The Journal of Laryngology & Otology (2018), ***132***, *191–197*.

doi:10.1017/S0022215118000026

REVIEW ARTICLE

Nasal changes associated with exercise in athletes: systematic review

P SURDA[1], A WALKER[2], J LIMPENS[3], W FOKKENS[1], M PUTALA[4]

[1]Department of Otorhinolaryngology, and, [3]Medical Library, Academic Medical Center, Amsterdam, The Netherlands, [2]Department of Otorhinolaryngology, St George's University Hospital, London, UK, and [4]Department of Physical Education and Sports, Comenius University, Bratislava, Slovakia

Abstract

Background: The prevalence of rhinitis in athletes has frequently been studied in combination with asthma, but the impact of exercise on the paracrine and secretory functions of nasal mucosa is less well established. This systematic review aimed to examine the effect of exercise on nasal mucosa in elite athletes.

Method: A systematic search of Medline, Embase and the non-Medline subset of PubMed, from inception to 8th March 2016, was performed to identify studies on rhinitis in athletes.

Results: Of the 373 identified unique articles, a total of 8 studies satisfied the criteria for this review.

Conclusion: There is no evidence in the existing literature that indicates a reduction in nasal airway induced by exercise. Olfaction and mucociliary transport time are affected in swimmers, which can likely be attributed to chlorine irritation and which resolves with training cessation. Short-term strenuous exercise may trigger changes in cytology and prolonged mucociliary transport time, which also resolve quickly with rest.

Key words: Athletes; Rhinitis; Swimming; Allergy

Introduction

Rhinitis in athletes has frequently been studied in combination with asthma. Reported prevalence varies widely, ranging from 27 to 74 per cent.[1–3] The impact of exercise on the paracrine and secretory functions of nasal mucosa is less well established. Moreover, repeated exposure to allergens and irritants such as those encountered in the exercise environment may cause changes leading to mucosal damage. The phenomenon of exercise-induced rhinorrhoea – 'runner's nose' – was described in 1979.[4] Nearly 20 years elapsed before the technology was available to accurately analyse nasal secretions, and, by proxy, the secretory function of nasal mucosa.

The aetiology and nature of the nasal changes induced by exercise depends on several factors. The acute effects of exercise on the nose have been well delineated: vasoconstriction of the capacitance vessels results in a measurable increase in nasal volume.[5] In aerobic exercise, nasal minute ventilation increases absolutely, but proportionately contributes less than at rest, as the low resistance oral airway is used preferentially.[6] Many of the environments and endeavours in which athletes are immersed can potentially harm nasal mucosa. For example, an exercise that takes place in cold air (skiers, snowboarders, ice hockey) or in chlorinated water (swimmers, divers, water polo) subjects the nasal mucosa to local irritants. Aerobic exercise that takes place outdoors may result in inhalation of above-average volumes of aeroallergens, nitrous oxide or pollution because of the increased minute ventilation required to sustain activity.[7–9]

The induction of nasal symptoms in swimmers is also determined by age and the hours spent in a swimming pool. When swimming up to 30 hours per week, swimmers inhale a large amount of air floating just above the water that is disinfected with either chlorine gas or hypochlorite liquid, and therefore elite athletes may be more affected than others.[10] However, there is a lack of evidence directly comparing the elite athlete to the recreational counterpart. As stated previously, age may be crucial factor, and children are more susceptible to chronic changes: a Belgian schoolchildren study showed that early swimming in chlorinated pools can cause permanent alterations of lower airway epithelium, predisposing them to allergic diseases.[10]

This systematic review aimed to examine the effect of exercise on the nasal mucosa in elite athletes.

Accepted for publication 1 October 2017 First published online 18 January 2018

Materials and methods

We sought to investigate nasal changes associated with exercise in athletes. The inclusion criteria were: studies that evaluated human participants aged at least 12 years, presented in articles that included an abstract, and which were published in the English language between January 1980 and October 2015. We defined an elite athlete as a person who trains more than 6 hours per week. We classified sports into three categories which represent their different environments: land, water and cold air.

Our review followed the Preferred Reporting Items for Systematic Reviews and Meta-Analysis ('PRISMA') guidelines for reporting. A medical information specialist (JL) performed a systematic search of Medline (Ovid), Embase (Ovid) and the non-Medline subset of PubMed, from inception to 8th March 2016, to identify studies on rhinitis in athletes. Both controlled vocabulary (including Medical Subject Heading terms) and words in titles, abstracts and author keywords were searched. We excluded studies indexed with animals, but not indexed with humans, conference abstracts and case reports, and studies with 'trauma' or 'concussion' in the title. The search consisted of two concepts: athletes (including all kinds of athletic sports, swimming and high-intensity training) and rhinitis (including synonyms for rhinitis, symptoms, underlying mechanisms of rhinitis and tests for rhinitis). We cross-checked the reference lists and the citing articles of the identified relevant papers, and adapted the search in case of additional relevant studies. The bibliographic records retrieved were imported and de-duplicated using Endnote. The entire Medline search is shown in Appendix 1.

Studies meeting the inclusion criteria were assessed in terms of quality using the Preferred Reporting Items for Systematic Reviews and Meta-Analysis and the Assessing the Methodological Quality of Systematic Reviews ('AMSTAR') checklist as guidelines. The studies that did not discuss the subject of interest were excluded. No minimum was set on the number of study participants.

Data collection

All abstracts and full-text articles were reviewed by two researchers (PS and AW); only case–control and cohort study designs were included (case reports, case series, other non-cohort study designs and non-systematic reviews were excluded).

Information obtained from each article included authors, year of publication, number of participants, number of participants per category (land, water, cold air), study design, outcomes and nasal changes associated with exercise in athletes. For each study, the following variables were recorded: changes in objective airway measurements, changes in smell and/or mucociliary clearance, and mucosal changes. Findings were tabulated and descriptively analysed, listing outcomes measured.

Results

A systematic review of titles, abstracts and full-text publications was performed, as described in Figure 1. Of the 373 identified unique articles, a total of 8 studies satisfied the criteria for this review.[1,11–17] The characteristics are described in Tables I–III. Demographic details and efforts to control confounding variables were incompletely reported. Three cohort and five case–control studies were included. The final group contained six studies examining changes in objective airway measurements, three that evaluated changes in smell and mucociliary clearance, and five that investigated mucosal changes.

In the eight studies included in this review, changes in objective measurements were reported in: mucociliary transport time, peak nasal inspiratory flowmetry, acoustic rhinometry, nasal cytology and ciliary beat frequency (Tables I–III). Several authors studied the objective changes in nasal patency assessed by peak nasal inspiratory flowmetry. There was no statistical difference in measurements before and after the exercise, or in comparison with healthy controls.[1,11–13] However, acoustic rhinometry showed a decreased cross-sectional area in one study in response to acute exercise in skiers, compared to swimmers, runners and boxers.[14] Unfortunately, that study did not include a healthy control group for comparison.

Mucociliary clearance was judged by three articles as impaired, based on mucociliary transport time, with normalisation to baseline over several days after the race.[13,15,18]

Two studies found increased neutrophil levels after exercise in swimmers and runners.[16,17] Furthermore, Muns also reported that the capacity of phagocytes to ingest *Escherichia coli* was significantly suppressed immediately after the race.[17] These findings seem to be reversible. The cellular changes in swimmers described by Gelardi *et al*. improved 1 month after the use of a nose clip, and the acute post-race changes in runners (neutrophil count and phagocytic activity) normalised 3 days after the running race.[16]

Two studies examined changes in nasal nitric oxide in swimmers before and after exercise.[11,12] The measurements showed no significant difference.

Discussion

This is the first systematic review to explore the effect of rhinitis on the nasal airway.

Main results summary

This systematic review of the literature identified eight studies that fulfilled the inclusion criteria. Nasal mucosa changes triggered by sport activity can be reflected in predominant neutrophilic infiltration, with reduced phagocytic activity, deterioration of olfaction, reduced ciliary beat frequency and prolonged mucociliary transport time.[13,14,16,17] These changes can be chronic or acutely related to a strenuous training

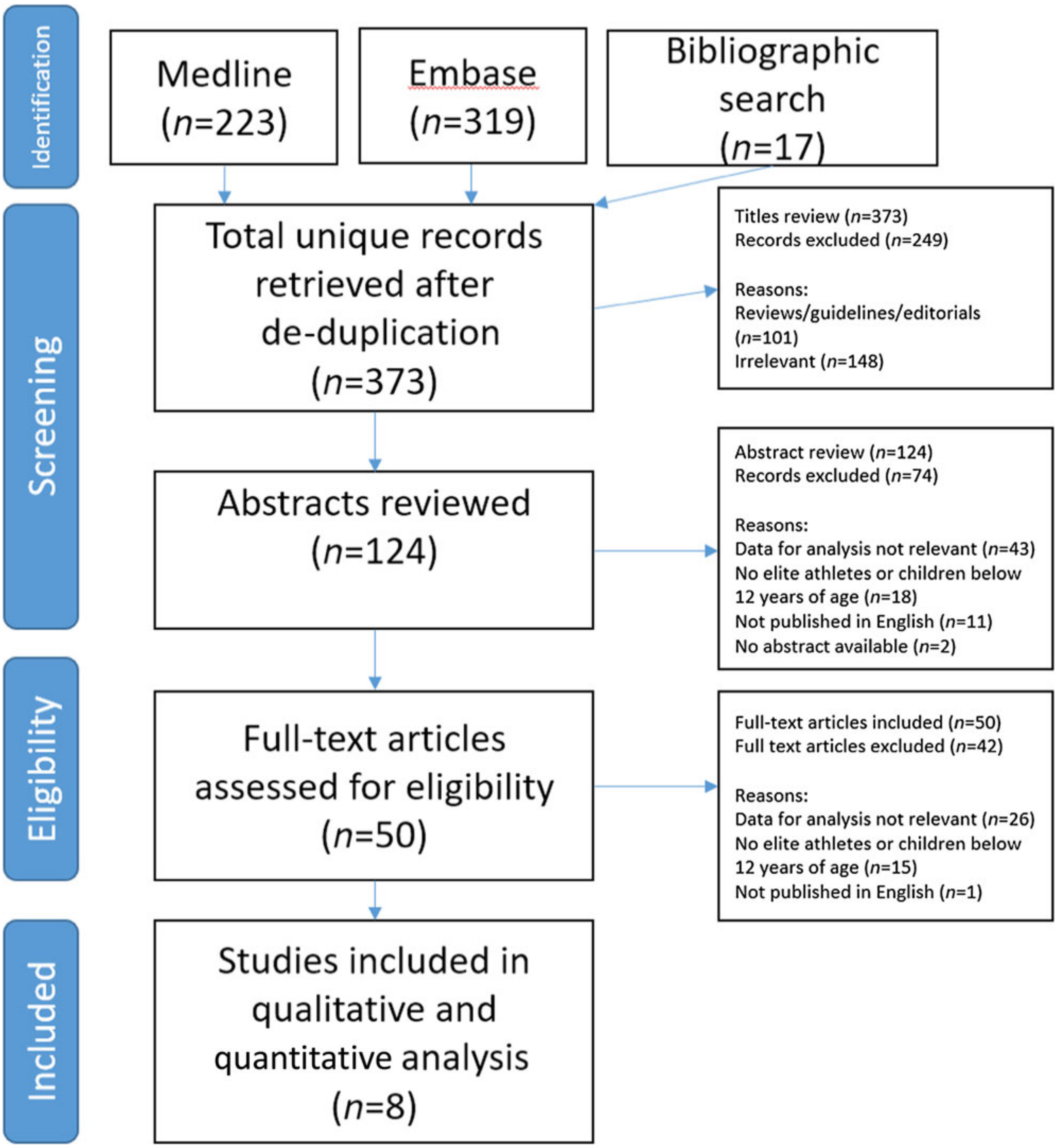

FIG. 1
Flow chart of data extraction and analysis.

exercise, and depend on the different sport activity and environment.

Mucociliary transport time was found to be prolonged in swimmers, which can be attributed to chlorine irritation.[13,14] Deterioration of mucociliary transport and reduced ciliary beat frequency can also be observed in runners after a 20 km race. Nasal lavage examination findings obtained immediately after a competition showed an increased number of neutrophils with reduced phagocytic activity.[15,17]

Acute nasal mucosa changes induced by strenuous exercise in runners recovered to the baseline level within 3 days after the competition. In elite swimmers, a decrease in neutrophilic infiltration and improvement of clinical symptoms were described after 2 weeks of training cessation or 30 days after the use of a nasal clip.[16]

Several authors studied changes in nasal patency using peak nasal inspiratory flowmetry before and after exercise. Interestingly, there was no significant difference observed.[11–13,16]

Quality of evidence

The overall quality of evidence in the papers investigating nasal changes associated with exercise was low to

https://doi.org/10.1017/S0022215118000026 Published online by Cambridge University Press

TABLE I
OBJECTIVE AIRWAY MEASUREMENT CHANGES

Study (year)	Study design	Participants (*n*)	Measurement time	Objective airway measurement changes
Passali *et al.*[14] (2004)	Case–control	106 land, water & cold air + boxers	Not specified	Acoustic rhinometry showed highest nasal resistance in skiers, followed by boxers
Bougault *et al.*[1] (2010)	Case–control	39 water + 30 controls	At least 12 h after last training session during intense period in winter or autumn	No significant difference in PNIF when compared to healthy controls
Alves *et al.*[12] (2010)	Case–control	32 land & water	Before & 5–10 min after training session	Significant improvement in PNIF after exercise in runners; in swimmers, PNIF non-significantly decreased
Clearie *et al.*[11] (2010)	Cohort	61 water	Before, immediately after, & 4–6 h after swimming exercise	No significant changes in PNIF described
Gelardi *et al.*[16] (2012)	Case–control	54 symptomatic swimmers + 20 controls	Immediately after exercise & following 1 month of nasal clip use during swimming	No difference in PNIF of symptomatic swimmers after exercise when compared to non-symptomatic swimmers
Ottaviano *et al.*[13] (2012)	Cohort	15 water + 15 controls	Swimmers & controls evaluated 2.8 ± 2.4 & 2.2 ± 1.7 days after last training session, respectively	No difference in PNIF after exercise when compared to non-swimming controls

H = hours; PNIF = peak nasal inspiratory flowmetry; min = minutes

moderate. The main reason why the screened articles did not meet the inclusion criteria was poor reporting of methods, such as unclear participant age and numbers of training hours per week.

Limitations

One of the major aims of the review was to distinguish between the physiological and pathological responses to exercise. Confounding was reduced in five studies that included a healthy control group. All studies were limited to a relatively small sample size.

Comparison with other reviews

No specific review articles of nasal changes associated with exercise in athletes were identified (in the peer-reviewed journals). Many of the available reviews were part of a case–control or cohort study. Methodology and search strategy were often not discussed.

Implications for clinical practice

The magnitude of rhinitis and associated nasal changes in athletes may be greater than it seems. The number of registered swimmers, who seem to be the most affected, exceeds 100 000 in Australia,[19] and the USA Swimming national governing body counts 404 448 members.[20] The observed cytology changes in swimmers and runners may impair the defence barrier of the upper respiratory tract and contribute to the increased susceptibility to upper respiratory tract infection.[17]

This review demonstrated that most of the nasal changes return to a baseline level after a few weeks of training cessation. However, there is emerging evidence that chronic exposure, as seen in swimmers, can cause permanent alterations of lower airway epithelium, predisposing the individuals to asthma and allergic diseases.[10] The presence of rhinitic symptoms in elite athletes is common. A lack of

TABLE II
SMELL AND MUCOCILIARY CLEARANCE CHANGES

Study (year)	Study design	Participants (*n*)	Measurement time	Smell & mucociliary clearance changes
Muns *et al.*[15] (1995)	Cohort	12 land	Daily for 1 week before & 1 week after race	Mucociliary transport time significantly prolonged post-race & returned to baseline over several days (saccharin sodium/indigo carmine method). Ciliary beat frequency significantly reduced only in first 24 h after race
Passali *et al.*[14] (2004)	Case–control	106 land, water & cold air + boxers	Not specified	Mucociliary transport time longest in swimmers, followed by skiers, runners & boxers
Ottaviano *et al.*[13] (2012)	Cohort	15 water + 15 controls	Swimmers & controls evaluated 2.8 ± 2.4 & 2.2 ± 1.7 days after last training session, respectively	Mucociliary transport time significantly shorter for non-swimmers than swimmers. Mean olfactory threshold for n-Butanol in swimmers significantly lower than in other athlete groups

H = hours

https://doi.org/10.1017/S0022215118000026 Published online by Cambridge University Press

TABLE III
MUCOSAL CHANGES

Study (year)	Study design	Participants (*n*)	Measurement time	Mucosal changes
Muns[17] (1994)	Case–control	12 land + 10 cold air	Daily for 1 week before & 1 week after race	Significant increase in number of neutrophils in nasal lavage immediately after 20 km run. Capacity of phagocytes to ingest *E coli* significantly suppressed immediately after race. Both parameters improved to normal levels by 3 days post-race
Clearie *et al.*[11] (2010)	Cohort	61 water	Before, immediately after, & 4–6 h after swimming exercise	No significant changes in NO described
Alves *et al.*[12] (2010)	Case–control	32 land & water	Before & 5–10 min after training session	No changes in NO described
Gelardi *et al.*[16] (2012)	Case–control	54 symptomatic swimmers + 20 controls	Immediately after exercise & following 1 month of nasal clip use during swimming	In symptomatic group, 19 (35%) swimmers had predominant neutrophilic inflammation. Inflammation & clinical symptoms reduced after 2 weeks of training cessation or after 30 days use of nasal clip
Ottaviano *et al.*[13] (2012)	Cohort	15 water + 15 controls	Swimmers & controls evaluated 2.8 ± 2.4 & 2.2 ± 1.7 days after last training session, respectively	Cytological study on nasal mucus showed that total number of ciliated cells did not differ statistically between swimmers & other athletes. Collection technique consisted of scrapings from middle portion of inferior turbinate

H = hours; NO = nitric oxide; min = minutes

recognition may lead to under-treatment of this condition.

Implications for research

All articles examining the changes in objective airway measurements occurring shortly after a training session showed no improvement. This finding might be biased by a physiological improvement of the nasal efficiency during exercise because of an increase in nasal sympathetic tone, causing constriction of nasal blood vessels through α-adrenergic receptor stimulation. However, repeated exposure to allergens and irritants, such as those encountered in the exercise environment, may cause changes, leading to mucosal damage and subsequently to mucosal oedema. Therefore, future research is needed to objectively evaluate a reduction in the nasal airway in the evening or during daytime activities.[16,21]

Furthermore, there is a well-described negative impact of rhinitis on quality of life in the general population, which in athletes might affect training and performance. This systematic search suggests that studies examining the association between rhinitis, performance and quality of life are lacking.

Conclusion

There is no evidence in the existing literature to indicate a reduction in nasal airway induced by exercise. Olfaction and mucociliary transport time are affected in swimmers, which are likely to be associated with chlorine irritation, and which resolve with cessation of the training. Short-term strenuous exercise may trigger changes in cytology and prolonged mucociliary transport time, which also resolves quickly with rest. For the purposes of future research, it is important to reliably differentiate between physiological changes in the nasal airway during exercise and abnormal changes induced by the sporting event or environment.

References

1 Bougault V, Turmel J, Boulet LP. Effect of intense swimming training on rhinitis in high-level competitive swimmers. *Clin Exp Allergy* 2010;**40**:1238–46
2 Kurowski M, Jurczyk J, Krysztofiak H, Kowalski ML. Exercise-induced respiratory symptoms and allergy in elite athletes: Allergy and Asthma in Polish Olympic Athletes (A(2)POLO) project within GA(2)LEN initiative. *Clin Respir J* 2016;**10**:231–8
3 Surda P, Walker A, Putala M, Siarnik P. Prevalence of rhinitis in athletes: systematic review. *Int J Otolaryngol* 2017;**2017**:8098426
4 Saketkhoo K, Kaplan I, Sackner MA. Effect of exercise on nasal mucous velocity and nasal airflow resistance in normal subjects. *J Appl Physiol* 1979;**46**:369–71
5 Dallimore NS, Eccles R. Changes in human nasal resistance associated with exercise, hyperventilation and rebreathing. *Acta Otolaryngol* 1977;**84**:416–21
6 Niinimaa V, Cole P, Mintz S, Shephard RJ. The switching point from nasal to oronasal breathing. *Respir Physiol* 1980;**42**:61–71
7 Bonini S, Bonini M, Bousquet J, Brusasco V, Canonica GW, Carlsen KH *et al*. Rhinitis and asthma in athletes: an ARIA document in collaboration with GA2LEN. *Allergy* 2006;**61**:681–92
8 Walker A, Surda P, Rossiter M, Little S. Nasal function and dysfunction in exercise. *J Laryngol Otol* 2016;**130**:431–4
9 Walker A, Surda P, Rossiter M, Little S. Rhinitis in elite and non-elite field hockey players. *Int J Sports Med* 2017;**38**:65–70

https://doi.org/10.1017/S0022215118000026 Published online by Cambridge University Press

10 Bernard A, Nickmilder M, Voisin C, Sardella A. Impact of chlorinated swimming pool attendance on the respiratory health of adolescents. *Pediatrics* 2009;**124**:1110–18
11 Clearie KL, Williamson PA, Vaidyanathan S, Short P, Goudie A, Burns P *et al*. Disconnect between standardized field-based testing and mannitol challenge in Scottish elite swimmers. *Clin Exp Allergy* 2010;**40**:731–7
12 Alves A, Martins C, Delgado L, Fonseca J, Moreira A. Exercise-induced rhinitis in competitive swimmers. *Am J Rhinol Allergy* 2010;**24**:e114–17
13 Ottaviano G, Staffieri A, Stritoni P, Ermolao A, Coles S, Zaccaria M *et al*. Nasal dysfunction induced by chlorinate water in competitive swimmers. *Rhinology* 2012;**50**:294–8
14 Passali D, Damiani V, Passali GC, Passali FM, Bellussi L. Alterations in rhinosinusal homeostasis in a sportive population: our experience with 106 athletes. *Eur Arch Otorhinolaryngol* 2004;**261**:502–6
15 Muns G, Singer P, Wolf F, Rubinstein I. Impaired nasal mucociliary clearance in long-distance runners. *Int J Sports Med* 1995;**16**:209–13
16 Gelardi M, Ventura MT, Fiorella R, Fiorella ML, Russo C, Candreva T *et al*. Allergic and non-allergic rhinitis in swimmers: clinical and cytological aspects. *Br J Sports Med* 2012;**46**:54–8
17 Muns G. Effect of long-distance running on polymorphonuclear neutrophil phagocytic function of the upper airways. *Int J Sports Med* 1994;**15**:96–9
18 Passali D. Does the nasal dilator help in sports activity? *Allergy* 1997;**52**:2
19 Swimming Australia. In: https://en.wikipedia.org/wiki/Swimming_Australia [18 December 2017]
20 USA Swimming. In: http://www.usaswimming.org/ [18 December 2017]
21 Bernard A, Nickmilder M, Dumont X. Chlorinated pool attendance, airway epithelium defects and the risks of allergic diseases in adolescents: interrelationships revealed by circulating biomarkers. *Environ Res* 2015;**140**:119–26

Address for correspondence:
Dr Pavol Surda,
KNO afdeling, A2-224,
AMC Ziekenhuis,
Meibergdreef 9,
1105 AZ Amsterdam, Netherlands

E-mail: pavol.surda@gmail.com

Dr P Surda takes responsibility for the integrity of the content of the paper
Competing interests: None declared

APPENDIX 1.
ENTIRE MEDLINE SEARCH

#	Searches	Results
1	athletes/ or athletic injuries/	26 906
2	sports medicine/	9699
3	sports/ or athletic performance/ or physical endurance/ or baseball/ or basketball/ or bicycling/ or boxing/ or football/ or golf/ or gymnastics/ or hockey/ or mountaineering/ or exp racquet sports/ or running/ or skating/ or exp snow sports/ or soccer/ or volleyball/ or weight lifting/ or wrestling/	83 326
4	Physical Exertion/im or Physical Exertion/ph	10 254
5	(athlet* or sport* or Olympic* or preolympi* or postolymp* or Paralymp* or field run* or sprint* or triathl* or biathl* or pentathlon or heptathlon or decathlon or marathon* or ultramarathon* or bicycling or cyclist* or mountaineer* or mountain bik* or ((high altitude or mountain*) adj3 climb*) or climber* or skiing or skier* or ski or skating or skater* or skateboarding or skateboarder* or rowing or rower* or (water adj3 polo*) or watersport* or football* or soccer or rugby* or baseball* or softball* or basketball* or volleyball* or racquet sport* or (hockey* not (hockey-stick* adj3 cilia)) or tennis* or (golf not g-protein*) or golfer* or boxing or kickbox* or (boxer* not (dog or dogs)) or weight lift* or wrestling or wrestler* or judo* or fencing or fencer* or "track and field" or ballet* or cross-country).tw,kf.	108 308
6	(AQUA adj6 questionnair*).tw,kf.	4
7	swimmer*.tw,kf. or (swimming.mp. and (competit* or race or contest* or match or matches or amateur* or professional* or train* or exercis*).tw,kf.)	8514
8	((high intens* or intense or stren?ous* or exhaustiv* or distanc* or endurance or prolonged or competit* or race or contest* or match or matches or amateur* or top or elite or outdoor or indoor) adj4 (running or runner* or train* or exercis* or work-out* or workout*)).tw,kf.	30 141
9	exercise-induced rhinit*.tw,kf.	4
10	or/1–9 [ATHLETES]	174 249
11	exp rhinitis/	28 854
12	rhinit*.tw,kf.	22 287
13	(nasal adj3 catarrh*).tw,kf.	82
14	((postnas* or post-nas*) adj2 drip*).tw,kf.	506
15	(hay fever or pollen allerg*).tw,kf.	6414
16	(rhinoconjunctivit* or rhino-conjuct* or AR-C or SAR-C or RQLQ*).tw,kf.	2195
17	(rhinosinusit* or rhino-sinusit*).tw,kf.	5774
18	(nasal adj2 (symptom* or allerg*)).tw,kf.	5040
19	((nasal or ENT) adj2 (function* or d?sfunct*)).tw,kf.	954
20	(rhinorrhoe* or athlete's nose or runny nose).tw,kf.	1194
21	(sino-nasal outcom* or SNOT* or MSNOT* or MSYPQ*).tw,kf.	476
22	Rhinomanometry/	531
23	mucociliary clearance/	2168
24	Sensory Thresholds/ and (smell or olfact*).mp.	1204
25	(rheolog* and (nose or nasal or rhin*)).mp.	299
26	(rhino-manomet* or rhinomanomet* or rhinosphygmomanometr* or rhinometr*).tw,kf.	2240
27	((nasal adj3 inspiratory adj3 (flow or airflow or flowmetr*)) or PNIF).tw,kf.	409
28	((mucociliar* or muco-ciliar* or ciliated) adj3 (transit or clearanc* or transport* or activity or function* or d?sfunction* or viab*)).tw,kf.	3547
29	(cilia adj3 (beat freq* or motility or immotil* or immobil* or loss* or loosing or disappear*)).tw,kf.	993
30	(MCTt or MMCC or NMCC or NMTT).tw,kf. and (nasal or nose or rhin*).mp.	20

31	(polymorphonuclear* or neutrophil* or PMN or PMNs or eosinophil* or phagocyt* or lymphocyt* or cytolog* or cytokin* or inflammator*).tw,kf. and (nasal or nose or NAL).mp.	11 819
32	(Nitric Oxide/ or (nitric oxid* or Fe-NO or N-NO).tw.) and (nose* or rhin* or nasal or NAL).mp.	1349
33	(?edem* adj3 epithel*).tw,kf. and (nose* or rhin* or nasal).mp.	19
34	(olfactory adj3 (scor* or threshold* or function* or d?sfunct* or mucos*)).tw,kf.	4424
35	sniffin* stick*.tw,kf.	399
36	exp Nasal Mucosa/an, cy, im, in, pa, ph, pp, se [Analysis, Cytology, Immunology, Injuries, Pathology, Physiology, Physiopathology, Secretion]	13 081
37	or/11–36 [RHINITIS]	71 774
38	10 and 37 [ATHLETES & RHINITIS]	249
39	(exp animals/ not humans/) or (exp Models, Animal/ or exp Animal Diseases/ or exp equidae/ or exp rodentia/ or exp amphibians/ or exp fishes/ or (buzzard or fish or fishes or guitarfish* or shark* or amphibian* or salamander* or frog* or urodela or mice or mouse or murine or hamster or guinea-pig*or rat or rats or sprague or wistar or horse or horses).ti.)	499 2998
40	(concussion* or concussed or trauma* or accident or accidents or fractur*).ti.	251 137
41	39 or 40 [EXCLUSION animals and trauma in title]	522 7908
42	38 not 41 [ATHLETES & RHINITIS FINAL SEARCH MEDLINE]	223

https://doi.org/10.1017/S0022215118000026 Published online by Cambridge University Press