2 pulse (ml/kg/min)] between ARinf and control athletes Pulmonary function • Lower FEV1% in infected athletes [97.5 (91.5–108)] compared to controls [109 (106–116)] (p = 0.007)
Crameri et al. 2020[38]	Confirmed general (upper/lower)	Physician diagnosis including pathology confirmed (PCR or culture) for pathogen	• Swiss army recruits assessed post-SARS-CoV-2 infection and compared to pre-infection measurements and non-infected homogenous controls • Assessment included CPET and muscle strength testing	• 45 (31-58 days) after SARS-CoV-2 positive test	Cardiorespiratory endurance • VO_2max (ml/ min/kg) decreased by −0.9 (−3.2 to 0.5) in symptomatically infected athletes compared to asymptomatic athletes and non-infected controls Muscle strength • No differences in upper extremity or trunk strength between infected (asymptomatic and symptomatic) and non-infected control athletes
=Marinkovic et al. 2016[39]	Suspected upper ARinf	Symptom checklist with algorithm/ scoring system	• Randomized double-blind placebo-controlled trial in elite athletes • Daily illness log data • Weekly training load data (using the IPAQ short form), influence of illness on training ability, and missed training days recorded throughout 14-week study period	• During ARinf episode	Training modification: • Self-reported training ability negatively affected during an ARinf episode, but this impact is inferred to be minimal for ~2 days

Van Tonder et al. 2016[40]	Suspected general ARinf	Symptom checklist with algorithm/ scoring system	• Prospective study in distance runners • Pre-race acute illness questionnaire completed during the 5-day pre-race period	• <12 days after ARinf episode	Event participation: • DNS rate: o Runners with systemic ARinf symptoms had a significantly higher DNS rate compared to controls (16.7% vs. 6.6%; RR=1.15; p=0.0317) o Runners with localised ARinf symptoms had a higher DNS rate compared to controls (localised symptoms: 7.9% vs. 6.6%) • DNF rate: o Runners with systemic ARinf symptoms had a higher DNF rate compared to controls (1.8% vs. 1.3%) o Runners with localised ARinf symptoms had a higher DNF rate compared to controls (localised symptoms: 1.5% vs. 1.3%) • Runners with self-reported symptoms of systemic ARinf 8-12 days before an event had ~1.15 x greater chance of not starting the race and less chance of finishing the race
Cunniffe et al. 2011[42]	Suspected upper ARinf	Self-reported symptoms with physician check (no examination)	• Prospective longitudinal observational study in elite Rugby Union players • Weekly illness rates and training load monitored over 4 months	• During ARinf episode	Training modification: • Rugby Union players reported that the presence of an ARinf reduced activity in 14.4% of all ARinf incidences
Fricker et al. 2005[43]	Suspected upper ARinf	Physician diagnosis (by history and clinical examination)	• Prospective observational study in distance runners • Daily illness log data • ARinf illness episodes recorded • Maximal exercise test at beginning and end of 4-month period • Submaximal running economy test monthly • Tests during healthy period and following ARinf episodes	• < 10 days after ARinf episode	Cardiorespiratory endurance: • No significant effect of a recent (<10 days) ARinf on cardiorespiratory endurance (maximal and submaximal tests) [VO_2 and VO_2max (mL.min-1.kg-1), VE (L.min-1), RER, HR (beats/min),blood lactate (mM)]
Weidner et al. 1997[45]	Confirmed upper ARinf	Physician diagnosis including pathology confirmed (PCR or culture) for pathogen	• Prospective experimental study in physically active students • Double-dose inoculation with rhinovirus (HRV16) • PFT and GXT to volitional fatigue pre- and post-inoculation	• The day after the second inoculation (peak of illness)	Cardiorespiratory endurance: • ARinf had little effect on cardiorespiratory endurance [VO_2 and VO_2max (mL.min-1.kg-1), VE (L.min-1), VT, RPE, RER, HR (beats/min)] Pulmonary function: • $FEV_{1.0}$/FVC lower in the severe ARinf group (84.2 ± 2.3%), compared with the mild ARinf group (88.9 ± 2.6%) and the control group (92.7 ± 2.2) but all values remained within the normal range
Weidner, Anderson et al. 1997[23]	Confirmed upper ARinf	Physician diagnosis including pathology confirmed (PCR or culture) for pathogen	• Prospective experimental study in physically active students • Double-dose inoculation with rhinovirus (HRV16) • Submaximal exercise test within 1-2 days of ARinf onset and 3 weeks later when asymptomatic • Kinematic video recording [stride length (m), stride frequency (hz), and ankle, knee and hip joint angle (deg)]	• Within 1-2 days of ARinf onset	Running biomechanics: • ARinf associated with longer and less frequent strides, when fever was present (p<0.04)

***1stVT VO_2:** first ventilatory threshold; **1stVT% Peak VO_2:** first ventilatory threshold expressed as percentage of peak oxygen uptake; **ARinf:** infective acute respiratory illness; **BR:** breathing reserve; **CON:** control group; **CPET:** cardiopulmonary exercise testing; **DNF:** did not finish; **DNS:** did not start; **FEF_{25-75}:** mean forced expiratory flow between 25% and 75%; **$FEV_{1.0}$**: forced expiratory volume in the first second; **$FEV_{1.0}$/FVC:** $FEV_{1.0}$ as a percentage of FVC; **FVC:** forced vital capacity; **HR:** heart rate; **HRR:** heart rate reserve; **IPAQ:** international physical activity questionnaire; **MEF_{25}:** maximal expiratory flow at 25% of the vital capacity; **MVV:** maximal ventilatory volume; **NS:** not significant; **PCR:** polymerase chain reaction; **PEF:** peak expiratory flow; **RER:** respiratory exchange ratio; **RPE:** rating of perceived exertion; **SARS-CoV-2:** severe acute respiratory syndrome coronavirus 2; **SBP:** systolic blood pressure; **SpO_2:** arterial saturation; **VE:** expired ventilation; **VE/VCO_2:** ventilatory efficiency; **VO_2:** oxygen uptake; **VO_2/kg:** oxygen uptake normalised to body weight; **VO_2/kg/HR:** amount of O_2 extracted per heart beat; **VO_2max:** maximum oxygen uptake; **VT:** ventilatory threshold; **VTex:** tidal volume.*

Table 3: Longer-term effects of acute respiratory infection on exercise and sports performance outcomes

Study	Illness classification	Diagnostic method	Study design / flow / testing	Timing of measurements in relation to ARinf	Summary effect of ARinf on outcome variable/s
Csulak et al. 2021[32]	Confirmed general (upper/lower)	Physician diagnosis including pathology confirmed (PCR or culture) for pathogen	• Hungarian swimmers preparing for the Olympics were assessed on their return to training post-SARS-CoV-2 infection • Training duration and change in standardised time-ranking points were compared to pre-infection and healthy control group performances from 2019-2021	• Point values from the FINA Point Scoring 2019 and 2021 tables	Training modification • SARS-CoV-2 infection had little effect on training hours per-week (24.5 ± 3.9) compared to a control group (24 ± 4.5) (p=0.71) Change in standardised points (FINA) • Similar improvement in FINA performance points between infected (55.6%) and control athletes (54.5%) (p=0.75) from 2019-2021
Savicevic et al. 2021[35]	Confirmed general (upper/lower)	Physician diagnosis including pathology confirmed (PCR or culture) for pathogen	• Professional football players match running performance (GPS data) was assessed post-SARS-CoV-2 infection throughout the 2020/2021 season in Croatia • Data were compared to pre-infection match averages and to non-infected teammates' averages in the same periods	ARinf • Pre-infection: all matches 30 days prior to infection • Post infection: all matches after RTP (±4 months of the season) Controls • First half of season's matches	Match performance post-SARS-CoV-2 infection (compared to pre-infection): • Fewer high-intensity accelerations (>±3 m/s^2) (count) within infected players (p=0.04) but not between infected and control players (p=0.28) • Fewer high-intensity decelerations (>±3 m/s^2) (count) within infected players (p=0.04) but not between infected and control players (p=0.54) • Similar values of total distance covered (m) and distances covered in different speed categories (e.g., low-intensity running (<14.3 km/h) (m), running (14.4-19.7 km/h) (m), high-intensity running (>19.8 km/h) (m), high speed running (19.8-25.1 km/h) (m), sprinting (>25.2 km/h) (m), total accelerations (>±0.5 m/s^2) (count), total decelerations (>±0.5 m/s2) (count), high intensity accelerations (>±3 m/s^2) (count), high intensity decelerations (>±3m/s^2) (count)]
Vaudreuil et al. 2021[36]	Confirmed general (upper/lower)	Physician diagnosis including pathology confirmed (PCR or culture) for pathogen	• NBA basketball players match play performance was analysed post-SARS-CoV-2 infection, and compared to pre-infection match and career averages • Data collected from publicly available statistics	• Matches played after SARS-CoV-2 positive test over the remainder of the season	Match performance post-SARS-CoV-2 infection (compared to pre-infection): • Reduction in minutes played per game (25.8 vs 28.7; p=0.04) • Fewer field goals per game (4.6 vs 5.4; p=0.02) • Insignificant decreases in averages for points (p= 0.06), rebounds (p=0.13), assists (p=0.23), steals (p=0.30), and blocks (p=0.71) per game
Wagemans et al. 2021[37]	Confirmed general (upper/lower)	Physician diagnosis including pathology confirmed (PCR or culture) for pathogen	• Weekly SARS-CoV-2 testing and assessment of hamstring, hip abductor, and hip adductor strength and jump performance (using Vald performance devices) in professional football players • Positive SARS-CoV-2 athletes compared to within-subject and non-infected controls pre- and post-infection	• 2 weeks, 4 weeks, 6 weeks and 8 weeks after SARS-CoV-2 positive test	Muscle strength [CMJ (cm), bilateral hip abduction (N), hip adduction (N), Nordic hamstring (N)] • Trivial differences in CMJ height, hip adductor, hip abductor, and hamstring muscle strength 2 weeks, 4 weeks, 6 weeks, and 8 weeks after SARS-CoV-2 infection compared to 1 week pre-infection
He et al. 2013[41]	Suspected upper ARinf	Symptom checklist with algorithm/ scoring system	• Prospective study in endurance athletes • Daily illness log data • Weekly training load (IPAQ – MET-hr/week) monitored for 16 weeks	• Effects of ARinf over 16 weeks	Training modification • 70% of subjects with an ARinf reduced their weekly training load by an average of 24% • Weekly training load negatively affected during an ARinf episode in endurance athletes
Fricker et al. 2005[43]	Suspected upper ARinf	Physician diagnosis (by history and clinical examination)	• Prospective observational study in distance runners • Daily illness log data • Weekly training volume (km/wk), load (mileage x intensity) and intensity (1-5; 1 = light, 5 = maximal) monitored over 4 months	• Effects of ARinf over 4 months	Training modification • ARinf reduces weekly training volume by 8% (p=0.01) and training load by 18% (p=0.05) compared to control runners but positively affects training intensity in illness-affected runners (p=0.05)
Pyne et al. 2000[44]	Suspected general ARinf	Physician diagnosis (by history and clinical examination)	• Prospective study in elite swimmers • ARinf illness episodes recorded over 5-month study period • Performance of each swimmer's best event rated in terms of the International Point Score (IPS) and final placing of each swimmer's best event	• Effects of ARinf over 5-month study period	Change in standardised points (FINA) • Competitive performance was higher in healthy swimmers (mean FINA = 955 points) than ARinf swimmers (mean FINA = 937 points) (p=0.11) at the second competition • There was a trend for healthy swimmers to perform substantially better (18 FINA points) than ARinf swimmers

***ARinf:** infective acute respiratory illness; **GPS:** global positioning system; **IPAQ:** international physical activity questionnaire; **MET:** metabolic equivalent; **PCR:** polymerase chain reaction.*

Discussion

The aim of this systematic review was to determine the effects of an ARinf, including SARS-CoV-2 infection, on acute (short-term) and longer-term (responses to training) exercise and sports performance outcomes in athletes. The primary outcome was that few studies have investigated the effects of ARinf on exercise and sports performance, and the limited data that are available are very heterogenous. Although the COVID-19 pandemic has prompted several recent studies on the effects of SARS-CoV-2 infection in athletes, the evidence of both the acute and longer-term effects of ARinf in athletes remains sparse and inconclusive. Variable outcomes have been reported ranging from trivial impact to marked impairment of physiological capacities, and measures of sports performance including completion rates, training volumes, and competition performance outcomes.

Acute (short-term) effects of ARinf on exercise performance parameters

The main findings from individual studies on the acute effects of ARinf on exercise performance were as follows: a) the aerobic threshold is reached sooner in athletes post-SARS-CoV-2 infection,[30] b) there is more evidence of cardiorespiratory endurance (VO_2max) not being affected than there is for significant reductions post-infection, b) an upper ARinf (rhinovirus) infection (2 days after inoculation) and SARS-CoV-2 infection caused marked reductions in pulmonary function tests ($FEV_{1.0}$/FVC and $FEV_{1.0}$% respectively), with greater reductions observed in more severe ARinf, but test results remained within normal ranges.

A major limitation of available data is that the severity of ARinf has not been well documented. The severity of an ARinf is very likely to influence its acute effect on performance outcomes. The severity of the illness is dependent on several factors, including the specific pathogen and variable host-response to an infection. There is some evidence that mild symptoms, particularly if they are localised to the upper respiratory region, are associated with a lower risk of an acute negative effect on exercise performance parameters compared to ARinf causing moderate to severe symptoms.[23, 43, 45] In this review, where mild severity of ARinf was reported it appears to be associated with minimal change in performance. VO_2max remained unchanged in athletes with mild SARS-CoV-2 infection[30-34] and with mild symptoms caused by a localised upper ARinf after rhinovirus inoculation.[45] In contrast, data from one study shows that athletes with more severe symptoms resulting from rhinovirus inoculation had significantly reduced lung function tests ($FEV_{1.0}$/FVC).[45] Furthermore, there was a significant decrease in VO_2max in athletes with symptomatic versus asymptomatic SARS-CoV-2 infection.[38]

A second limitation with the available data is that the acute effects of an ARinf on other exercise performance indicators such as muscle function, neuromuscular control, coordination, and flexibility have not been studied.[17, 47, 48] In our systematic review we identified only one study on muscle strength which observed no changes as an effect of ARinf.[38] However, additional data from a review on the acute effects of acute infections in general, and not specifically acute respiratory tract infections, show that an acute infection resulted in reductions in several exercise performance outcomes as follows: isometric muscle strength (-5 to -15%), isometric muscle endurance (-13 to -18%), and aerobic exercise capacity (-25%).[22] The decline in muscle strength and endurance was correlated to the muscle protein loss caused by the infection, and the magnitude of impairment in muscle strength was related to the individual's perception of subjective symptoms, including myalgia and headache.[22] The nervous system and neuromuscular control can also be negatively affected by acute infection and fever. Impaired coordination ability and speed in the performance of motor skills, reductions in submaximal force generation, slower reaction time, and decreased attention and vigilance, have been reported during an infection.[22, 25] These acute effects of infection on musculoskeletal, neuromuscular and nervous system parameters are also important because they may increase the risk of injury during or immediately after an ARinf. Acute illness has been linked to an increased risk of ankle sprains, dislocations and other damage to joints, ligaments and tendons,[22] but the relationship between ARinf and risk of injury has not been studied.

Acute (short-term) effects of ARinf on sports performance parameters

A wide range of abilities are required by an athlete to excel in sports, given the diverse physical and cognitive demands of individual and team sports. Outcomes of sports performance are generally sanctioned by international or national sports federations (event or race time, standardised points, ranking) or are readily quantifiable by a coach or sports scientist (e.g. reduced volume or intensity of training, interpretation of match performance from match statistics and GPS data). These outcomes can provide an objective means of reporting changes or differences in sports performance. Given the wide range of possible sports performance outcomes, it is not surprising that, in this review, there was substantial heterogeneity in the measurement or assessment of sports performance. Although similarities could be identified between studies using the same cluster of outcome measures of sports performance, there was no combination of studies that employed identical methodology. The main findings from individual studies on the acute effects of ARinf on sports performance parameters were that: a) runners were less likely to start a race if they had a recent ARinf (8-12 days prior to a race), b) during an upper ARinf, self-reported training ability and training capacity is reduced, and c) an ARinf with fever altered running kinematics (measured stride length, stride frequency and joint angles) 2 days after inoculation with rhinovirus.

Our first finding on the acute (short-term) effects of ARinf on sports performance parameters, from a single study, was that runners with self-reported symptoms of systemic respiratory illness 8-12 days prior were 1.15 x less likely to start a race than those who remain healthy.[40] In support of this, a secondary study that was not included in this review, reported that runners with pre-race symptoms of a systemic infective illness (of which 80% were ARill) were not only 1.6 x less likely to start, but had a 4.9 x greater risk of not finishing the race.[49] The inability to start or finish a race (or an event) can be considered a prominent indicator of sports performance because it immediately disqualifies the athlete from competition. For most athletes, participating in sporting competitions is the reward of significant sacrifice and prolonged hard training. A decision not to start or having to withdraw from a sporting competition indicates that an acute illness can be a substantial adverse outcome for an athlete.

A second finding on the acute (short-term) effects of ARinf on sports performance parameters, was that during an upper ARinf, self-reported training ability and training capacity was reduced. The results of three studies showed a clear reduction in training load in the presence of ARinf.[41-43] A limitation of these findings is that measurement of training load varied substantially in studies and included three different methodologies (session RPE x session duration,[42] mileage x intensity,[43] and MET-hr/week measured by the short form IPAQ).[41] Nevertheless, these studies reported a reduction in training load between 18-24% as a result of ARinf.[41, 43] These data are supported by findings from a secondary study where 31% of an elite athlete cohort (n=70) ceased all training and 19% reduced their training volume or intensity as a result of symptoms of an ARinf.[6] The effects of acute ARill and ARinf on training and/or competition days lost has recently been reviewed.[12] In this referenced review, about 20% of all ARill and ARinf results in >1 day loss from training and competition.[12] Time loss from acute illness is particularly important for elite athletes. For example, the likelihood of achieving a sports performance goal is increased by 7 x if athletes are able to complete >80% of planned training week,[22, 26] and if one or more training days have to be modified in a week the chances of achieving key sports performance goals are reduced by 26%.[26] In another study where acute illness episodes were documented in male professional football players (1,261,367 player-days), ARill resulted in the highest illness burden with 3.1 absence days per 1000 player-days.[1] These studies highlight the potential negative acute effects of an ARinf on training ability and subsequent sports performance, particularly for elite athletes.

Longer-term effects of ARinf on sports and exercise performance parameters

Outcomes of longer-term effects of ARinf on sports performance, such as a change in points or sports performance time, are meaningful for practical application in the management of athletes with ARinf. However, the longer-term effects of ARinf on sports performance have only been reported in a limited number of studies which provide evidence of both affected and unaffected performance post-ARinf but the overall balance of evidence reveals a trend for reduced training load, reduced standardised sports performance-dependent points and impaired match play post-ARinf. In the one study, ARinf in swimmers resulted in a decrease of 18 FINA points over a training period of 5 months.[44] These data are supported by results from another study where mild acute illness (all illness, not just respiratory) in swimmers was associated with a decrease of 3 FINA points in females and 5 FINA points in males.[50] The margins of success and differences in performance in top-level athletes are often very narrow, and small effects of ARill on sport and exercise performance could have substantial effects on competition outcomes for these athletes.

The evidence for longer-term effects of ARinf on exercise parameters is extremely sparse and deductions cannot be drawn from a single known study on muscle strength post-SARS-CoV-2 infection.[37] For both sports and exercise performance parameters further research is needed, particularly post-SARS-CoV-2 infection, given evidence of multi-organ involvement[21] and prolonged symptoms that may have a significant impact on health, sports participation and general wellbeing for weeks to months.[19, 51-54]

Other indirect effects of ARinf on exercise and sports performance outcomes

The effects of ARinf on exercise performance and sports performance outcomes are not always explicit. Symptoms of ARinf may also indirectly contribute to decrements in exercise performance.[2, 55] For example, nasal congestion, which can alter airflow dynamics and ventilation during exercise, can cause disrupted sleep, impaired concentration and visual coordination. ARinf associated with tiredness, fatigue and impaired quality of life can also potentially negatively affect exercise performance.[55, 56] The effects of acute illness in athletes' exercise and sports performance, including ARinf, has also been compared to the effects of overuse injuries because athletes often continue to train and play despite having mild symptoms/pain that can reduce performance.[1, 23, 45, 57] Therefore, if the athletes do continue to train and compete through ARinf, the true effects on the athlete's exercise performance parameters could remain unclear.[1, 23, 45, 57, 58]

Study limitations

Despite our robust research design in accordance with PRISMA guidelines, there are also limitations of this systematic review. The main limitations are sparsity of data and the heterogenous nature of the data we could include in this study. These shortcomings made it challenging to formulate conclusions about the acute- and longer-term effects of ARinf on exercise and sports performance outcomes. We were not able to pool data from individual studies because of the underlying methodological heterogeneity, and thus the results are reported as a narrative interpretation rather than a meta-analysis. Secondly, the precise inclusion criteria, including publications written in English only and specific to infective acute respiratory illness (exclusive of noninfective and acute illness in general), may have excluded relevant studies. However, a small number of secondary studies known to the researchers were included as contributing evidence to ensure a more comprehensive discussion of the topic. It should also be noted that recent contributions to the field of study prompted by the COVID-19 pandemic had very small sample sizes so the results should be interpreted and applied to clinical practice with caution. It is not known how applicable the results from SARS-CoV-2 studies are to other ARinf and further research is needed to determine this. Further limitations in interpreting the effects of ARinf on exercise performance include restricted study cohorts (high performance or elite athletes in one sport),[43, 50, 57] and short surveillance periods (e.g. the Olympic Games, World Championships or a competition period spanning a few weeks).[59-61]

Summary and conclusions

In summary, there are only limited data on the effects of ARinf on exercise and sports performance, although several more studies have emerged during the COVID-19 pandemic (albeit with small sample sizes). There is substantial heterogeneity in experimental methodology between studies, and more research is required to provide definitive practical and clinical answers to the sports community to better understand the effects of ARinf on exercise and sports performance. Overall, the results indicate that there is a trend towards a decrease in exercise and sports performance outcomes in the presence of ARinf in athletic cohorts. However, these findings should be applied with caution in the field. Future work is required to standardise diagnostic approaches, confirmation of the diagnosis, detailed categorisation of symptoms (type, severity and duration), and the development of a framework for quantifying and standardising exercise and sports performance effects of ARinf. A combination of observational studies of sporting events, prospective longitudinal studies of athletes in training and competition, and controlled laboratory trials, will generate new knowledge. Given the wide diversity of sport types, it is likely that a multi-component framework is needed to establish the effects of ARinf on exercise and sports performance more clearly. Evidence-based information on the effects of ARinf on exercise and sports performance will guide clinical management of athletes in a variety of settings, improve return to sport guidelines for athletes post-ARinf and inform the direction of future research investigations.

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