The benefits of a systematic assessment of respiratory health in illness-susceptible athletes

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A systematic approach to the identification of respiratory problems is deliverable within a world-class sport performance programme and identifies previously unrecognised and potentially modifiable factors in illness-susceptible athletes https://bit.ly/37lM4ck

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ABSTRACT Respiratory tract illness is a leading cause of training and in-competition time loss in elite athletes. Asthma is known to be prevalent in athletes, but the coexistence of other respiratory problems in those deemed to be susceptible to respiratory tract illness is unknown. The aim of this study was to apply a comprehensive prospective approach to identify respiratory problems and explore relationships in athletes with heightened respiratory illness susceptibility.

UK World Class Performance Programme athletes prospectively completed a systematic review of respiratory health with validated questionnaires and respiratory-focused investigations, including studies of nasal flow, exhaled nitric oxide, spirometry, bronchoprovocation testing and allergy testing.

Systematic respiratory health assessment was completed by 122 athletes (55 females, mean±SD age 24±4 years). At least one respiratory health issue, requiring intervention, was identified in 97 (80%) athletes and at least two abnormalities were found in 73 (60%). Sinonasal problems were the most commonly identified problem (49%) and 22% of athletes had a positive indirect bronchoprovocation test. Analysis revealed two respiratory health clusters: 1) asthma, sinus problems and allergy; and 2) laryngeal and breathing pattern dysfunction. Respiratory illness susceptible athletes had 3.6±2.5 episodes in the year prior to assessment and were more likely to have allergy (OR 2.6, 95% CI 1.0–6.5), sinonasal problems (2.6, 1.1–6.0) and symptoms of laryngeal (5.4, 1.8–16.8) and breathing pattern dysfunction (3.9, 1.1–14.0) than nonsusceptible athletes (all $p<0.05$).

A systematic approach to respiratory assessment identifies a high prevalence and coexistence of multiple respiratory problems in illness-susceptible athletes.

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Introduction

Respiratory tract illness (RTI) is a highly prevalent and important issue in athlete care [1, 2]. Indeed, RTI is the most common non-injury-related presentation to a sports medicine clinic and accounts for approximately two-thirds of all medical-related consultations [2, 3]. In addition, it commonly impacts in-competition health and performance, with an International Olympic Committee consensus statement indicating that 5–7% of athletes develop an RTI during an international sporting event [4].

The reasons why RTI is problematic for certain athletic groups is unclear [2]. Strenuous and prolonged exercise is associated with immune dysregulation, and both environmental (*e.g.* allergen exposure) and social (*e.g.* close group contact) factors are relevant in the aetiology of RTI in athletic individuals [5]. It is also likely that certain "host" factors may increase RTI susceptibility. In this respect, it is recognised that asthma is highly prevalent in some groups of athletes, *e.g.* aquatic and winter sports athletes [6, 7], but the role, coexistence and potential contribution of other respiratory issues in RTI susceptibility has not been systematically evaluated.

In other aspects of respiratory care (*e.g.* difficult-to-treat asthma) it is now recognised that, in order to optimise care, it is important to detect and simultaneously treat any potentially relevant or contributory factors. Thus, it is important to detect and treat coexisting allergies and any potential contribution from sinonasal problems, gastroesophageal airway reflux, breathing pattern dysfunction and/or laryngeal problems [8, 9]. This so-called "systematic approach" to respiratory or airway health has been shown to improve symptom control, quality of life and reduce exacerbation frequency [10].

It is conceivable that a similar approach, when applied systematically to the respiratory care of athletes, could identify multiple simultaneous respiratory issues associated with RTI susceptibility, *i.e.* issues that potentially contribute to heightened susceptibility. Certainly, prior studies indicate that the treatment for asthma-related problems in elite athletes is associated with improved pulmonary function, airway inflammation and potentially improved athletic performance [11]. Likewise, a recent questionnaire-based approach to the detection of allergy and respiratory health issues was associated with reduced illness frequency in rugby players preparing for international competition [12].

The primary aim of this study was to evaluate the application of a prospective, systematic approach to the assessment of respiratory athlete health (SARAH) in Olympic-level athletes, to describe and characterise the prevalence and coexistence of respiratory problems encountered. A secondary aim was to discern differences in the likelihood and pattern of respiratory problems in athletes pre-defined as exhibiting a heightened frequency or impact of RTI. We hypothesised that RTI-susceptible athletes would exhibit a higher frequency of respiratory problems and that many of these issues would be undetected and coexist in the same individual.

Methodology

Study population and study design

Elite athletes from all 24 UK Sport-funded Olympic World Class Programmes were invited to participate, with those aged <18 years, current smokers and those with a history of cardiovascular or metabolic disease excluded. Ethical approval for the study was obtained from the University College London research ethics committee (12513/001). Following informed consent, athletes prospectively completed online questionnaires and, as detailed later, attended on a single occasion for a SARAH assessment, comprising a medical interview and programmed investigations (lasting ∼75 min).

SARAH assessment

Questionnaires

Prior to and following assessment, athletes completed a respiratory health survey evaluating their respiratory and allergy symptoms, diagnoses and treatment. An interview was conducted to clarify any issues and to allow completion of the Pittsburgh Vocal Cord Dysfunction Index (VCDI) [13]. In addition, athletes completed several validated questionnaires: the Allergy Questionnaire for Athletes (AQUA) [14] (baseline only), Mini Asthma Quality of Life Questionnaire (mini-AQLQ) [15] (athletes with a current asthma diagnosis), Mini Rhinoconjunctivitis Quality of Life Questionnaire (mini-RQLQ) [16], Newcastle Laryngeal Hypersensitivity Questionnaire (LHQ) [17], Hull Airways Reflux Questionnaire [18] and the Sinonasal Outcome Test (SNOT-22) [19] (athletes with sinonasal symptoms only).

Measurements

Physiological investigations included nasal inspiratory peak flow, fraction of exhaled nitric oxide (F_{eNO}), spirometry, indirect bronchoprovocation testing (eucapnic voluntary hyperpnoea (EVH) test) and skin-prick testing (figure 1 and supplementary material for specific methodology). Athletes were required

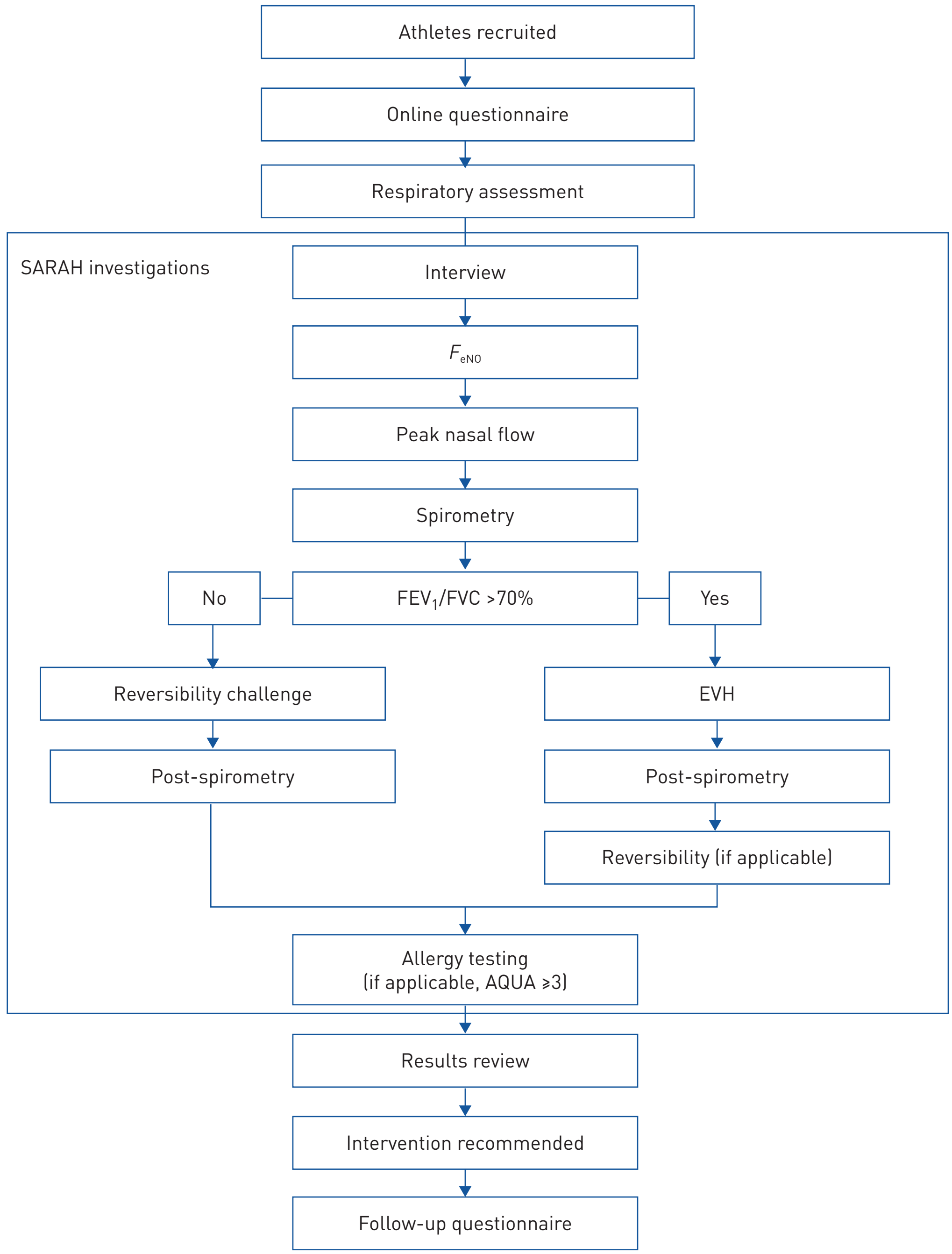

FIGURE 1 Study design and schedule of systematic assessment of respiratory health tests. SARAH: systematic approach to the assessment of respiratory athlete health; F_{eNO}: fraction of exhaled nitric oxide; FEV_1: forced expiratory volume in 1 s; FVC: forced vital capacity; EVH: eucapnic voluntary hyperpnoea; AQUA: Allergy Questionnaire for Athletes.

to be free from any significant respiratory illness in the 4 weeks prior to assessment and refrained from exercise and caffeine for ⩾4 h prior to testing.

Study classification and outcomes

Following the SARAH process, all results were reviewed by a respiratory physician (JH) to provide a red, amber and green rating, highlighting to the athlete's sports physician a need for intervention immediately, observe/consider action and normal/no action required. This process was informed by the clinical history and relevant SARAH assessment findings, as follows. 1) Allergy: history, AQUA score (⩾3 as abnormal) and skin-prick test result; 2) sinus and nasal dysfunction: history, mini-RQLQ score, SNOT-22 score (to assess rhinitis severity) and nasal peak flow (>120 $L \cdot s^{-1}$ taken as normal); 3) laryngeal dysfunction: symptom report, Newcastle LHQ score (<17.1 as abnormal) and VCDI score (⩾4 as abnormal); 4) breathing pattern (observations during EVH); 5) asthma/exercise-induced bronchoconstriction (EIB)/ airway inflammation: mini-AQLQ score, F_{eNO}, spirometry and EVH result; and 6) airway reflux: Hull reflux cough score (>13 as abnormal).

Athletes were classified as being "RTI-susceptible", based on self-report and cross-checked against their electronic medical records, if they had two or more occurrences of respiratory illness, resulting in at least 2 days of restricted training in the past 18 months and/or one occurrence causing ⩾5 days of restricted training.

Statistical analysis

Data are expressed as mean±SD for parametric variables and as median (interquartile range (IQR)) otherwise. Group differences were analysed using the Mann–Whitney U-test, McNemar's tests or Chi-squared analysis with continuity correction, as appropriate. For analysis of SARAH outcome, red and amber classifications were grouped into a single category, *i.e.* based on a need for clinician intervention. The relationship between respiratory problems in the same athlete was evaluated using the Jaccard index, with an agglomerative approach to hierarchical clustering. Baseline to follow-up data were analysed using a Wilcoxon signed rank test. All statistical calculations were made with R [20]. Statistical significance was accepted as p<0.05.

Results

Subject characteristics

A SARAH assessment was completed in 122 athletes (45% female), aged 24±4 years, from 12 Olympic sports (table 1), between October 2018 and February 2020. Over half of the athletes (n=71, 58%) reported exercise-related respiratory symptoms in the year prior to assessment, including cough (n=54, 44%), wheeze (n=29, 24%), chest tightness (n=39, 32%) and difficulty breathing (n=22, 18%). A self-reported history of asthma or EIB was indicated by 39 (32%) athletes, with 23 (19%) currently prescribed treatment (all prescribed short-acting β_2-agonist inhaler therapy, and 14 (61%) prescribed inhaled corticosteroids).

TABLE 1 Athlete characteristics

	Total	RTI-susceptible	Non-RTI-susceptible	p-value RTI-susceptible *versus* non-RTI-susceptible
Subjects	122	88	34	
Age years	24 (21–27)	24 (22–27)	24 (21–26)	0.36
Height cm	176 (170–182)	176 (171–181)	176 (168–183)	0.67
Weight kg	71 (65–767)	71 (65–75)	72 (65–81)	0.49
Male/female	67/55 (55/45)	46/42 (52/48)	21/13 (62/38)	0.46
Ethnicity Caucasian/non-Caucasian	116/6 (95/5)	85/3 (97/3)	31/3 (91/9)	0.44
Athletes reporting respiratory symptoms	71 (58)	54 (61)	17 (50)	0.60
Current diagnosis of asthma/EIB	23 (19)	20 (23)	3 (9)	0.33
Prior diagnosis of hay fever	22 (18)	19 (22)	3 (9)	0.14
Received influenza vaccine#	66 (59)	44 (55)	22 (71)	0.19
Number of RTIs in past 18 months¶	2 (1–4)	3 (2–5)	0 (0–1)	<0.01
Athletes reporting type of RTI				
URTI/cold/flu	130	62	4	<0.01
Chest infection/pneumonia	26	26	0	<0.01
Allergy-related illness	9	9	0	0.12
Asthma-related illness	9	9	0	0.12
Sinusitis	17	15	2	0.19
Breathing problems	4	4	0	0.49
Other	4	2	0	1.00
Reflux	1	1		
Tonsillitis	1	1		

Data are presented as n, median (interquartile range) or n (%), unless otherwise stated. All terminology is presented as described by athletes. Sporting disciplines include summer sports (athletics, boxing, canoeing, cycling, diving, hockey, modern pentathlon, netball, sailing, triathlon) and winter sports (bobsleigh and skeleton). RTI: respiratory tract illness; EIB: exercise-induced bronchoconstriction; URTI: upper respiratory tract infection. #: n=111, as 11 athletes answered "I don't know" (RTI-susceptible n=80, non-RTI-susceptible n=31); ¶: n=109, as 13 athletes answered "I don't know" (RTI-susceptible n=81, non-RTI-susceptible n=28).

As expected, the 88 RTI-susceptible athletes (72% of total cohort) reported a greater occurrence of respiratory illness in the previous 18 months, when compared with non-RTI-susceptible athletes (median (IQR) of 3.0 (2.0–5.0) *versus* 0.0 (0.0–1.0) episodes; p<0.001), with the vast majority of illness episodes reported using terms consistent with an upper respiratory tract infection (table 1, including definition of conditions). Of the susceptible athletes, 35 (40%) reported receiving an antibiotic prescription for a presumed infective RTI, with the number of courses being 1.7±0.8 in the preceding 18-month period. A higher proportion of RTI-susceptible athletes also reported exercise-related breathlessness (p=0.02); however, there was no difference in the prevalence of any other regular respiratory symptoms nor demographic characteristics or vaccination history between the groups.

SARAH outcome: overall

The SARAH assessment identified at least one significant respiratory issue (*i.e.* red/amber, requiring intervention) in 80% of athletes (n=97) and two or more problems in 60% (n=73) (table 2 and figure 2). Almost half of all athletes had evidence of an asthma-related issue (such as a new asthma/EIB diagnosis±heightened airway inflammation), but overall sinonasal problems were most prevalent, detected in 49% (n=60) of athletes. Respiratory issues from gastrointestinal reflux were least frequently reported, but still found in 15% (n=18) of the total cohort. The coexistence of multiple respiratory issues (*i.e.* in the same athlete) was prevalent, with groupings identified between asthma, allergy and sinonasal problems and laryngeal and breathing pattern dysfunction (figure 3).

Overall, respiratory abnormalities were more prevalent in RTI-susceptible athletes, with a higher proportion of allergy, sinonasal problems, laryngeal dysfunction and breathing pattern dysfunction, but not reflux or asthma (table 2). Of these, clinical features indicative of sinonasal problems and laryngeal dysfunction were the most prominent issues in RTI-susceptible athletes, with odds ratios of 2.6 and 5.4, respectively (both p<0.05).

SARAH outcome: specific investigations

Allergy

Allergenic symptoms were reported in 59 (48%) athletes with the majority of athletes reporting symptoms on exposure to grass pollen (57%, n=33) and certain foods (17%, n=10). Of those who underwent skin-prick testing (n=54; n=5 not undertaken due to history of anaphylaxis), 58% (n=31) were atopic with grass sensitivity being the most frequently detected allergen (supplementary table E1). In those who reported a clinical history of hay-fever symptoms and completed skin-prick testing, only 52% (n=11) had confirmatory evidence of grass sensitisation.

Upper airways assessment

60 athletes (49% of total cohort) had sinonasal problems identified, with 27% (n=33) of the total athlete cohort fulfilling criteria for chronic rhinosinusitis, on the SNOT-22 assessment tool (67% mild, 27% moderate, 6% severe). Peak nasal inspiratory flow was found to be impaired in 70 (57%) athletes (56% mild, 40% moderate, 4% severe); however, of these, 39 (56%) athletes did not report any sinonasal issues, and indeed there was no significant relationship between peak nasal inspiratory flow and sinonasal symptom scores.

An abnormal VCDI score was evident in 20 (16%) athletes, and 11% of the total cohort (n=14) had an abnormal Newcastle LHQ score (*i.e.* indicative of laryngeal hypersensitivity), with a positive association

TABLE 2 Proportion of athletes with respiratory abnormalities requiring follow-up

	Total	RTI-susceptible	Non-RTI-susceptible	OR (95% CI)	p-value RTI-susceptible *versus* non-RTI-susceptible
Subjects	122	88	34		
Allergy	42 (34)	35 (40)	7 (21)	2.55 (1.0–6.5)	0.05
Asthma/EIB	56 (46)	45 (51)	11 (32)	2.19 (1.0–5.0)	0.07
Sinonasal problems	60 (49)	49 (56)	11 (32)	2.63 (1.1–6.0)	0.02
Laryngeal dysfunction	41 (34)	37 (42)	4 (12)	5.44 (1.8–16.8)	<0.01
Breathing pattern dysfunction	27 (22)	24 (27)	3 (9)	3.88 (1.1–13.9)	0.04
Airway reflux	18 (15)	12 (14)	6 (18)	0.74 (0.3–2.2)	0.85

Data are presented as n or n (%), unless otherwise stated. RTI: respiratory tract illness; EIB: exercise-induced bronchoconstriction.

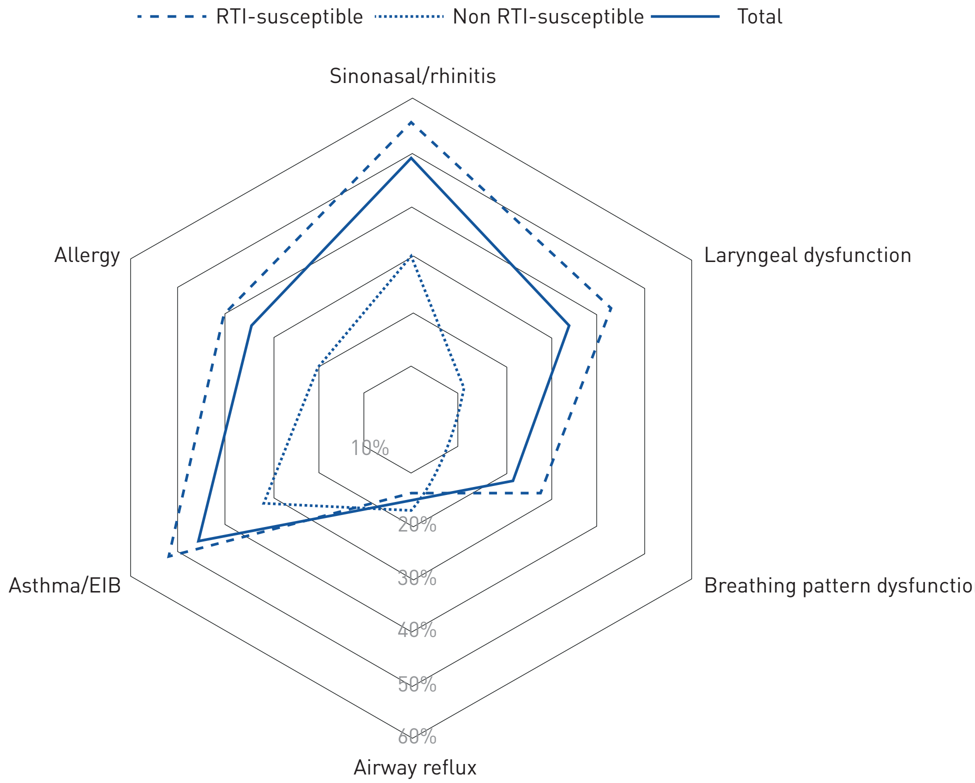

FIGURE 2 Proportion of athletes requiring intervention for an identifiable respiratory condition. RTI: respiratory tract illness; EIB: exercise-induced bronchoconstriction.

found between subjective report of exercise-associated inspiratory wheeze and both the VCDI ($p<0.01$) and LHQ ($p=0.04$).

Lower airways assessment

Nearly all athletes (89%, n=109) had normal resting baseline lung function; however, 22% (n=27) of the total cohort subsequently had a positive EVH test (range −10–−55% fall in forced expiratory volume in 1 s), indicative of underlying EIB. Of these athletes, only six (22%) were currently receiving treatment for asthma or EIB, and half (52%, n=14) had an elevated F_{eNO}, *i.e.* had both heightened airway inflammation and airway hyperresponsiveness. Of the EVH-negative athletes, 12 (15%) were prescribed asthma medication, *i.e.* in the absence of confirmatory findings of asthma.

No differences were observed between RTI-susceptible and non-RTI-susceptible athletes in markers of lower airway dysfunction, *i.e.* baseline lung function, F_{eNO} or EVH test results (table 3).

Treatment recommendations and follow-up

Overall, a further intervention or medical assessment was recommended in 98 (80%) cases. Interventions recommended included topical nasal treatment; initiation, discontinuation or change in asthma therapy; onward referral for chest radiography, allergy or ENT specialist review; or therapy-based assessment for laryngeal or breathing pattern problems (supplementary table E2).

77 (63%) athletes completed a follow-up questionnaire (74%, n=57 RTI-susceptible and 26%, n=20 non-RTI-susceptible). The number of days between athlete assessment to completion of the follow-up questionnaire was 369 (288–431) days. At follow-up, 70 (91%) reported either an improvement or no change in how troubled they were by their respiratory symptoms (median (IQR) baseline 2 (1–4) to follow-up 1 (1–2); 0=not troubled at all; $p<0.01$) and 42% of affected athletes (n=25) no longer reported sinonasal problems.

Discussion

This study systematically identified and characterised respiratory illness factors potentially implicated in RTI susceptibility, in a cohort of elite athletes preparing for Olympic competition. The assessment process, undertaken prospectively in a large cohort of elite athletes, across a broad range of athletic disciplines,

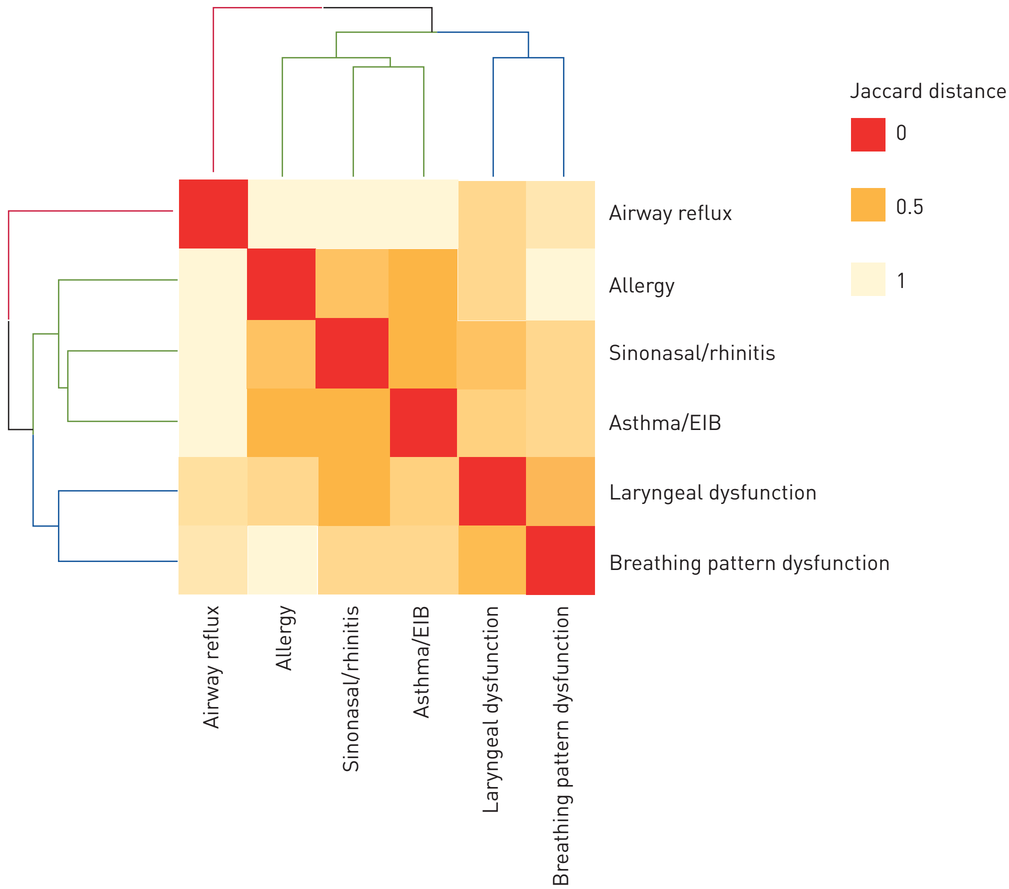

FIGURE 3 Heatmap demonstrating relationship between coexisting respiratory problems in athlete cohort. Colour density reflecting strength of relationship between coexisting respiratory issues, using dissimilarity matrix and Jaccard distance. Hierarchal clustering revealing relationship between 1) asthma, allergy and sinonasal problems; and 2) laryngeal and breathing pattern dysfunction. EIB: exercise-induced bronchoconstriction.

TABLE 3 Airway inflammation, spirometry and eucapnic voluntary hyperpnoea (EVH) results

	Total	RTI-susceptible	Non-RTI-susceptible	p-value RTI-susceptible *versus* non-RTI-susceptible
Subjects	122	88	34	
FEV_1	4.00 (3.54–4.68)	3.95 (3.56–4.54)	4.24 (3.58–4.88)	0.26
FEV_1 % predicted	104 (94–111)	103 (95–110)	106 (95–117)	0.24
FVC	5.01 (4.40–5.73)	5.01 (4.41–5.68)	5.12 (4.33–5.87)	0.80
FVC % predicted	109 (100–116)	110 (101–116)	108 (97–117)	0.76
FEV_1/FVC (%)	82 (76–86)	82 (76–85)	84 (78–88)	0.09
Biggest percentage fall in FEV_1[#]	7 (4–11)	8 (4–12)	7 (4–9)	0.35
F_{eNO} ppb	19 (13–28)	20 (13–30)	18 (14–25)	0.18
F_{eNO} >25 ppb[¶]	40 (33)	32 (36)	8 (24)	0.17
Obstruction at baseline	13 (11)	11 (13)	2 (6)	0.43
Positive EVH	27 (22)	23 (19)	4 (12)	0.12

Data are presented as n, median (interquartile range) or n (%), unless otherwise stated. RTI: respiratory tract illness; FEV_1: forced expiratory volume in 1 s; FVC: forced vital capacity; F_{eNO}: fraction of exhaled nitric oxide. #: for athletes completing EVH (total n=109; RTI-susceptible n=77, non-RTI-susceptible n=32); ¶: for athletes completing F_{eNO} (total n=116; RTI-susceptible n=82, non-RTI-susceptible n=34).

revealed a high prevalence of respiratory dysfunction and interrelated abnormalities. Specifically, 80% of athletes had at least one identifiable respiratory abnormality and the frequency of respiratory issues identified was greater in athletes classified as being susceptible to RTI. These findings provide novel insight into the presence and potential impact of respiratory-specific factors in RTI-susceptible elite athletes and as such highlight a process that could enhance athlete health.

It has been known for some time that the prevalence of both respiratory symptoms and disease is significantly greater in athletes than in the general population [4, 21]. Asthma or at least airway hyperresponsiveness is consistently encountered in approximately a quarter of elite athletes engaged in endurance-based sport [6, 11, 22] and most notably those partaking in winter or aquatic sports, where prevalence rates as high as 70% have been reported previously [7, 23]. More recently there has been increased recognition of the heightened prevalence of other respiratory tract issues in athletes, including sinonasal problems [24] and laryngeal dysfunction [25]. In the current study, we found a similarly high prevalence of respiratory symptoms and asthma-related problems, with one in four of the total cohort having evidence of airway hyperresponsiveness upon formal bronchoprovocation testing, utilising diagnostic methodologies thought to represent the gold-standard approach to asthma diagnosis in competitive athletes [6, 22]. However, the current study now acts to highlight, for the first time, the co-presence of different respiratory problems occurring concurrently within the same athlete. Accordingly, we found that two or more respiratory issues were present in 59% of athletes and a moderate relationship existed between different groups of respiratory problems.

It has been proposed that the heightened prevalence of respiratory dysfunction in athletes could be explained by several factors including the impact of exposure to certain potentially noxious environments [26–29] and impact of airway drying from prolonged periods of hyperpnoea [21, 30]. It is likely that some of these risks or common exposures underpin the heightened prevalence of overlapping and coexisting respiratory tract abnormalities, *e.g.* sinonasal problems and asthma [24], but equally, this may be explained by a commonality in allergic and inflammatory pathways, as has been proposed as part of a "unified airway" hypothesis in the general population [31]. Certainly, we found heightened airway inflammation in a third of athletes and in many cases inadequate prescription of anti-inflammatory airway treatment, *i.e.* only regularly prescribed in 60% of asthmatic cases. Consistent with this notion is the finding from our hierarchal cluster model which revealed a close grouping between asthma, allergy and sinonasal problems in the same athlete and clustering between the non-inflammatory entities of laryngeal and breathing pattern dysfunction. Good control of underlying inflammation in both the upper and lower airway is recognised to be important to minimise risk of exacerbation on exposure to viral pathogens and this is particularly relevant in the current COVID-19 endemic [32].

A key aim of the current study was to not simply report the prevalence of respiratory factors in a cohort of elite athletes, but to now extend our understanding of the importance of these findings by exploring any potential relationship with an athlete's history of exacerbations or frequency of RTI episodes. Accordingly, we characterised the cohort based on their prior history of RTI. The significant and deleterious impact of RTI is highlighted by our finding of a median of almost four significant RTI episodes (*i.e.* leading to time loss in training or competition) over an 18-month period, in those classified as RTI-susceptible. This aligns with more general data from the English Institute of Sport (EIS), indicating that a vast amount of athlete training and preparation time is lost to respiratory illness. Indeed, unpublished data from the EIS obtained from 1300 athletes across 20 Summer Olympic World Class Programmes showed respiratory illness accounted for a total of 10 500 days lost (5% of all injury and illness-related time-loss) between 2016 and 2019, making it the clinical diagnostic category posing the greatest health burden. In addition, it aligns with the broader data from other elite sports settings and specifically from the figures for RTI prevalence at Olympic games [33, 34] and other surveillance data in elite sport [35], indicating high levels of competition disruption from RTI. Moreover, it is alarming that these figures have remained static; thus while advances have been made in understanding and managing risk factors underlying musculoskeletal injury [36], this has not been the case with respiratory health in athletes.

As outlined in the introduction, the reasons underpinning the development of RTI in an athlete are likely to be multifactorial and include factors such as increased infection exposure, but also potential immune vulnerability. Moreover, although clinicians generally attribute an infective aetiology to acute respiratory-type symptoms, this supposition has been challenged, not least by a consistent failure to isolate infective pathogens in studies evaluating this area [37].

In our cohort, the vast majority of RTIs were described and recorded as being indicative of acute infections, with terms used such as "a cold" or "URTI", and athletes were administered antibiotics frequently for these episodes. Therefore, it is of note that we found increased odds of underlying sinonasal or laryngeal problems in RTI-susceptible athletes and that our findings thus highlight the possibility that targeted preventative intervention in this context may act to reduce or improve susceptibility. A systematic approach applied in the context of general (non-athlete) asthma assessment has been shown to improve exacerbation frequency, and thus similar findings may be evident in elite athlete care. However, the nature of the current study design (*i.e.* observational) does not allow any further conclusive statements to be made and a randomised controlled design would be needed to describe the true impact of SARAH assessment on RTI susceptibility. Moreover, any consideration to undertake a screening programme in this context would need to address the other key components of such a process (*e.g.* overall cost–benefit analysis, availability, *etc.*). It is encouraging that athletes who completed a follow-up questionnaire reported a general improvement in respiratory symptoms and specifically their sinonasal problems. In addition, the SARAH process was relatively simple to deliver, took ∼75 min to undertake and ensured robust diagnoses were established or refuted, allowing unnecessary medication to be withdrawn.

Methodological considerations

There are several methodological issues in need of consideration. In order to obtain a broad sample of athletes, we encouraged sports teams to send us both susceptible and non-susceptible athletes. However, in the overall cohort there was a greater proportion of RTI-susceptible athletes and this may potentially be explained by a desire for clinicians to investigate any factors that may underpin respiratory illness in their athletes. Therefore, it is possible that the increased prevalence of respiratory issues is at least partially explained by some bias in referral pattern. Moreover, the overall number of athletes recruited only represents a fraction of the total athlete pool within the UK Sport-funded Olympic World Class Programme. We did not aim to recruit the entire cohort, but accept that it is possible that a sampling bias could be relevant in amplifying the prevalence findings. Regardless, the significant frequency of respiratory problems in nonsusceptible athletes underpins the impact of respiratory illness across the broader elite athlete performance system.

The current study included athletes competing at the elite level only, participating in a broad range of sporting disciplines and while we did not identify any relevant patterns based on simple athlete demographics (*e.g.* sex), the study was not designed nor powered to assess differences between certain sports. In this respect, it would be informative for future studies to evaluate and compare the impact of different levels of sporting ability (*e.g.* elite *versus* non-elite) and disciplines (*e.g.* aquatic *versus* non-aquatic) on respiratory comorbidities and RTI susceptibility. Indeed, some prior studies indicate that "super-elite" athletes (*i.e.* those ranked near the top in their discipline) appear to have a reduced prevalence of RTI [2].

In order to characterise the population and outcomes, we had to pre-define RTI susceptibility; the definition utilised may not entirely align with other studies and may be considered arbitrary. We selected the cut-point used as seemingly relevant to athlete care and being impactful of performance. This was based on discussion with sports medicine experts within the UK Olympic sports medicine community; commenting that illness events that caused the loss of almost a week of training time within a major competition preparation cycle was relevant in terms of impact on athletic preparation. Likewise, our primary outcome was based on a respiratory issue requiring some form of intervention and based on respiratory specialist's review of the data. This approach was based on a pragmatic approach and although it would have been ideal to have a face-to-face consultation with the physician, this is unrealistic in large performance systems and all such systems are mindful of the time loss to any nonsporting-related activity. Certainly, the feedback provided to sports clinicians by the reporting system was designed to be entered directly into the athlete online medical record and thus be immediately accessible to the athlete's medical team.

Conclusion

This study provides evidence that a systematic approach to the evaluation of the respiratory issues in elite athletes can reveal a high percentage of potentially modifiable illness factors that may ultimately act to enhance an athlete's health. The SARAH process we describe is feasible and deliverable within a cohort or team performance structure and ensures robust diagnosis. Further work is now needed to determine whether the systematic and widespread application of this approach to athlete care is associated with a sustained improvement in RTI susceptibility and thus overall training time availability.

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