Tampere University

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To Finnish cross-country skiing

ABSTRACT

Competitive cross-country skiers, due to their exposure to extreme cold conditions during training and competition, are subjected to significant strain on their airways. This unique situation leads to a high prevalence of asthma among with a possible impact on their performance. The prominence of acute respiratory infections (ARinf), which hinders their ability to train and compete, is another significant concern for these athletes.

The aim of this thesis was to compare the differences in the prevalence of asthma, use of asthma medication, onset age of asthma and asthma control in Finnish cross-country skiers compared to controls and to study the types of respiratory symptoms and prolonged cough in cross-country skiers and controls. In cross-country skiers only, the burden of acute illness or respiratory tract infection in asthmatic and non-asthmatic skiers on competition success and possible effects of asthma on days of absence from training and competition were studied.

To investigate these issues, a postal survey was conducted involving competitive Finnish cross-country skiers (n = 1282) who participated in the national championships in their respective age category from 13 years to seniors in the season 2018/2019. The control group (n= 1754) was matched in terms of age, gender, and region. The total response rate in the current study was 27.4% (n = 351) in skiers and 19.5% (n = 338) in controls. In skiers and controls, the median age was 16.5 vs. 17.0 years (interquartile range 14.3–21.5 vs. 15–22.5) and 58.1% vs. 69.5% were women.A higher prevalence of asthma was found among skiers (25.9%) compared to the controls (9.2%), with the median age of the first asthma-related symptoms being higher in skiers (13.0 years) than controls (8.0 years). The Asthma Control Test (ACT) score median was 22.0 in both groups, but skiers had better asthma control with 89.0% achieving well-controlled asthma (ACT score ≥20), compared to 77.4% of controls. Among the skiers with asthma, 82.4% used regular inhaled corticosteroids (ICS), and 80.2% used bronchodilators. A fixed combination of ICS and long-acting β2-agonist was regularly used by 47.3% of the skiers and 22.6% of the controls with asthma.

In the most successful quartile of skiers, the prevalence of asthma was the highest (56.1%) in. Asthma in skiers was more often non-allergic (60.1%) compared to the

controls (38.7%). Being a skier showed a higher risk for non-allergic asthma (OR 5.05, 95% CI 2.65 to 9.61) than allergic asthma (OR 1.92, 1.08–3.42). High training volume was a significant risk factor for non-allergic asthma in skiers.

In terms of exercise-related symptoms, skiers showed a higher prevalence of cough after exercise (60.6% vs. 22.8% in controls) and phlegm production during and after exercise. Symptoms provoked by exercise were similar in asthmatics and non-asthmatics, but symptom prevalence was higher in asthmatic individuals. Chronic cough lasting more than eight weeks was rare, reported by only 4.8% of controls and 2.0% of skiers.

A larger proportion of asthmatic skiers (76.9%) than non-asthmatic skiers (62.2%) had to refrain from competitions due to ARinf. The median duration of a single ARinf episode was longer for asthmatic skiers (5.0 days) compared to non-asthmatics (4.0 days), leading to more days of absence due to ARinf throughout the season (median 15 days vs. 10 days).

Competitive cross-country skiers, especially the most successful ones, demonstrate a high prevalence of non-allergic, well-controlled asthma. Skiers also experience a greater burden of exercise-related respiratory symptoms and a more significant impact of acute respiratory infections, leading to training and competition absences. These findings underscore the importance of effective asthma management and ARinf reduction strategies in this specific athlete population. Although skiers have a high prevalence of asthma and high prevalence of respiratory symptoms, it seems it does not prevent a successful and triumphant athletic career.

TIIVISTELMÄ

Maastohiihto on olympialaji, jossa hiihtäjät altistuvat harjoituksissa ja kilpailuissa vaativille olosuhteille. Kylmä ja kuiva ilma rasittavat merkittävästi heidän hengitysteitään. Tämä mahdollisesti johtaa astmaan ja siihen liittyvien oireiden korkeaan esiintyvyyteen hiihtäjillä ja se saattaa vaikuttaa suorituskykyyn. Akuutit hengitystieinfektiot ovat myös yksi yleisimmistä syistä harjoitteluista ja kilpailuista poisjäämiseen.

Tämän väitöskirjan tarkoituksena oli vertailla eroja astman esiintyvyydessä, astmalääkkeiden käytössä, astman alkamisiässä ja astman hallinnassa suomalaisilla kilpahiihtäjillä verrattuna samanikäisiin verrokkeihin sekä tutkia erilaisia hengitysoireita ja pitkittynyttä yskää. Hiihtäjillä tutkittiin myös akuutin sairauden tai hengitystieinfektion vaikutusta kilpailumenestykseen sekä mahdollisia astman vaikutuksia harjoittelu- ja kilpailupäivien poissaoloihin.

Tutkimus toteutettiin postikyselynä, johon kutsuttiin 1282 ikäluokkansa suurimpaan mestaruuskilpailuun ilmoittautunutta maastohiihtäjää 2018–2019. Verrokkiryhmä (n = 1754) kutsuttiin tutkimukseen iän, sukupuolen ja kotiseudun mukaan kaltaistettuna. Vastausprosentti tutkimuksessa oli 27,4 % (n = 351) hiihtäjillä ja 19,5 % (n = 338) verrokeilla. Mediaani-ikä hiihtäjillä ja verrokeilla 16,5 vs. 17,0 vuotta (interkvartiiliväli 14,3–21,5 vs. 15–22,5) ja naisia oli hiihtäjistä 58,1 % ja verrokeista 69,5 %.

Astman esiintyvyys oli suurempi hiihtäjillä kuin verrokeilla (25,9 % vs. 9,2 %, $p < 0.001$) ja ensimmäisten astmaan liittyvien oireiden alkamisikä oli korkeampi hiihtäjillä kuin verrokeilla (13,0 vs. 8,0 vuotta, $p < 0.001$). Astmatestin (ACT) tulosten mediaani oli molemmissa ryhmissä 22,0, mutta hiihtäjillä oli useammin hyvä astman hallinta (89,0 % vs. 77,4 %, ACT $\geq$ 20 p). Astmaa sairastavista hiihtäjistä 82,4 % käytti säännöllisesti inhaloitavaa glukokortikoidia (ICS), ja 80,2 % käytti avaavaa lääkitystä. Astmaa sairastavista yhdistelmälääkitystä käytti säännöllisesti 47,3 % hiihtäjistä ja 22,6 % verrokeista.

Jaettuna kilpailumenestyksen mukaan hiihtäjillä astma oli yleisintä menestyneimmässä neljänneksessä (56,1 %). Hiihtäjien astma oli useammin ei-allergista (60,1 %) verrattuna verrokkeihin (38,7 %). Kilpahiihto oli suurempi riski ei-allergiselle astmalle (OR 5,05, 95 % CI 2,65–9,61) kuin allergiselle astmalle (OR

1,92, 1,08–3,42). Suuri harjoitusmäärä oli merkittävä riskitekijä ei-allergiselle astmalle hiihtäjien keskuudessa.

Hiihtäjillä oli enemmän rasituksen jälkeistä yskää kuin verrokeilla (60,6 % vs. 22,8 %) ja limannousua rasituksen aikana ja sen jälkeen. Astmaatikoilla rasitukseen liittyvät oireet olivat samanlaisia kuin verrokeilla, mutta oireiden esiintyvyys oli korkeampi astmaa sairastavilla. Pitkittynyt yli kahdeksan viikkoa kestävä yskä oli harvinaista ja sitä oli 4,8 %:lla verrokeista ja 2,0 %:lla hiihtäjistä.

Suurempi osuus astmaa sairastavista hiihtäjistä (76,9 %) kuin astmaa sairastamattomista hiihtäjistä (62,2 %) joutui jättämään kilpailun väliin hengitystieinfektion vuoksi. Yksittäisen sairausepisodin mediaanikesto oli pidempi astmaa sairastavilla hiihtäjillä (5.0 päivää, IQR 3.8–6.8 vs. 4.0 päivää, IQR 3.0–6.7, $p = 0.017$), mikä johti useampiin poissaolopäiviin hengitystieinfektion takia kauden aikana (mediaani 15 päivää (IQR 8–28) vs. 10 päivää (IQR 6–18), p = 0.006).

Maastohiihtäjillä astma on hyvin yleinen sairaus. Astmaa on erityisesti menestyneimmillä urheilijoilla, astma on useimmiten ei-allergista ja oirehallinta on hyvä. Hiihtäjillä on myös paljon rasitukseen liittyviä hengitysoireita ja hengitystieinfektioita, jotka johtavat harjoituksista ja kilpailuista poisjäämiseen. Näiden tulosten perusteella astman tehokas hoito ja hengitystieinfektioiden vähentäminen on tärkeää. Vaikka hiihtäjillä on paljon astmaa ja hengitysoireita, näyttää siltä, että se ei estä menestyksekästä urheilu-uraa.

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ABBREVIATIONS

ACT	Asthma Control Test
AMP	Adenosine 5'-monophospate
ARinf	Acute respiratory infection
BHR	Bronchial hyperresponsiveness
CI	Confidence interval
EIB	Exercise-induced bronchoconstriction
EILO	Exercise-induced laryngeal obstruction
EVH	Eucapnic voluntary hyperpnoea
FEV1	Forced expiratory volume in the first second
FinEsS	Finland-Estonia-Sweden postal questionnaire study
FIS	The International Ski Association
FVC	Forced vital capacity
IQR	Interquartile range
LABA	Long-acting β2-agonist
LCQ	Leicester Cough Questionnaire
MMEF	Maximal mid-expiratory flow
RTI	Respiratory tract infection
TUE	Therapeutic use exemption

LIST OF ORIGINAL PUBLICATIONS

I Mäki-Heikkilä R, Karjalainen J, Parkkari J, Huhtala H, Valtonen M, Lehtimäki L. Higher prevalence but later age at onset of asthma in cross-country skiers compared with general population. *Scand J Med Sci Sports.* 2021;31(12):2259-2266. doi:10.1111/sms.14040

II Mäki-Heikkilä R, Karjalainen J, Parkkari J, Huhtala H, Valtonen M, Lehtimäki L. High training volume is associated with increased prevalence of nonallergic asthma in competitive cross-country skiers. *BMJ Open Sp Ex Med.* 2022;8:e001315. doi:10.1136/bmjsem-2022-001315

III Mäki-Heikkilä R, Koskela H, Karjalainen J, Parkkari J, Huhtala H, Valtonen M, Lehtimäki L. Cross-country skiers often experience respiratory symptoms during and after exercise but have a low prevalence of prolonged cough. *BMJ Open Sp Ex Med.* 2023;9(2):e001502. doi:10.1136/bmjsem-2022-001502

IV Mäki-Heikkilä R, Karjalainen J, Parkkari J, Huhtala H, Valtonen M, Lehtimäki L. Acute respiratory infections hamper training and competition in cross-country skiers, especially in those with asthma. *Int. J. Circumpolar Health.* 2023;82(1):2223359. doi:10.1080/22423982.2023.2223359

AUTHOR'S CONTRIBUTION

The author led the study conception and design in all studies. The literature search, data collection, statistical analyses and the first versions of manuscripts were carried out by the author in all studies.

1 INTRODUCTION

Cross-country skiing is a form of sport where athletes compete on snow using cross-country skis and ski poles. Today, there are two different techniques: classical and free. Competition distances range from short sprints up to 1.8 kilometers to long-distance competitions up to 50 kilometers (Figure 1). As for the season 2022–2023, the competition distances are the same for men and women (International Ski Federation, 2022b). In juniors, the competition distances are shorter.

Figure 1. The last national race of the 2022–2023 season in Rovaniemi, Finland. Women's 15 km mass start in classical style. Photo: Lauri Vuorinen

Having been an Olympic discipline since the inaugural Olympic Winter Games in Chamonix, 1924, cross-country skiing is deeply ingrained in the history of winter sports. The International Ski Federation (FIS) was founded during these games (International Ski Federation, 2022a). In the last Winter Olympic games held in Beijing 2022, 24% of the medals were awarded in events where athletes utilised cross-country skis to compete: cross-country skiing, biathlon, and Nordic combined.

In Finland, the Finnish Ski Association is the main body of organising cross-country skiing competitions and national championships and the Hopeasompa finals, which serve as the equivalent for national championships for skiers aged 13 to 16 years. The first national championships were held in 1909 ("Hiihtomestaruuskilpailut," 1909) and the first Hopeasompa finals in 1972 in Alavus under the name of Nuorten talvikisat ("Hyrynsalmen Viestivoima Kehittyi Pöllimetsässä," 1972).

Cross-country skiers' exposure to subfreezing conditions during winter training and competition poses unique challenges to their airways. The first research on respiratory health issues in cross-country skiers was published by Larsson et al. in 1993, revealing a high prevalence of asthma and respiratory symptoms among skiers (K. Larsson et al., 1993). From that point until 2020 by the recent systematic review and meta-analysis by the author and colleagues, over 30 articles have been published on the subject of asthma in competitive cross-country skiers (Mäki-Heikkilä et al., 2020). Although considerable progress has been made in understanding asthma within the context of competitive cross-country skiing, comprehensive insights into the etiology, pathophysiological mechanisms, and the diverse spectrum of respiratory symptoms manifested by athletes during and post-exercise remain areas of ongoing research.

The safeguarding of athlete health and performance, particularly through ensuring safe participation in sports, is a fundamental aspect of sports medicine. This is especially relevant in disciplines such as cross-country skiing, where athletes are routinely exposed to environmental conditions that pose respiratory challenges.

Respiratory symptoms and issues in cross-country skiing often emerge at a young age (Mäki-Heikkilä et al., 2020). Recognizing and expanding knowledge in this domain is imperative. Such efforts facilitate the development and refinement of strategies to enhance athlete care. A deeper understanding of the development and progression of respiratory issues in young skiers may enable the creation of more effective prevention, monitoring, and treatment protocols. These advancements not only safeguard the well-being of athletes but also contribute to the wider field of sports medicine, offering models to manage similar challenges across various sports disciplines and promoting public health.

The overarching objective of this line of research is the creation of a sporting environment that minimises health risks for athletes. Concentrating on the unique respiratory challenges encountered by cross-country skiers, this research endeavors to contribute a richer, more detailed understanding of sports-related respiratory issues. Such insights are crucial in shaping future research and clinical practices, aiming to ensure a safe and healthy career for athletes in sports.

2 REVIEW OF THE LITERATURE

2.1 Cross-country skiing

2.1.1 Cardiorespiratory demands

Cross-country skiing is a highly demanding Olympic winter sport. High maximal oxygen uptake and anaerobic capacity are essential, in addition to high levels of upper body power (Sandbakk & Holmberg, 2014, 2017). Minute ventilation in elite skiers may well exceed 200 l/min, and their forced vital capacity (FVC) and forced expiratory volume in one second (FEV1) often exceed normal values (Holmberg et al., 2007). Furthermore, world class skiers possess one of the highest maximal oxygen uptake values across all sports, ranging from 80 to 90 and from 70 to 80 mL · kg^{-1} · min^{-1} in men and women, respectively (Holmberg et al., 2007; Sandbakk & Holmberg, 2017; Tønnessen et al., 2015).

2.1.2 Environmental conditions

Most of the training during the winter is carried out outdoors and cross-country skiing competitions are held outdoors in variable terrain. In the recent Olympic Winter Games held in Bejing 2022, other disciplines using cross-country skis include Nordic combined and biathlon. These three disciplines were the only Olympic endurance sports which were held in subfreezing conditions. Typical outdoor temperature in the Nordic countries during the winter season ranges between –0°C and –20°C and the relative humidity is 70 to 90% (Pirinen et al., 2012).

It is essential to differentiate between two distinct measures of humidity: relative humidity and absolute humidity. Relative humidity is expressed as a percentage, indicating the ratio of the current water vapor content to the maximum possible at a given temperature. Conversely, absolute humidity quantifies the mass of water vapor present in a unit volume of air, generally measured in grams per cubic meter.

While the relative humidity levels during winter in Nordic countries may range between 70 and 90%, the absolute humidity decreases concomitantly with temperature. Consequently, the air exhibits low absolute humidity despite high relative humidity values. This disparity between absolute and relative humidity has physiological implications. Figure 2 visualises this observation through a graphical representation of absolute humidity content, calculated using the Buck equation, across a range of temperatures (Buck, 1981). Correspondingly, empirical evidence suggests that low levels of absolute humidity, as opposed to relative humidity, is associated with an increased likelihood of positive test results for exercise-induced bronchoconstriction (EIB) among children undergoing exercise testing outdoors (Tikkakoski et al., 2019).

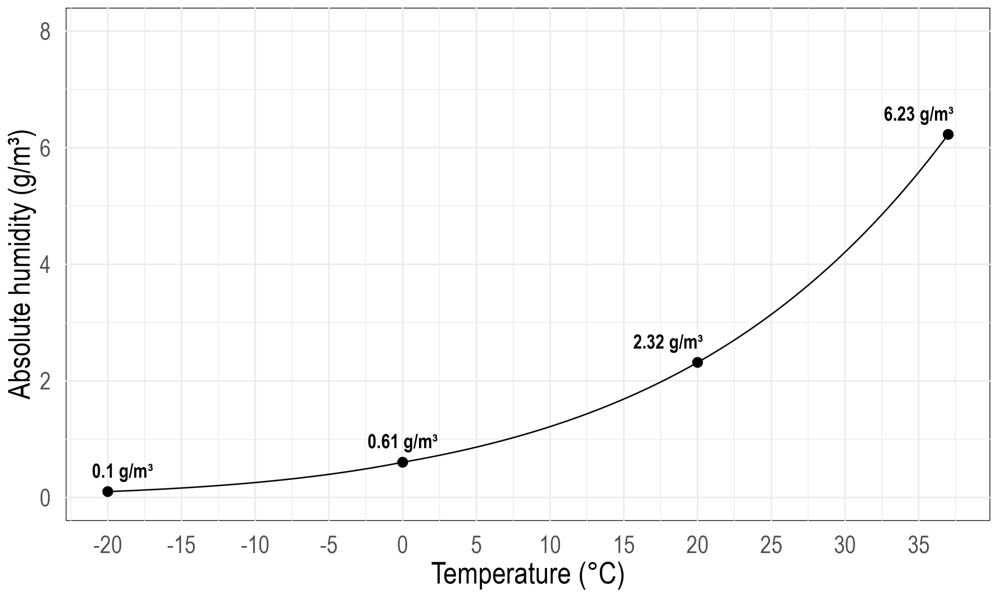


Figure 2. The relationship between absolute humidity (in g/m³) and temperature (in degrees Celsius) of air with 100% relative humidity over a temperature range from −20 to 37°C using the Buck equation (1981). Key temperatures are marked with dots, and the corresponding absolute humidity values are labeled.

For competition, temperature limits are established in the rulebooks by the International Ski Federation FIS and International Biathlon Union. In seniors, the temperature limit is –20°C (International Biathlon Union, 2021; *THE INTERNATIONAL SKI COMPETITION RULES (ICR), BOOK II CROSS-COUNTRY*, 2021; *THE INTERNATIONAL SKI COMPETITION RULES (ICR),* *BOOK VII NORDIC COMBINED*, n.d.) across all disciplines. National ski federations may set their own temperature limits for juniors and in Finland, the current temperature limit is –15°C for athletes under 16 years of age (*Maastohiihdon Kilpailusäännöt, Kausi 2022*, 2022).

2.1.3 Heating and humidification of air in the airways

In conditions where the ambient air is cold and dry, there is a physiological need to warm and humidify the air during respiration. It is widely accepted that under normal resting conditions, inhaled air is fully humidified and heated to reach the body temperature in the alveoli, approximately 37°C and 100% relative humidity and at rest, the temperature of exhaled air is close to 37°C (McFadden et al., 1982). Most of the heating occurs in the upper airways and in major thoracic airways. With increasing ventilation and decreasing inhaled air temperature, the point where inhaled air is fully saturated and humidified moves distally in the airways.

In a subsequent study by the same research group, the inhaled air temperature was measured using a heat probe inserted up to the first subsegmental level using inair at 26°C and –19°C at different minute ventilations (McFadden et al., 1985). In very cold air at ventilation rate of 100 l/min, most of the heating occurs in the mouth, where the air temperature reaches 20°C, 22°C at the carina, 24°C at the right lower lobe, and finally, 32°C at the first subsegmental level. During exhalation the warm air mixes with the colder air in the upper airways, resulting in a measured temperature of 32°C. Cooler air holds less water vapor and any excess water condenses back to the airway lumen. (McFadden et al., 1985).

2.1.4 The effect of cold air on exercise performance

Cold air not only impacts the human airways but also musculature and overall exercise performance. In a study by Wiggen et al., fourteen cross-country skiers performed three double poling tests in a climate chamber set at 6°C and –14°C, beginning 20 minutes after their entrance into the chamber. It was observed that power output decreased in two different sprint tests, and peak power at exhaustion was significantly reduced during a longer endurance test at –14°C. (Wiggen et al., 2013)

Sandsund and colleagues conducted a laboratory study involving nine male cross-country skiers. The skiers ran in a climate chamber wearing skintight ski suits suitable for racing on a treadmill at six different temperatures (20°C, 10°C, 1°C, –4°C, –9°C and –14°C). The study found that the time to exhaustion was longest at –4°C, suggesting that both insufficient and excessive clothing affects exercise performance. (Sandsund et al., 2012) Although the choice of suitable clothing influences exercise performance, research into clothing preferences in different temperatures has not yet been conducted (Gatterer et al., 2021).

2.2 Respiratory symptoms

The presence of respiratory symptoms serves as an initial clinical indicator that may warrant further investigation into potential underlying respiratory conditions. Respiratory symptoms would include, but are not limited to, chest tightness, shortness of breath, coughing, and wheezing. Reasons behind respiratory symptoms may be airway responsiveness to external triggers, acute respiratory infection or chronic lung diseases, such as asthma. Factors such as exercise intensity, duration of exposure to triggering environments, and individual susceptibility can influence the severity and frequency of these symptoms.

Cough is one of the most common reasons for medical consultations and its causes are often common, ranging from acute infections to environmental irritants. In epidemiological studies, cough is classified into three categories based on its duration: acute current cough if it lasts less than three weeks, prolonged cough if it lasts more than three weeks but less than eight weeks, and chronic cough if it persists for over eight weeks (Irwin et al., 2018).

Cough, a common symptom observed during and after endurance exercise (Boulet et al., 2017), has been widely reported among skiers during and after exercise (section 2.3.1). However, the potential impact of this symptom on performance decline or the evolution into prolonged cough remains undetermined. Similarly, while the incidence of cough as a respiratory symptom during and after exercise in skiers has been explored, a noticeable gap in research is the lack of studies investigating prolonged cough in athletes across all sports (Boulet et al., 2017; Boulet & Turmel, 2019; Hull et al., 2017). The question of whether repeated high-intensity exercise in cold air could inflict damage on the airways and induce long-term cough reflex hypersensitivity remains unresolved. In athletes training in cold air, cough reflex sensitivity to capsaicin was observed to be unchanged over the season, although a more frequent cough was noted up to eight hours post-training (Turmel,

Bougault, et al., 2012). This implies that while training might not alter the sensitivity of the cough reflex, it may serve as a trigger for cough.
Potential aetiologies for prolonged cough in athletes have been discussed, but clear evidence is still lacking, and epidemiological studies have not been conducted. Proposed reasons for prolonged cough in athletes include asthma, upper airway cough syndrome, exercise-induced laryngeal obstruction (EILO), non-asthmatic eosinophilic bronchitis, gastroesophageal reflux, and post-infectious cough, among others (Boulet & Turmel, 2019).

2.3 Asthma

The etymology of the word "asthma" is historically described as laboured breathing and not a disease at all in ancient Greek literature (Netuveli et al., 2007). Later, Sir John Floyer described the modern approach of asthma as bronchial constriction (Gauthier et al., 2015). Today, asthma is recognissed as a specific disease, not merely a symptom.

Asthma is an inflammatory disease of the bronchi, which is characterised by variable airflow obstruction (*Global Initiative for Asthma. Global Strategy for Asthma Management and Prevention*, 2022). This condition is marked by variable airway obstruction mostly due to contraction of smooth muscle but also due to mucosal swelling, mucus plugging and airway remodelling. Asthma is usually associated with chronic airway inflammation (*Global Initiative for Asthma. Global Strategy for Asthma Management and Prevention*, 2022). Asthma is categorised into different endotypes based on the underlying inflammatory mechanisms. The most frequent inflammatory endotypes include allergic eosinophilic asthma, non-allergic eosinophilic asthma, neutrophilic asthma and pauci-granulocytic asthma (Wenzel, 2012).

2.3.1 Asthma and exercise

The relationship between physical exercise and asthma is complex and seemingly contradictory. While physical exercise is recommended for all patients with asthma, there is a potential for it to exacerbate symptoms and induce bronchoconstriction, irrespective of one's level of physical activity. Conversely, participation in competitive endurance sports appears to elevate the risk of developing asthma (see chapter 2.3.2).

Several theories aim to explain the onset of exercise-induced bronchoconstriction and asthma attacks. Under normal breathing conditions, air is conditioned to 37°C and 100% relative humidity. Both the osmotic and thermal theories explore mechanisms by which high ventilation rates during exercise may lead to bronchoconstriction (Anderson & Kippelen, 2005; Kippelen et al., 2018).

During exercise, increased ventilation can cause the airway epithelium's mucosal surface to dry out. This alteration in osmolarity prompts epithelial cells to release water, potentially triggering the release of inflammatory mediators such as histamines and leukotrienes, which contribute to bronchoconstriction. (Anderson & Kippelen, 2005) Concurrently, the release of water leads to cooling of the mucosal surface, instigating vasoconstriction. This, in turn, would result in reactive hyperemia, vascular engorgement, leakage, and edema. (Kippelen et al., 2018)

The thermal theory provides an alternative explanation, focusing on temperature changes in the airways during exercise. Inhaling cooler and drier air during exercise requires the air to be conditioned to body temperature and 100% relative humidity. This conditioning process cools the airway epithelium. As ventilation increases, distal airways become more involved in heating and humidifying the air, which could result in epithelial damage, airway swelling, and ultimately, bronchoconstriction. (Anderson & Kippelen, 2005)

After exercise, the airways undergo a rewarming process. Upon cessation, the airways rewarm and this rapid change in temperature may also contribute to bronchoconstriction. The thermal theory suggests that these temperature-induced changes could activate neural reflexes that cause the airway smooth muscles to contract, resulting in bronchoconstriction. (Anderson & Kippelen, 2005)

A third theory proposes airway injury as a potential cause, suggesting that mechanical stress from high ventilation rates, especially in cold and dry environments, may lead to micro-injuries in the airway epithelium (Kippelen et al., 2018). These injuries could initiate an inflammatory response, releasing various mediators like histamines, prostaglandins, and leukotrienes. Repeated episodes of such injury and inflammation could eventually lead to airway remodeling, characterised by structural changes such as increased smooth muscle mass and mucus production, contributing to persistent bronchoconstriction and airflow limitation. Potential triggers for airway injury would also include foreign particulate matter, such as pollutants. (Kippelen et al., 2018)

2.3.2 Asthma in endurance athletes

Asthma is a common medical condition among athletes and its prevalence in various sports correlates with the required levels of ventilation. A study by Fitch et al. from the Olympic Games analysed exemptions for β_2 -agonists, revealing a significant reliance for these drugs in endurance sports (Fitch, 2012). Athletes using β2-agonists appeared to be disproportionately represented among medal winners at the Winter Olympics. For example, at the 2002 Salt Lake City Olympics, 5.2% of athletes were authorised to use β2-agonists, and this group won 15.6% of the medals. The figures for subsequent Winter Olympics in Turin 2006 were 7.7% vs. 14.4%, and 7.1% vs. 11.8% in Vancouver 2010. After 2010, the requirement for therapeutic use exemptions for commonly used β2-agonists salbutamol and salmeterol was discontinued (*2010 Prohibited List Summary of Major Modifications*, 2009), making similar data collection efforts unfeasible in the future.

In a study involving German Olympic athletes, participants were divided into three groups based on ventilation requirements: low, mid, and high. Sports demanding low ventilation included archery and shooting, mid-level ventilation sports encompassed various ball sports. Running, triathlon, and winter endurance sports such as cross-country skiing, biathlon, and speed skating were placed in the high ventilation category. The prevalence of asthma and the use of related medication was observed to be the highest among the high ventilation sports. (Selge et al., 2016)

Chapter 2.1.2 discussed the impact of environmental conditions on airways. Factors other than cold and dry air, such as air pollution from exhaust gases, pollen, wildfires, and particulate matter (PM), pose substantial health risks (Rundell, 2012). Indoor air lacking proper ventilation can also exacerbate respiratory conditions. Pollution's effects on the airways are multifaceted, causing various pathogenic mechanisms, including a decrease in lung function and vascular dysfunction (Rundell, 2012).

For endurance athletes, strategies to reduce pollution exposure could include training in less polluted areas, selecting training routes with less car traffic, adjusting training times, and opting for indoor training during seasons with high pollen counts or peak traffic pollution. The effectiveness of using breathing masks to decrease pollutant exposure, however, remains unverified.

Swimming, extensively studied in asthma research, poses unique demands on the airways due to the environment. The air above chlorinated swimming pools contains chloramines, an external irritant to the airways, which are believed to provoke and sustain airway inflammation (Bougault et al., 2009).

Despite the intense physical demands associated with summer endurance disciplines such as running and cycling, there is a noticeable deficit of comprehensive epidemiological studies examining the prevalence of asthma in these sports.

2.4 Respiratory symptoms and asthma in cross-country skiers

The focus of this thesis is to explore asthma and respiratory symptoms in cross-country skiers. This chapter is based on the systematic review and meta-analysis conducted by the author and colleagues (Mäki-Heikkilä et al., 2020) and it integrates the latest research findings in this area of study.

2.4.1 Prevalence of respiratory symptoms

Respiratory symptoms in skiers are often reported using point prevalence, indicating the proportion of individuals experiencing specific symptoms at a given time. The first study on respiratory symptoms in cross-country skiers by Heir and Oseid in 1994 found that 58% of 153 Norwegian skiers had two or more respiratory symptoms and that skiers with asthma had more symptoms than non-asthmatic skiers, except for cough. (Heir & Oseid, 1994). The most prevalent symptom during exercise in skiers was cough with 56% of skiers experiencing it occasionally and 16% regularly. Moreover, two or more symptoms were reported by 58% of skiers, three or more by 34% and at least four symptoms by 18% of skiers. Compared to non-asthmatic skiers, those with asthma reported higher prevalence of symptoms other than cough. The study also included controls matched by age, sex and home municipality and were significantly less symptomatic by exercise-induced chest symptoms occasionally and regularly including chest tightness, cough, wheezing and sputum production and shortness of breath regularly. (Heir & Oseid, 1994)

Sue-Chu et al. reported respiratory symptoms separately for Norwegian and Swedish cross-country skiers. In winter, 42% of Norwegian and 64% of Swedish skiers ($p<0.001$) reported coughing during training. In summer, the respective percentages dropped to 10% in Norwegian and 9% in Swedish skiers. Additionally, 46% of Norwegian and 51% of Swedish skiers experienced wheezing and breathlessness or chest tightness. Some respiratory symptoms were reported on exertion and at rest. Abnormal shortness of breath on exertion was reported by 30% and 26% of Norwegian and Swedish skiers, respectively. Chest tightness was more prevalent on exertion than at rest in Norwegian skiers (39% vs. 9 %) and Swedish skiers (38% vs 19%) Cold air increased respiratory symptoms in 14% of adolescent Norwegian skiers and in 45% of Swedish skiers, without providing a specific comparison point. (Sue-Chu et al., 1996)

Norqvist et al. investigated asthma and asthma-related symptoms among Swedish skiers aged 15–34 years (n = 238), finding 22% (n = 51) had experienced asthma-related symptoms in the last 12 months. Skiers were categorised into two groups: adolescent skiers aged 15–19 years and seniors aged 20–34 years. Older skiers reported more asthma-related symptoms (26% vs. 20%) but no statistical comparisons between age groups were made. Among younger skiers, females had more asthma-related symptoms (30% vs. 10%, $p < 0.001$) though this difference was not significant in the older group (24% in males vs. 29% in females, $p = 0.582$). Wheezing or whistling during the last 12 months was reported separately and was similarly prevalent in both younger and older groups (29% vs. 36%). (Norqvist et al., 2015).

In a screening study by Turmel and others, 50% of 44 skiers and biathletes had exercise-induced symptoms but potential differences between genders were not reported (Turmel, Poirier, et al., 2012). Rundell and others, found that 62% of cross-country skiers (n = 21) reported at least one symptom and 48%, 19%, and 5% had two or more, three or more or at least four respiratory symptoms (Rundell et al., 2001).

In a more recent study by Eklund et al, 16% of high-school aged skiers had asthma-related symptoms with a significant difference in the prevalence of symptoms between sexes (9% in males vs. 23% in females, p = 0.005). (Eklund et al., 2018) The latest study by Lennelöv et al. reported that early adolescent had current wheezing in 25%, exercise-induced wheezing in 21% and wheezing without a common cold in 20% of the skiers. Males and females had similar proportions of wheezing. When skiers were grouped by asthma, 80% of the skiers with current asthma had current wheezing whereas only 9% of skiers without asthma diagnosis had current wheezing. (Lennelöv et al., 2019)

2.4.2 Prevalence of asthma

Studies investigating the prevalence of asthma can be categorised into three types based on how asthma was defined and diagnosed in the study: (1) self-reported physician-diagnosed asthma, which is the most common approach in the literature; (2) asthma diagnosed based on lung function measures conducted within the study; and (3) a combination of self-reported physician-diagnosed asthma or asthma diagnosed based on lung function tests within the study. A recent meta-analysis by the author and colleagues is included as a part of this literature review (Mäki-Heikkilä et al., 2020).

Studies reporting prevalence of self-reported physician-diagnosed asthma. Postal self-administered questionnaires have been used in six studies outside this thesis to assess the prevalence of self-reported physician-diagnosed asthma (Eklund et al., 2018; Heir & Oseid, 1994; Langdeau et al., 2004; L. Larsson et al., 1994; Lennelöv et al., 2019; Norqvist et al., 2015). The details of the studies are presented in Table 1.

Table 1. Characteristics of the studies assessing the prevalence of self-reported physician-diagnosed asthma. Partially reproduced from Mäki-Heikkilä et al. 2020.

Year	Author and country	Participants	Sex and age	Self-reported physician-diagnosed asthma
1994	Larsson et al, Sweden	299 cross-country skiers from upper secondary schools, national ski teams and the Swedish army; 127 controls from same upper secondary schools	172 M, 127 F, age 18.5 ± 2.4 years (mean)	15% in skiers, 6% in controls
1994	Heir and Oseid, Norway	153 elite cross-country skiers, 241 controls matched for age, sex and home municipality	106 M, 47 F, age 25.5 years (mean)	14.4% in skiers, 5.0% in controls ($p < 0.01$)
2004	Langdeau et al, Canada	20 cross-country skiers and 6 biathletes in Quebec	Cannot be extracted	15.3% (cross-country skiing and biathlon combined)
2015	Norqvist et al, Sweden	236 cross-country skiers or biathletes in upper secondary schools, junior and senior national ski teams or universities	Upper secondary school 17 (15–19), national teams 24 (18–34), university athletes (23 (19–31), mean and (range)	30.9%
2018	Eklund et al, Sweden	244 cross-country skiers, biathletes and ski-orienteers in upper secondary schools	127 M, 117 F, age 16.8 ± 1.2 y	Total 27%, males 20%, females 34%, controls 19%
2019	Lennelöv et al, Sweden	87 cross-country skiers that had participated in national championships	41 M, 46 F, age 12.8 (SD 0.7) y	Total 23%, males 22%, females 24%, controls 12%

In a meta-analysis conducted by the author of this dissertation and colleagues, the first five studies listed in table 1 were included with the most recent article by Lennelöv et al. not yet published at that time (Mäki-Heikkilä et al., 2020). The mean prevalence of asthma in these five other studies was 21% (confidence interval, CI 95% 14–28%). The figure from the meta-analysis is included in Figure 3. Considering all these studies collectively, there appears to be an increasing trend over time in the prevalence of self-reported asthma.

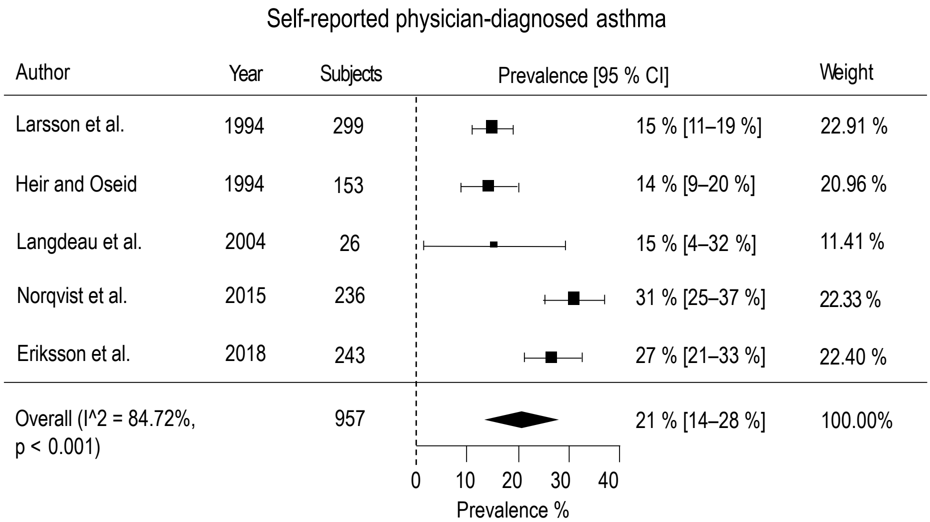


Figure 3. Forest plot of the studies reporting the prevalence of self-reported physician-diagnosed asthma in 957 participants. (modified from Mäki-Heikkilä et al. 2020)

Subgroup analysis results concerning the prevalence of self-reported physician-diagnosed asthma across different age groups and sexes were reported by Norqvist et al. Among skiers between 15 and 19 years of age, the overall prevalence of asthma was 29%, and it was significantly higher in females (38%) than in males (21%, $p = 0.016$). In skiers from 20 to 34 years of age, the prevalence of asthma was 35%, and there was no difference between sexes (32% in males vs. 39% in females, $p = 0.492$). (Norqvist et al., 2015)

Studies reporting prevalence of asthma based on current lung function measures. Only one study, conducted by Turmel et al., has reported the prevalence based on having asthma-like symptoms and objective lung function testing. In this study in Quebec, Canada, including cross-country skiers and biathletes, were screened as part of a larger study. They found a prevalence of 20% of physician-diagnosed asthma based on lung function measures in 44 skiers. The criteria used was ≥12% FEV1 improvement after β2 -agonist and/or the presence of airway hyperresponsiveness in EVH (eucapnic voluntary hyperpnoea) or methacholine challenge (≤ 4 mg/ml or ≤ 16 mg/ml with active inhaled corticosteroid treatment) and asthmatic symptoms. (Turmel, Poirier, et al., 2012)

Studies reporting prevalence of asthma based on combined criteria of previous physician-diagnosed asthma or current lung function measures. In four studies, the criteria for asthma were a combination of either having a previous physician-diagnosed asthma or having asthma-like findings in current lung function tests (K. Larsson et al., 1993; Michalak et al., 2002; Sue-Chu et al., 1996; Turmel, Poirier, et al., 2012). The studies are presented in Table 2.

Table 2. Characteristics of studies assessing prevalence of asthma based on combined criteria of previous physician-diagnosed asthma or current lung function measures. Reproduced from Mäki-Heikkilä et al. 2020.

Year	Author and country	Participants	Sex and age	Diagnostic criteria	Total asthma prevalence
1993	Larsson et al, Sweden	42 cross-country skiers in Stockholm and Östersund	36 M, 6 F, age 24 years (mean)	BHR (bronchial hyperresponsiveness) to methacholine and two asthma-like symptoms OR a previous diagnosis of asthma with active asthma medication use	55%
1996	Sue-Chu et al, Norway and Sweden	118 cross-country skiers in senior secondary school in Norway, 38 cross-country skiers in senior secondary school and 15 skiers serving as conscripts in Sweden	Norway 90 M 28 F, age 17.0 ± 1.1 years, Sweden 36 M 17 F, age 18.4 ± 1.4 years	Total cases of asthma defined as current asthma cases or physician-diagnosed asthma cases currently treated with steroids	Norway: 12% Sweden: 42%
2002	Michalak et al, France	180 cross-country skiers or biathletes	121 M 59 F, age 18 ± 2 years (mean)	Increase in FEV 1 by ≥ 12% or 200 ml in the bronchodilation test or self-reported physician-diagnosed asthma	14%0
2012	Turmel et al, Canada	34 cross-country skiers and 10 biathletes	29 M, 15 F	≥ 12% FEV1 improvement after β2 -agonist and/or the presence of airway hyperresponsiveness to EVH or methacholine challenge (≤ 4 mg/ml or ≤ 16 mg/ ml with active inhaled corticosteroid treatment) and asthmatic symptoms	20%

The mean prevalence of asthma in these four studies was 28% (CI 95% 13–46%) and is presented in Figure 4.

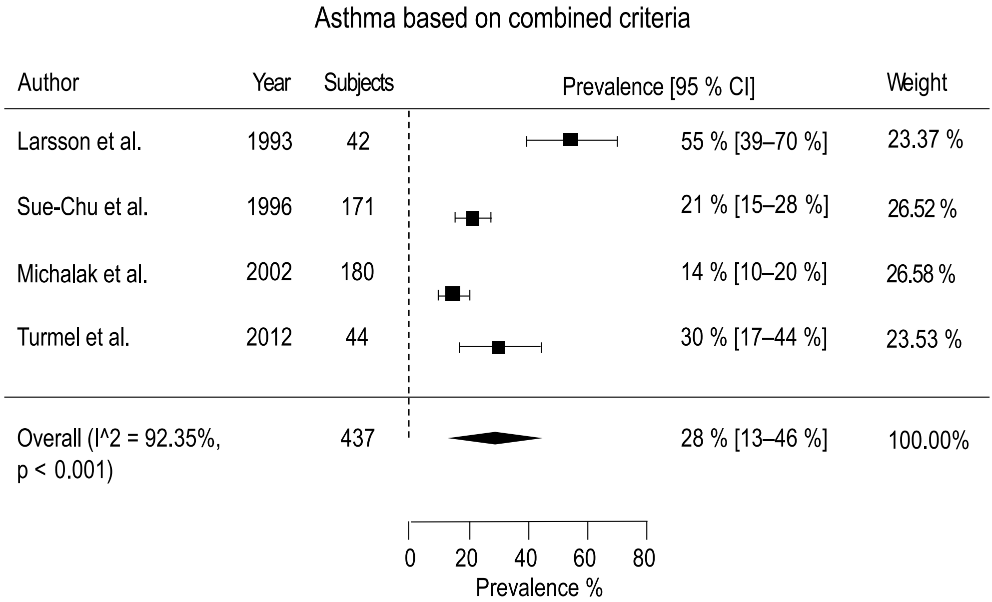


Figure 4. Total asthma prevalence from four studies is 28% in 437 participants. Modified from Mäki-Heikkilä et al. 2020.

2.4.3 Possible underdiagnosis of asthma among cross-country skiers

Several studies have highlighted the potential underdiagnosis of asthma in skiers. It has been noted that previously healthy skiers without a prior asthma diagnosis or medication use often met the diagnostic criteria for asthma based on lung function tests. There is an observed decrease over time in the prevalence of undiagnosed asthma among previously healthy skiers, falling from 55% to 20% from 1993 to 2010, excluding data from a recent, smaller study of 13 participants (Dickinson et al., 2011; K. Larsson et al., 1993; Ogston & Butcher, 2002; Pohjantähti et al., 2005; Sue-Chu, Henriksen, et al., 1999; Sue-Chu et al., 2010).

In 1993, Larsson et al. conducted a study with 42 cross-country skiers, diagnosing asthma based on positive methacholine challenge test results and the presence of at least two asthma symptoms. Thirty-four percent of the previously healthy skiers met these diagnostic criteria (K. Larsson et al., 1993). In a later study conducted by Sue-

Chu et al. in 1999, 40% (12/30) of previously healthy skiers were considered to have ski asthma, defined similarly by a positive methacholine challenge test and the presence of asthma-like symptoms. (Sue-Chu, Henriksen, et al., 1999)

Ogston and Butcher used a field exercise challenge as a diagnostic test and discovered that 31% (20/91) of unmedicated high school skiers experienced exercise-induced bronchoconstriction (Ogston & Butcher, 2002). A Finnish study by Pohjantähti and others reported that 35% (7/20) of the previously healthy skiers had a decrease in FEV1 by ≥ 10%, a decrease in MMEF (maximal mid-expiratory flow) by ≥ 20% or a decrease in both (2 FEV1, 7 MMEF) with a similar challenge (Pohjantähti et al., 2005). In 2010, Sue-Chu et al. compared different diagnostic tests and observed that 25% (12/48) of the previously healthy skiers exhibited bronchial hyperresponsiveness in either the methacholine challenge test or the EVH test, meeting the criteria for therapeutic use exemption (TUE) at that time (Sue-Chu et al., 2010). Lastly, a British multisport study by Dickinson et al. showed that 62% (8/13) of the biathletes included, who were previously healthy, but had bronchial hyperresponsiveness in the EVH test (Dickinson et al., 2011).

2.4.4 Risk factors and onset age of asthma or asthma-related symptoms

To date, there is only one study assessing possible risk factors for developing asthma among competitive skiers. Eklund and colleagues found in a study of 244 skiers from a high school population that family history of asthma and any nasal allergy, including allergic rhinitis, were significant risk factors for asthma both among competitive skiers and non-skiers (Eklund et al., 2018).

The age of asthma onset in skiers has been studied in Norway and Sweden in four different studies (Eklund et al., 2018; Heir & Oseid, 1994; K. Larsson et al., 1993; Norqvist et al., 2015). The age at onset ranged from early adolescence to early adulthood, and the onset occurred at a later age in the skiers than in the controls.

Eklund et al. compared junior elite cross-country skiers, biathletes and ski-orienteers to controls in upper secondary schools in Sweden. The median age at onset of asthma in the skier group was significantly higher than that in the controls (12 vs. 8 years, $p < 0.001$). The age at onset of asthma was distributed evenly from birth into adolescence in the control group and was concentrated to the 10–15-year-old age range in the skier group. The mean age of the skiers was 16.8 ± 1.2 years. (Eklund et al., 2018)

In another Swedish study conducted by Norqvist et al, the onset age of asthma in both skiers in the 15–19-year-old group and those in the 20–34-year-old group was mostly in early adolescence (Norqvist et al., 2015).

In a study by Heir and Oseid, 16 of 22 skiers with self-reported symptoms recalled their onset age of asthma. Fifteen skiers reported an onset age in late adolescence or early adulthood. Only one skier reported the onset of asthma in early childhood. (Heir & Oseid, 1994)

Moreover, Larsson et al. reported that none of the 42 skiers with asthma in their study recalled their onset age of asthma to be during childhood (K. Larsson et al., 1993).

2.4.5 Use of asthma medication

Use of asthma medication has been reported in several studies among skiers. Asthma medication use was defined as the use of one or more of the following medications: inhaled bronchodilators (β2 -agonists or anticholinergic agents), inhaled anti-inflammatories (corticosteroids, cromoglycates), oral theophylline or corticosteroids (Table 3). In our recent meta-analysis, the prevalence of asthma medication use in skiers was on average 23% (CI 95% 19–26%) across six studies with 1146 participants and is represented in Figure 5. (Mäki-Heikkilä et al., 2020).

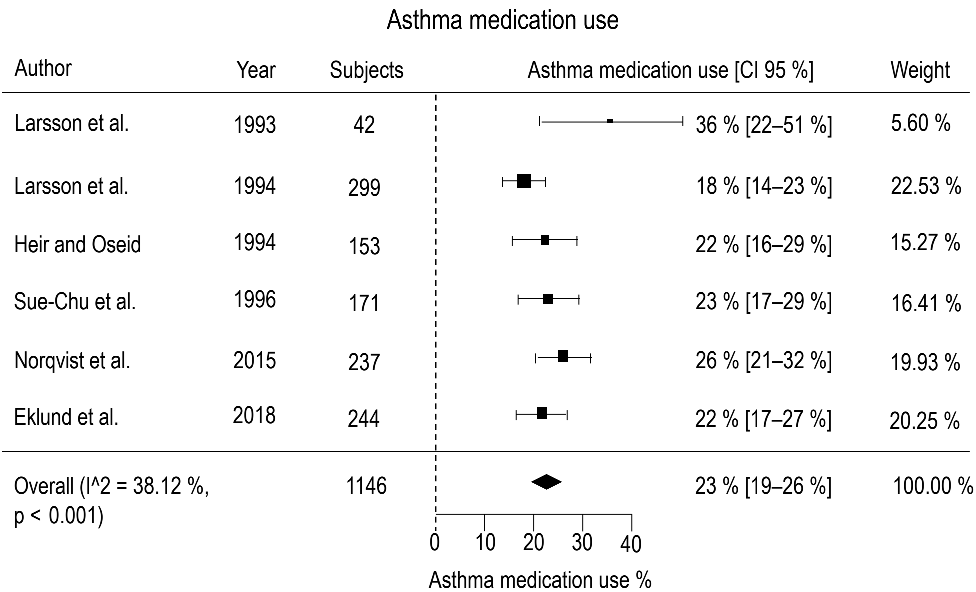


Figure 5. Forest plot of asthma medication use in six studies with 1146 participants. (Modified from Mäki-Heikkilä et al., 2020)

Table 3. Characteristics of studies assessing the prevalence of asthma medication use among skiers. Partially reproduced from Mäki-Heikkilä et al., 2020.

Year	Author and country	Participants	Sex and age	Use of asthma medication in skiers	Use of asthma medication in controls
1993	Larsson et al, Sweden	42 skiers and 29 controls	36 M, 6 F, age 24 years (16–50 years)	36 % 15/42	0 %, healthy controls recruited
1994	Larsson et al, Sweden	299 cross-country skiers from upper secondary school, national ski team and Swedish army. 127 controls from same upper secondary schools	172 M, 127 F, age 18.5 ± 2.4 years (mean)	18 %	7 %
1994	Heir and Oseid, Sweden	153 elite cross-country skiers, 241 controls matched for age, sex and home municipality	106 M, 47 F, age 25.5 years (mean)	22.2 % (34/153, 25 regularly, 9 occasionally)	4,6 % (11/241, 7 regularly, 4 occasionally)
1996	Sue-Chu et al, Norway and Sweden	118 cross-country skiers in senior secondary school in Norway, 38 skiers in senior secondary school and 15 military conscripts in Sweden	Norway 90 M 28 F, age 17.0 ± 1,1 years, Sweden 36 M 17 F, age 18.4 ± 1,4 years	total 23 % (Sweden 38 %, Norway 16 %); β_2-agonist 21 % (38 SWE, 14 % NOR), ICS (inhaled corticosteroids) 10 % (SWE 23 %, NOR 4 %)	No controls
2015	Norqvist et al, Sweden	237 cross-country skiers or biathletes in upper secondary schools, junior and senior national ski teams or universities	Upper secondary school 17 years (15–19), national teams 24 years (18–34), university athletes (23 (19–31), mean and (range)	15–19 years 25 %, 16 % M, 35 % F (p = 0.005); 20–34 years 28 %, 18 % M, 38 % F (p = 0.061); total 26 %	No controls
2018	Eklund et al, Sweden	244 cross-country skiers, biathletes and ski-orienteers in upper secondary schools	127 males, ♀117 females, age 16.8 ± 1.2 years	22 % (14 % M, 23 % F) (last 12 mo) (p 0.003)	Total 11 % (p = 0.03 compared to skiers), 8 % M, 14 % F
2019	Lennelöv et al, Sweden	87 cross-country skiers that had participated in national championships	41 M, 46 F, age 12.8 (SD 0.7) y	Medication for only athletes with asthma were reported: SABA/LABA 95%, ICS 65%, ICS+LABA 25%, other 35%	Only subjects with asthma: SABA/LABA 100%, ICS 61%, ICS+LABA 26%, other 14%

2.4.6 Asthma-related pathophysiological features in skiers

Airway inflammation in skiers with or without asthma has been investigated using bronchial biopsies in three studies (Karjalainen et al., 2000; Sue-Chu et al., 1998; Sue-Chu, Larsson, et al., 1999), using induced sputum in one study (Sue-Chu, Larsson, et al., 1999) and using exhaled nitric oxide in three studies (Stang et al., 2018; Sue-Chu, Henriksen, et al., 1999; Zebrowska et al., 2015).

The results of the six studies assessing airway inflammation in skiers are summarised in Table 4. In short, the studies that used bronchial biopsies revealed an increased presence of lymphoid aggregates and inflammatory cells in the bronchial mucosa or bronchoalveolar lavage fluid of skiers, most of whom were identified as asthmatic, compared to healthy controls. However, these findings were not as pronounced as those in non-skiing asthmatic controls. In contrast, measurements of exhaled nitric oxide and inflammatory markers in induced sputum did not show significant differences between asthmatic skiers and healthy controls.

Table 4. Characteristics of studies investigating airway inflammation in cross-country skiers. Partially reproduced from Mäki-Heikkilä et al., 2020.

Year	Author and country	Participants	Protocol	Main finding
1998	Sue-Chu et al, Norway, Sweden	44 skiers and 12 healthy controls. 59% of the skiers had asthma-like symptoms and were hyperresponsive to methacholine	Bronchial biopsy from second and third generation carinae	Lymphoid aggregates in skiers 64% vs. 25% in controls
1999	Sue-Chu, Larsson et al, Norway	30 skiers and 10 healthy controls. 63% of the skiers were hyperresponsive to methacholine, and 40% were hyperresponsive and had asthma-related symptoms	Bronchial biopsy and bronchoalveolar lavage	Macroscopic inflammatory index based on the visual evaluation of bronchial mucosa was significantly higher in skiers than in controls (3.1 vs. 1.3, $p = 0.008$). Subjects with “ski asthma” had higher percentages of lymphocytes and lower percentages of macrophages in BAL fluid compared with healthy controls, but these results were not significantly different from those of healthy skiers

Year	Author and country	Participants	Protocol	Main finding
1999	Sue-Chu, Henriksen et al, Norway	44 skiers, 29 mild asthmatic controls and 82 healthy controls. Nine skiers were hyperresponsive to methacholine and had asthmatic symptoms	Exhaled nitric oxide concentration at rest. Expiratory flow rate was set to 250 ml per second	Exhaled nitric oxide concentrations were not different compared to healthy controls (6.5 vs. 5.2 ppb), but asthmatic controls had threefold higher levels compared to skiers (6.5 vs. 19.2 ppb, $p < 0.01$). The atopic skiers had twofold greater exhaled nitric oxide concentrations compared to non-atopic skiers (values not available)
2000	Karjalainen et al, Sweden, Norway, Estonia	40 skiers with no prior diagnosis of asthma, 12 asthmatic controls and 12 healthy controls. 75% of the skiers were hyperresponsive to methacholine and 53% were hyperresponsive and had asthma-related symptoms	Bronchial biopsy from second and third generation carinae	Skiers had higher counts of T-lymphocytes, macrophages and eosinophils compared with controls. the counts of macrophage, mast cell and eosinophil cell counts were significantly lower in skiers compared to asthmatic subjects, but neutrophil count was significantly higher in skiers compared to asthmatic controls. Tenascin thickness in subepithelial basement membrane was significantly thicker in skiers compared to healthy controls but in nonhyperresponsive skiers the tenascin thickness was lower compared to patients with asthma
2014	Zebrowska et al, Poland	12 elite female cross-country skiers	Exhaled nitric oxide concentration at rest	Exhaled nitric oxide concentrations were reported to be within a normal range (18.7 ± 4.8 ppb)
2018	Stang et al, Norway	10 skiers and 10 swimmers with previous asthma diagnosis, 9 skiers and 10 swimmers with no previous diagnosis of asthma, 24 healthy controls	FeNO, spirometry, skin prick test, methacholine challenge, induced sputum	Most results of the skiers were pooled together with the results of the swimmers. Although the results of the skiers were not explicitly analysed separately, it seemed that there were no significant differences in the levels of inflammatory cells or mediators induced between the asthmatic skiers, healthy skiers and non-athletic controls

Norwegian cross-country skiers and controls were monitored for one year to evaluate seasonal changes in bronchial reactivity and respiratory tract infections during their mandatory military service (Heir, 1994; Heir et al., 1995; Heir & Larsen, 1995). There were no significant differences in lung function between the groups or notable changes in lung function during the study period. However, the provocative doses in the methacholine test (which indicate a 10% reduction in FEV1) decreased during the winter, suggesting an increase in bronchial responsiveness, but then increased again towards the summer. The methacholine test was also administered when a subject had a respiratory infection. Among skiers, the provocative dose significantly decreased following a respiratory infection, unlike in controls. The provocative dose in skiers did not return to baseline values until six weeks post-infection (Heir, 1994; Heir et al., 1995; Heir & Larsen, 1995).

Kennedy and others followed eighteen female skiers for one season, performed an analysis of induced sputum and used the Leicester Cough Questionnaire (LCQ) (Kennedy et al., 2015). Measurements were taken three times during the season: at the beginning and end of the training season, and during the competition season. No changes were observed in induced sputum cell counts or LCQ scores between the measurements taken during the training season. However, there was a significant increase in the numbers of lymphocytes and eosinophils in induced sputum from the first to third measurements (0.17 vs. 0.55×10^6 1/g, 0.014 vs. 0.104×10^6 1/g, $p < 0.05$) (Kennedy et al., 2015).

2.4.7 Effect if anti-asthmatic treatment in non-asthmatic and asthmatic skiers

Two studies have explored the effect of bronchodilators on lung function and exercise performance in skiers (Sandsund et al., 1998; Sue-Chu, Sandsund, et al., 1999) and one study assessed the effect of anti-inflammatory treatment (Sue-Chu et al., 2000).

Sandsund and others studied salbutamol exclusively in cross-country skiers. Eight male skiers completed two exercise tests in a climatic chamber set to − 15 °C after the inhalation of salbutamol (3 × 400 µg) or placebo (Sandsund et al., 1998). Three skiers were using anti-asthmatic medication but had not been diagnosed with asthma. The withdrawal of medication before the test was not reported. FEV1 increased significantly after the inhalation of salbutamol before the test and was higher during the test compared to the levels with the placebo at all six time points. No significant changes were observed in maximal oxygen uptake or blood lactate levels, and salbutamol did not have performance-enhancing effects. (Sandsund et al., 1998)

In 1999, Sue-Chu and others investigated the effect of salmeterol on physical performance on a treadmill in a climatic chamber in eight healthy male cross-country skiers at −15°C (Sue-Chu, Sandsund, et al., 1999). The inhalation of 50 µg salmeterol significantly improved the FEV1 level before, during, and after the exercise test but did not have an effect on the time to exhaustion (392.5 s with salmeterol vs. 395.6 s with the placebo, $p = 0.84$). (Sue-Chu, Sandsund, et al., 1999)

Another study by Sue-Chu and colleagues assessed the effects of a 22-week budesonide treatment in 25 cross-country skiers with 'ski asthma' (defined as having two or more asthma-like symptoms, including wheezing and abnormal breathlessness or chest tightness upon exertion, at rest, or upon exposure to irritants, and bronchial hyperresponsiveness (BHR) to methacholine) who had not used anti-asthmatic medication. This study found no significant improvement in lung function, airway inflammation, or tenascin expression (Sue-Chu et al., 2000)

2.4.8 Other asthma-related studies in cross-country skiers

Three studies have compared bronchial reactivity in skiers using various diagnostic tests (Stensrud et al., 2007; Sue-Chu et al., 2010; Wilber et al., 2000), while another investigated the correlation between self-reported symptoms and bronchial hyperresponsiveness (Stenfors, 2010) Additionally, a longitudinal case study followed three cross-country skiers for 9–12 years (Verges et al., 2004). These studies, summarised in Table 5, reveal significant variations in bronchial hyperresponsiveness (BHR) among skiers, depending on the testing protocols used. Stenfors's findings suggest that self-reported symptoms poorly predict BHR, and Verges et al. observed fluctuating signs of airway obstruction in skiers over time.

Table 5. Other asthma-related studies in cross-country skiers. Modified from Mäki-Heikkilä et al. 2020.

Year	Author and country	Subjects	Protocol	Main finding
2000	Wilber et al, USA	34 biathletes and 14 cross-country skiers participating in Olympic trials	The incidence of EIB in qualified Olympic athletes by spirometry after Olympic trial race (FEV 1 ≥ 10%)	In the qualifying Olympic team, no biathletes had EIB, 57% of female and 43% of male cross-country skiers had EIB
2010	Sue-Chu et al, Norway	58 cross-country skiers (18.1 yrs), 10 skiers with prior asthma diagnosis	Airway hyperresponsiveness to methacholine (PD20 ≤ 1814 µg), AMP (adenosine 5-monophospate, ≤ 50.5 mg), mannitol (≤ 635 mg), 8 min EVH test and 4.7 km field exercise challenge (≥ 10% FEV 1 decrease at two consecutive time points)	Heterogenous responsiveness to different stimuli among skiers. Among 58 skiers, 40% had positive methacholine test, 9% had positive AMP test, and 5% had positive mannitol test. Among 33 skiers 9% had a positive EVH test, and 18% had a positive field exercise challenge
2007	Stensrud et al, Norway	24 Norwegian national cross-country team skiers	Spirometry after cross-country ski race (≥ 10% FEV1), methacholine challenge (PD 20 ≤ 1600 µg = 8 µmol)	After a ski race 8% of the skiers had bronchial obstruction. 38% had a positive methacholine test
2010	Stenfors, Sweden	46 cross-country skiers or biathletes on national or international level	Multiple self-reported symptoms compared to bronchial hyperresponsiveness in methacholine or mannitol challenge and EVH	Self-reported symptoms had reasonable negative predictive values but very low positive predictive values in relation to bronchial hyperresponsiveness
2004	Verges et al, France	One female 19 years, and two male cross-country skiers 21 and 22 years of age and one unreported skier	Follow-up study 9–12 years with intermittent lung function tests, including spirometry and methacholine challenge	Three reported athletes developed objective signs of variable airway obstruction but tests were not systematically positive

2.5 Acute respiratory infections in skiers

Acute respiratory infections (ARinfs) are one of the main causes that prevent athletes from training (Schwellnus et al., 2022a). The impact of ARinfs on cross-country skiers has been examined in a limited number of studies with varying designs. A retrospective study by Svendsen et al. analysed 7000 weeks of training diaries from 37 skiers and discovered that, on average, skiers experienced ARinf three times per year, with a median symptom duration of 19 days (range 6–43 days) (Svendsen et al., 2016). In contrast, young adults in the general population typically encounter two to six acute respiratory viral infections annually (Bayer et al., 2014; Byington et al., 2015; Monto, 2002; Ruuskanen et al., 2022). After intense competition periods, such as the Tour de Ski, the participating athletes were at three times higher risk of ARinf compared to athletes not participating in the Tour de Ski (Svendsen et al., 2015). Furthermore, during the Nordic Ski World Championships, skiers were at a seven times higher risk of ARinf than the controls of the general population (Valtonen et al., 2021).

Given the potential relationship between asthma and increased frequency of ARinfs in the general population with asthma (Kisiel et al., 2021), it has been challenging to demonstrate the possible effect of asthma on increased days of absence from training.

3 AIMS OF THE STUDY

The aim of this dissertation was to assess respiratory symptoms and asthma-related issues in Finnish competitive cross-country skiers and controls with similar age, gender and region using a cross-sectional postal survey. The specific study aims were as follows:

1. To compare the differences in the prevalence of asthma, allergic and non-allergic asthma, use of asthma medication, onset age of asthma and asthma control in Finnish cross-country skiers and controls (Study I and II)
2. To examine how performance level and training volume are related to asthma and its type and to assess the possible risk factors for allergic and non-allergic asthma in cross-country skiers. (Study II)
3. To study the prevalence of respiratory symptoms in cross-country skiers, with a focus on prolonged cough and asthma subgroups at rest, during exercise and after exercise compared with controls (Study III)
4. To study the burden of respiratory tract infections in asthmatic and non-asthmatic skiers on competition success and possible effects of asthma on days of absence from training and competition. (Study IV)

4 METHODS

This dissertation is based on four separate articles representing data collected with a cross-sectional postal survey sent to competitive cross-country skiers and controls. The first article compared the differences in in the prevalence of asthma, use of asthma medication, onset age of asthma and asthma control. The second article compared the differences in asthma-related issues defined by competition success in cross-country skiers and examined the possible differences of allergic and non-allergic asthma in cross-country skiers and controls. The third article presented the number of asthma-related symptoms and chronic cough in cross-country skiers and controls. The fourth and final article studied the effect of acute illness or respiratory tract infection on competition success and possible effects of asthma on days of absence from training and competition.

4.1 Inclusion criteria

A postal invitation with a password to an online questionnaire was sent to cross-country skiers in May 2019 and to controls in February 2020. All Finnish cross-country skiers who had enrolled in either national championships or the largest national junior skiing competition when they were 13–16 years of age (Hopeasompa competition) were invited to participate in the study (n = 1 282). There was no upper age limit to participate in the study if the athlete had enrolled to the national championships in seniors or juniors. In terms of performance level, the invited athletes represented highly trained/national level athletes (Tier 3) through world class athletes (Tier 5) (McKay et al., 2022).

The controls were matched to the skiers who had responded regarding age, gender, and region of the country in which they lived.

4.2 Data collection

The Finnish Ski Association collaborated in the study by sending invitations to the athletes. Later, a similar questionnaire was sent to a matched control group collected from the Finnish Digital and Population Data Services Agency.

The invitation letter sent to the control group also contained a paper version of the questionnaire. Cross-country skiers received a single reminder, whereas the controls were sent two reminders.

4.3 Sample size

The sample size was calculated based on the expected difference in asthma prevalence between the skiers and controls. We assumed an asthma prevalence of 10% in the controls and at least 20% in competitive skiers (Study I). To have a statistical power of 90% (correct negatives) with alpha-error of <5% (wrong positives), we needed at least 263 participants in both groups to find such a difference in asthma prevalence. Therefore, we decided to invite all the competitive skiers of at least 13 years of age (n = 1 282) and six healthy controls for each responded skier to get a sample of sufficient size regardless of possible low response rate. Because we could not identify from the population registry up to six controls for each skier fulfilling these criteria, the invited number of controls was 1 733 (on average 5.1 invited controls for each responded skier).

4.4 Questionnaire

The survey was conducted as a postal invitation with a password to answer online in cross-country skiers and controls received a similar invitation and questionnaire was included in paper form as well. The questionnaire consisted of 88 questions divided into 12 sections. All results based on the questionnaire are not included in this thesis. The full questionnaire is included as Appendix 1. The included questions are presented below.

Basic information included gender, date of birth, height and weight. Self-reported physician-diagnosed asthma was defined according to FinEsS (Finland-Estonia-Sweden postal questionnaire study) questionnaire (Pallasaho et al., 1999) as answering ‘yes’ to both questions “Have you ever had asthma” and “Have you ever had asthma diagnosed by a physician". In studies II-IV, asthma was reported as current asthma. It was defined as self-reported physician-diagnosed asthma (as above) and at least one of the following criteria: current three asthma-related symptoms (cough, chest pain, shortness of breath, wheezing or sputum production), active use of any asthma medication or ACT score of less than 25 points.

Participants with asthma were asked additional questions. For the onset age of asthma, participants with asthma were asked at which age they experienced their first asthma-related symptoms and at which age asthma was diagnosed.

Asthma was defined as allergic if the participant reported a doctor-diagnosed allergy and asthma-related symptoms when exposed to furry animals or pollens. Otherwise, asthma was defined as non-allergic.

Use of asthma medication was an open text field in which responders could fill in their medications.

Weekly training volume was defined in two ways: If the responder knew the exact volume of training hours the preceding season, the result was divided by 52 weeks. In other case, responders filled in their approximation of weekly training during summer and winter and the mean weekly training volume for the whole season was calculated. The question is presented in Table 6.

Table 6. The estimation of weekly training volume.

Evaluate your weekly training volume in a week during summer (May–October)	
Cross-country skiing, roller skiing or Nordic walking	hours
Other forms of endurance training (for example running and cycling	hours
Other forms of training (team sports or other sports)	hours
Evaluate your weekly training volume in a week during winter (November–April)	
Cross-country skiing, roller skiing or Nordic walking	hours
Other forms of endurance training (for example running and cycling	hours
Other forms of training (team sports or other sports)	hours

4.5 Definition of competition success

FIS points system is developed by the International Ski Association FIS to rank skiers by their competition performance. FIS points are awarded based on the level of competition and relative time loss to the winner, not ranking. For each responder over 16 years of age, FIS points were obtained from the International Ski Associations 8th FIS points list from season 2018/2019, which was in effect at the time of the study (*8th Cross-Country List 2018/2019*, n.d.). FIS points were used to categorise responders into subgroups by performance level. The best possible points are 0.00 (the less, the better), which are awarded to winners at World Cup level.

4.6 Non-responder analysis

After data collection, the Finnish Ski Association provided age and gender of the non-responding skiers, and the FIS points for skiers were obtained from the International Ski Associations 8th FIS points list from season 2018/2019, which was in effect at the time of the study (*8th Cross-Country List 2018/2019*, n.d.) Then, an analysis was performed to compare age, gender and success of the responders and non-responders.

4.7 Ethical issues

The study was approved by the Ethics Committee of Pirkanmaa Health Care District (R18108). Written informed consent was obtained from each respondent and from guardians for participants under 18 years of age. The consent forms with return envelopes were sent in the invitation mail.

4.8 Statistical methods

Statistical analyses were performed using SPSS version 27.0 (IBM Corp, Armonk, NY). The continuous variables were tested for normality (Kolmogorov-Smirnov). Unpaired t tests and Mann-Whitney U tests were used for the comparisons between the groups, as appropriate, and the results are presented as median (IQR) or mean (SD). Pearson's chi-square test or Fisher's exact test was used for comparisons of the categorical variables.

Binary logistic regression was used to calculate the risk factors for current asthma, allergic asthma and non-allergic asthma. Variables were included in the multivariable analysis if the p value was <0.1 in the univariate analyses. A p value of <0.05 was considered statistically significant.

5 RESULTS

5.1 Basic characteristics of study participants

A total of 345 cross-country skiers and 338 controls participated in the study, yielding response rates of 26.9% and 19.5%, respectively. The basic characteristics of both skiers and controls are detailed in Table 7. It was observed that the controls were slightly older, and a higher percentage of controls, compared to skiers, were female. Furthermore, cross-country skiers were more actively involved in other competitive sports and, on average, trained more per week compared to controls.

Table 7. Participants' characteristics in cross-country skiers and the controls.

	Cross-country skiers n = 351		Controls n = 338		
	Median/n	Q_1-Q_3/%	Median/n	Q_1-Q_3/%	p
Age, yrs.	16.5	14.3–21.5	17.0	15–22.5	0.033
Body mass index, kg/m^2	21.0	3.6	21.8	5.4	<0.001
Females	204	58.1	235	69.5	0.002
Engaged in competitive sports other than cross-country skiing	223	63.5	88	26.0	<0.001
Team sports	36	16.1	54	61.3	<0.001
High ventilation sports (cycling, running, triathlon, orienteering, aerobic gymnastics)	195	87.6	7	7.9	<0.001
Moderate ventilation sports (combat sports, gymnastics, dancing)	0	0	19	21.6	<0.001
Low ventilation sports (shooting, horseback riding, weightlifting)	34	15.2	5	5.7	0.022
Smoking	0	0	20	5.9	<0.001
Training or heavy exercise/week, hours, mean (SD)	10.0	8.0–10	2.4	1.0–4.5	<0.001

P values were obtained with a Mann-Whitney U test for continuous variables and a Chi-squared test or Fisher's test for categorical variables.

5.2 Prevalence of asthma and types of asthma

The prevalence of self-reported physician-diagnosed asthma (ever asthma) was 27.4% (n = 92) in cross-country skiers and 10.6% (n = 36) in the controls ($p < 0.001$). Current asthma was reported by 91 (25.9%) skiers and 31 controls (9.2%) ($p < 0.001$) with no differences in asthma prevalence between sexes in either of the groups. All analyses regarding asthma as a classifying variable have been grouped by current asthma in this thesis.

Details on the prevalence of asthma and asthma-related factors are compiled in Table 8. It was observed that non-allergic asthma was more common among skiers, whereas allergic asthma was more prevalent in the control group.

Table 8. Prevalence of asthma by category.

	Cross-country skiers n = 351		Controls n = 338		
	Median/n	Q_1-Q_3/%	Median/n	Q_1-Q_3/%	p
Physician-diagnosed allergy to pollens or animals	113	32.2	82	24.5	0.025
Self-reported allergic rhinitis	160	45.7	122	36.9	0.019
Asthma in parents or siblings	137	39.0	100	29.6	0.007
Use of any asthma medication	123	35.0	39	11.5	<0.001
Has been diagnosed with or been investigated for asthma	189	53.8	69	20.4	<0.001
Current asthma	91	25.9	31	9.2	<0.001
Allergic asthma (% of current asthma)	36	39.6	19	61.3	0.036
Non-allergic asthma (% of current asthma)	55	60.4	12	38.7	
Age at first asthma-related symptoms in participants with asthma, yrs.*	13.0	8.25–16.0	8.0	2.25–11.75	<0.001
Age at diagnosis of asthma, yrs.*	15.0	12.0–17.8	10.0	3.0–12.0	<0.001
Time from onset of asthma-related symptoms to diagnosis of asthma, yrs.*	1.0	1.0–3.0	1.0	0–4.0	0.789
Asthma Control Test score*	22.0	21–24	22.0	19–24	0.611

*In participants with current asthma. P values were obtained with a Mann-Whitney U test for continuous variables and a Chi-squared test or Fisher's test for categorical variables.

5.3 Asthma in relation to performance level

In total, 163 (46.4%) skiers had participated in FIS competitions to earn FIS points. The prevalence of asthma and other asthma-related factors among these skiers are presented according to their performance level (Table 9). In the most successful subgroup of skiers, as measured by the lowest FIS points, the prevalence of asthma was the highest (56.1%). They were also the oldest and trained the most. The use of asthma medication differed between the groups, with more successful skiers using more often asthma medication. Asthma was well controlled in all subgroups. In skiers who did not report current asthma, 37.7% (98/260) reported that asthma had been suspected and investigated but not confirmed was made. In the performance level-based subgroup analysis, 85% of skiers in the most successful quartile had either been investigated for or diagnosed with asthma. Skiers with asthma had lower (better) average FIS points compared to skiers without asthma (173.22 (117.46) vs. 213.65 (108.83), $p = 0.026$).

Skiers who did not have FIS points were mostly juniors under 16 years of age (n =132) who did not yet participate in FIS competitions along with some athletes over 16 who had not yet competed in FIS events to earn points (n = 56). In this population (n = 188), 62.8% were females (n = 118), 37.8% had a known family history of asthma (n = 71), 62.2% were suspected of having or diagnosed with asthma (n = 117), 14.9% had current asthma (n = 28), 6.4% had allergic asthma (n = 12), 8.5% had non-allergic asthma (n = 16). Median (interquartile, IQR) age was 14.4 (13.6–15.7), and the median weekly training hours was 8.6 (7.0–10.5) hours. In addition, in juniors under 16 years of age, the prevalence of asthma was 16.7% (n = 22).

Table 9. Participant characteristics, training volume, the prevalence of asthma, use of asthma medication and asthma control in cross-country skiers divided by performance level according to FIS points. (Study II)

	Skiers with FIS points n = 163								
	Best quartile n = 41		2^{nd} quartile n = 41		3^{rd} quartile n = 41		Poorest quartile n = 40		p-value between the quartiles
FIS points range	0–120.54		120.25–185.13		185.14–247.52		247.53–999		
	Median/n	Q_1-Q_3/%	Median/n	Q_1-Q_3/%	Median/n	Q_1-Q_3/%	Median/n	Q_1-Q_3/%	
Females	16	39.0	22	53.7	25	61.0	23	57.5	0.205
Age	24.1	22.2–27.3	21.2	18.0–27.9	19.8	18.6–24.9	19.1	17.4–24.4	<0.001
Parents or siblings with asthma	13	31.7	18	43.9	20	48.8	15	37.5	0.419
Weekly training, hours	14.4	12.5–15.4	12.3	10.7–13.4	11.5	10–13.1	9.7	7.8–11.3	<0.001
Has been diagnosed with or been investigated for asthma	35	85.3	29	70.7	28	68.3	26	65.0	<0.001
Use of any asthma medication	25	61.0	22	53.7	16	39.0	17	42.5	0.171

	Skiers with FIS points n = 163								
	Best quartile n = 41		2nd quartile n = 41		3rd quartile n = 41		Poorest quartile n = 40		p-value between the quartiles
FIS points range	0–120.54		120.25–185.13		185.14–247.52		247.53–999		
	Median/n	Q_1-Q_3/%	Median/n	Q_1-Q_3/%	Median/n	Q_1-Q_3/%	Median/n	Q_1-Q_3/%	
Current asthma	23	56.1	17	41.5	11	26.8	12	30.0	0.028
Allergic asthma (% of current asthma)	8	34.8	8	47.1	3	27.2	5	41.7	0.730
Non-allergic asthma (% of current asthma)	15	65.2	9	52.9	8	72.8	7	58.3	
Asthma Control Test score among participants with current asthma	23.0	18–25*	22.0	18–25*	21.8	19–25*	21.8	17–25*	0.522

P values were obtained with a Mann-Whitney U test for continuous variables and a Chi-squared test or Fisher's test for categorical variables.

5.4 Onset age of asthma

In participants with asthma, the median age at first asthma-related symptoms (13.0 (8.25–16.0) vs. 8.0 (2.25–11.75) years, p <0.001). and median age at diagnosis of asthma (15.0 (12.0–17.8) vs. 10.0 (3.0–12.0), p <0.001) were higher in skiers compared with the controls. There was no difference between the groups in the time from first asthma-related symptoms to diagnosis of asthma, and in 57.1% (n = 52) of the skiers and 41.9% (n = 13) of the controls, asthma was diagnosed within one year after the first symptoms (p = 0.143). There were 16 cross-country skiers (4.6%

of all skiers and 19.7% of skiers with asthma) who reported having been diagnosed with asthma before they started cross-country skiing. In skiers whose asthma was diagnosed after they had started competitive cross-country skiing, the mean (SD) times from starting a competitive skiing career to first asthma-related symptoms and asthma diagnosis were 6.1 (4.2) and 8.3 (4.5) years, respectively. In participants with no asthma diagnosis, 38.0% (98/258) of skiers and 14.3% (39/273) of the controls reported as having been suspected and examined for asthma, but no diagnosis had been made. The prevalence of asthma according to age in skiers and the controls is presented in Figure 6.

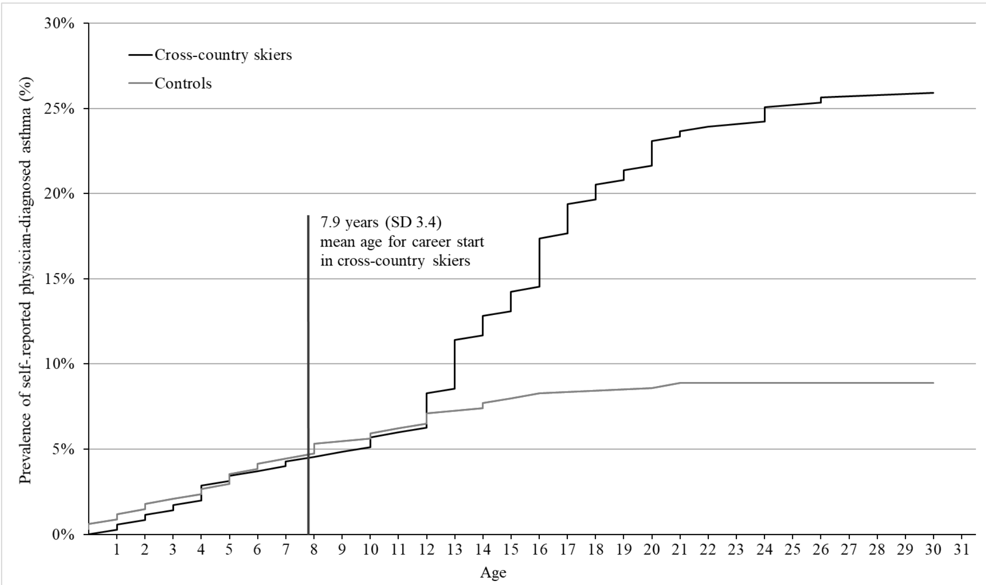


Figure 6. Prevalence of self-reported physician-diagnosed asthma according to age calculated based on reported age at diagnosis among the participants with asthma. The median age at asthma diagnosis was 15.0 (IQR 12.0–17.8) years in cross-country skiers and 10.0 (IQR 3.0–12.0) years in the controls ($p = 0.001$). A rapid increase in the prevalence occurs at 12 years of age in the cross-country skiers. The difference in the prevalence of asthma between the groups was statistically significant ($p < 0.05$) from 14 years of age onwards. Reproduced from Study I.

The prevalence of allergic and non-allergic asthma in skiers and controls was calculated based on their reported age at asthma diagnosis to illustrate the relationship between age at diagnosis and type of asthma (as shown in Figure 7). In cross-country skiers, a notable increase in the prevalence of non-allergic asthma was observed from the age of 10. Starting from 14 years of age onwards, a statistically significant difference ($p < 0.05$) in the prevalence of non-allergic asthma was observed between skiers and controls. However, the difference in the prevalence of allergic asthma between skiers and controls was not statistically significant.

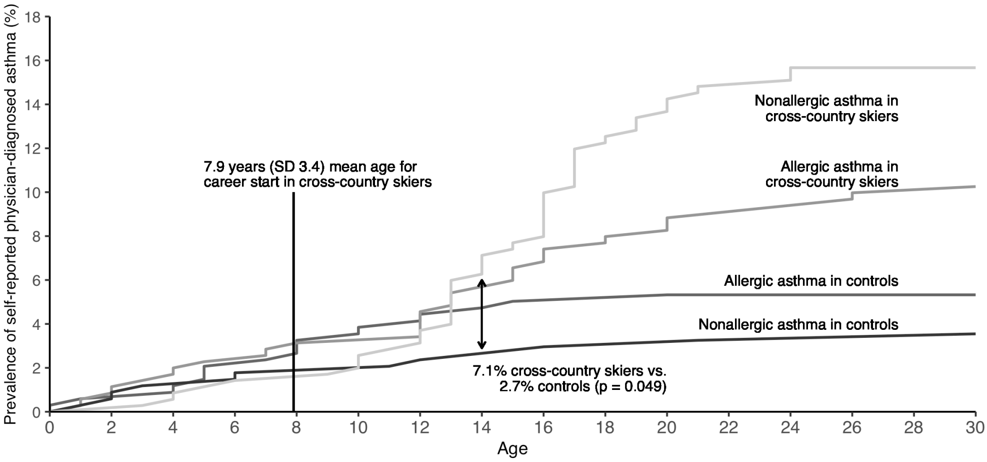


Figure 7. Prevalence of self-reported physician-diagnosed asthma according to age calculated based on reported age at diagnosis among the participants with asthma and divided by asthma status. Reproduced from Study II.

5.5 Use of asthma medication

Table 10 presents the use of asthma medication based on asthma status. In cross-country skiers, 98.9% (90/91) of those diagnosed with asthma and 12.7% (33/260) of those without an asthma diagnosis used asthma medication. In the control group, these percentages were 87.1% (27/31) for those with asthma and 3.9% (12/307) for those without. The use of inhaled corticosteroids (ICS) was more common among skiers with asthma compared to controls with asthma, and skiers with asthma tended to use ICS more regularly rather than seasonally, unlike the controls with asthma. A fixed combination of ICS and long-acting β2-agonist (LABA) was regularly used by 47.3% (n = 43) of the skiers and 22.6% (n = 7) of the controls with asthma, a difference that was statistically significant (p = 0.016). LABA monotherapy was not used by any of the athletes or controls. Additionally, none of the controls used anticholinergic agents as asthma medication.

Table 10. The use of asthma medication by asthma status. (Modified from Study I)

	Cross-country skiers (n = 351)					Controls (n = 338)					
	Asthma n= 91		No asthma n= 260		p	Asthma n = 31		No asthma n = 307		p	Difference between groups with asthma
	n	%	n	%		n	%	n	%		
Regular use of any ICS	75	82.4	6	2.3	<0.001	14	45.2	0	0	<0.001	<0.001
Seasonal use of any ICS	6	7.7	6	2.3	0.053	7	22.6	2	0.7	<0.001	0.02
Any use of β2-agonist or anticholinergic agent	73	80.2	28	10.8	<0.001	24	77.4	11	3.6	<0.001	0.739
Use of short-acting β2-agonist or anticholinergic agent	73	80.2	28	10.8	<0.001	24	77.4	10	3.3	<0.001	0.739
Use of long-acting β2-agonist or anticholinergic agent	14	15.4	1	0.4	<0.001	2	6.5	0	0	<0.001	0.203

P values were obtained with Chi-squared test or Fisher's test.

The question considering the use of asthma medication was an open text field. Based on the responses in 60.9% (n = 75) of the skiers and 33.3% (n = 13) of the controls who were using asthma medication, the indication for the use of bronchodilators could be identified. Among the skiers who provided any indication for usage, all reported employing bronchodilators pre-emptively before exercise. Conversely, only four controls (10.3%) indicated pre-emptive use of bronchodilators.

5.6 Asthma control

Asthma was well-controlled (ACT score ≥20) in 89.0% (n = 81) of the skiers and 77.4% (n = 24) of the controls with asthma (p = 0.045). Asthma was poorly controlled (ACT score ≤15) in none of the skiers but in 16.1% (n = 5) of the controls with asthma and the lowest scores reported were 17 and 12 in skiers and controls, respectively.

When asthma control was grouped by performance level in skiers, no difference was found between groups with FIS points (Table 11). Among skiers with no FIS points including juniors, the median (IQR) ACT score was 23 (21–24).

Table 11. Asthma control by performance level.

	Best quartile n = 41		2nd quartile n = 41		3rd quartile n = 41		Poorest quartile n = 40		
FIS points range	0–120.54		120.25–185.13		185.14–247.52		247.53–999		
	Median	Range	Median	Range	Median	Range	Median	Range	p
ACT score	23.0	18–25	22.0	18–25	21.8	19–25	21.8	17–25	0.522

P values were obtained with a Mann-Whitney U test.

5.7 Risk factors related to asthma

The risk factors for current asthma in cross-country skiers and the controls are presented in Table 12. In both groups, asthma in parents or siblings and allergic rhinitis were associated with current asthma. In cross-country skiers, older age, higher training volume and success – here measured by FIS points – were also associated with current asthma. Being a cross-country skier was associated with OR of 3.47 (95% CI 2.23–5.38, $p < 0.001$) for having asthma, 1.92 (1.08–3.42, $p < 0.027$) for having allergic asthma and 5.05 (2.65–9.61, $p < 0.001$) for having non-allergic asthma.

Skiers' risk factors for allergic and non-allergic asthma are presented according to the univariate and multivariate analyses in Tables 13 and 14, respectively. We found that older age and higher training volume were associated with non-allergic asthma, while older age, family history of asthma and allergic rhinitis were associated with allergic asthma (Table 13). In the multivariable analyses, the association between larger training volume and non-allergic asthma persisted, while older age, family history of asthma and allergic rhinitis were independently associated with allergic asthma (Table 14).

Table 12. Univariate analysis of the risk factors for current asthma in cross-country skiers and controls, represented as odds ratios (OR) with 95% confidence intervals. (Study II)

	All		Skiers		Controls	
	OR (95% CI)	p	OR (95% CI)	p	OR (95% CI)	p
Being a cross-country skier	3.47 (2.23–5.38)	<0.001	NA		NA	
Age (per year)	1.05 (1.02–1.08)	0.001	1.07 (1.03–1.12)	<0.001	1.04 (0.99–1.09)	0.112
100 hours more training or heavy exercise per year	1.30 (1.20–1.40)	<0.001	1.36 (1.19–1.56)	<0.001	1.01 (0.82–1.25)	0.919
Parents or siblings with asthma	2.76 (1.85–4.11)	<0.001	2.15 (1.32–3.48)	0.002	3.88 (1.82–8.27)	<0.001
Female gender	1.01 (0.67–1.52)	0.956	1.14 (0.70–1.85)	0.602	0.78 (0.34–1.80)	0.554
Allergic rhinitis	2.83 (1.89–4.24)	<0.001	2.11 (1.30–3.43)	0.003	4.89 (2.17–11.01)	<0.001
50 FIS points less	NA		1.19 (1.02–1.39)	0.03	NA	

Binary logistic regression method was used.

Table 13. Univariate analysis of the risk factors for allergic and non-allergic asthma in cross-country skiers represented as odds ratios (OR) with 95% confidence intervals. (Study II)

	Non-allergic asthma n = 55			Allergic asthma n = 36		
	OR	95% CI	p	OR	95% CI	p
Age	1.05	1.00–1.09	0.032	1.07	1.02–1.12	0.05
100 hours more training per year	1.35	1.16–1.58	<0.001	1.18	0.99–1.41	0.064
Parents or siblings with asthma	1.63	0.91–2.91	0.098	2.40	1.19–4.84	0.014
Female gender	1.00	0.56–1.79	0.992	0.76	0.37–1.56	0.46
Allergic rhinitis	0.69	0.38–1.25	0.224	16.20	4.86–53.95	<0.001
50 FIS-points less	0.87	0.73–1.04	0.137	1.15	0.92–1.43	0.217

Binary logistic regression method was used.

Table 14. Multivariable analysis for the risk of current asthma in cross-country skiers represented as odds ratios (OR) with 95% confidence intervals. (Study II)

	All		Non-allergic asthma		Allergic asthma	
	OR (95% CI)	p	OR (95% CI)	p	OR (95% CI)	p
Age	1.06 (1.01–1.11)	0.011	1.02 (0.97–1.07)	0.411	1.08 (1.02–1.14)	0.011
100 hours more training per year	1.29 (1.11–1.50)	0.001	1.33 (1.12–1.58)	0.001	1.10 (0.89–1.36)	0.379
Parents or siblings with asthma	2.41 (1.42–4.08)	0.001	1.81 (0.98–3.33)	0.057	2.47 (1.15–5.30)	0.021
Allergic rhinitis	2.14 (1.27–3.60)	0.004	0.64 (0.34–1.19)	0.642	16.38 (4.82–55.67)	<0.001

Binary logistic regression method was used.

5.8 Respiratory symptoms

Number of different respiratory symptoms in cross-country skiers and controls at different states is presented in Figure 8, and all percentages from figures on respiratory symptoms are presented in Supplemental file 1 of the original publication (Study III). Both groups were mostly asymptomatic at rest, but symptoms increased in both groups during and after exercise. Skiers had more exercise-related respiratory symptoms than the controls (Figure 8). Moreover, skiers tended to have more symptoms after than during exercise.

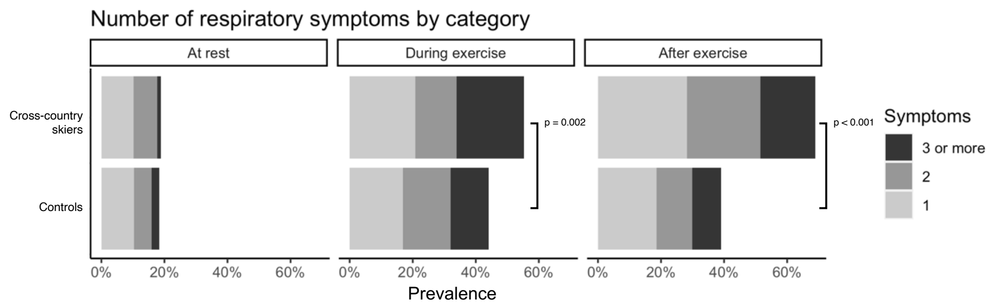


Figure 8. Number of different respiratory symptoms in cross-country skiers and controls at rest, during exercise and after exercise. Reproduced from Study III.

The most common respiratory symptoms in cross-country skiers were cough, phlegm production, wheezing and shortness of breath. Only chest tightness was uncommon in cross-country skiers. The distribution of various respiratory symptoms was more equal among the controls (Figure 8). There were significant differences between the groups regarding respiratory symptoms. Cough was more prevalent after exercise in skiers. Phlegm production was more common in skiers both during and after exercise. In the controls, wheezing was more common at rest than in skiers, but during exercise and after exercise, skiers experienced wheezing significantly more often. (Figure 9)

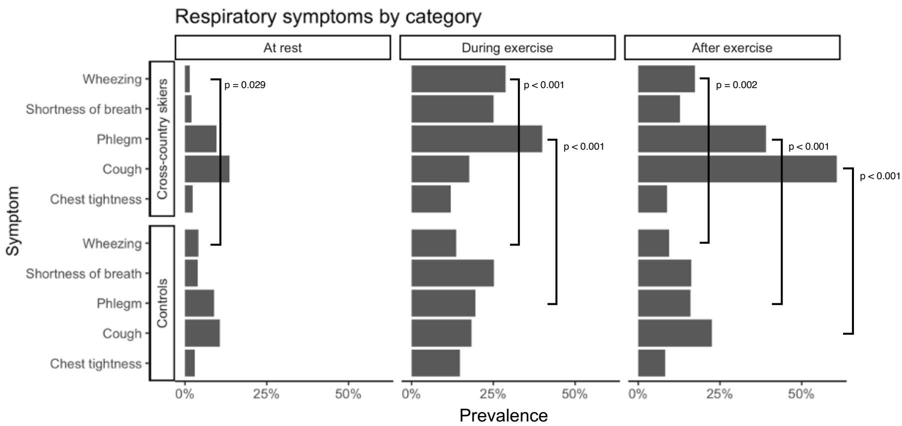


Figure 9. Prevalence of different respiratory symptoms in cross-country skiers and controls at rest, during exercise and after exercise. Reproduced from Study III.

Because asthma was more prevalent among skiers, the prevalence of respiratory symptoms in different physical activity categories according to asthma status is shown in Figure 9. Skiers and controls with asthma reported a similar number of respiratory symptoms at rest and during exercise, but cross-country skiers with asthma had more symptoms after exercise than the asthmatic controls. In participants without asthma, cross-country skiers had more symptoms during and after exercise compared with the controls.

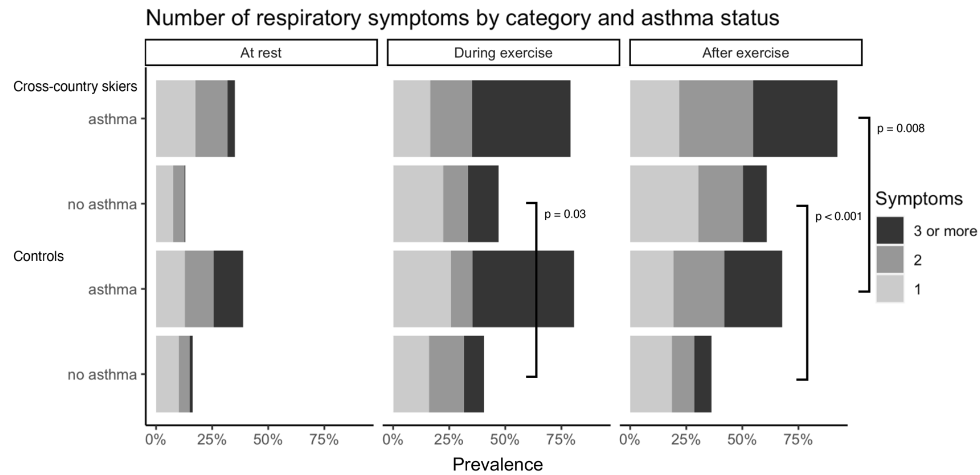


Figure 10. Number of respiratory symptoms in cross-country skiers and controls at rest, during exercise and after exercise according to the asthma status. Reproduced from Study III.

When respiratory symptoms were grouped by category and asthma status, a higher prevalence in all symptoms was found in participants with asthma. The relative proportions of different symptoms between asthmatic and non-asthmatic participants were similar (i.e., asthma did not provoke specific symptoms), but the prevalence of symptoms in general was higher in participants with asthma (Figure 11).

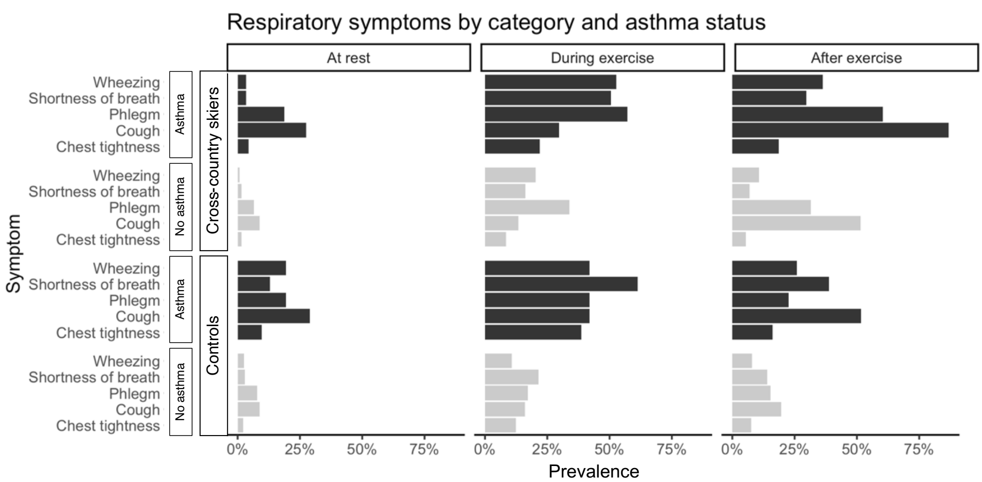


Figure 11. Prevalence of different respiratory symptoms in cross-country skiers and controls at rest, during exercise and after exercise according to asthma status. Reproduced from Study III.

The most frequent triggers of respiratory symptoms identified were dust, tobacco smoke, exhaust gases, cold air, pollen, and strong odours. These triggers elicited more respiratory symptoms in participants with asthma compared to those without asthma. Among participants without asthma, cold air was a more common trigger for symptoms in skiers than in controls. Conversely, strong odours more frequently triggered symptoms in asthmatic controls than in asthmatic skiers. This information is detailed in Table 15.

Table 15. Triggers causing respiratory symptoms. (Study III)

	No asthma n = 567					Asthma n = 122				
	Controls n = 307		Cross-country skiers n = 260		*p* between groups with no asthma	Controls n = 31		Cross-country skiers n = 91		*p* between groups with asthma
	n	%	n	%		n	%	n	%	
Cold air	55	18.0	68	26.1	0.025	19	61.3	56	62.2	1.000
Dust, tobacco smoke, exhaust gases	100	32.7	89	34.4	0.739	22	71.0	55	60.4	0.404
Pollen	46	15.0	56	21.6	0.055	17	54.8	42	46.7	0.564
Hairy animals	21	6.9	18	7.0	1.000	11	36.7	18	19.8	0.103
Strong odours	51	16.7	28	10.7	0.058	16	51.6	23	25.3	0.013
Humid, misty air	15	4.9	10	3.8	0.693	3	9.7	17	18.7	0.399

P values were obtained with Chi-squared test or Fisher's test.

5.9 Prolonged cough

Current cough, both acute and prolonged, was more prevalent in controls compared with skiers (Table 16). When skiers and controls were pooled together, participants with prolonged coughs also reported coughs more frequently at exercise and after exercise (Table 17). Further, participants with prolonged coughs reported cold air and strong odours as triggers for their respiratory symptoms more frequently. Chronic cough lasting more than eight weeks was rare and was reported in 16 controls (4.8%) and 7 skiers (2.0%) ($p = 0.047$).

Table 16. Current cough in cross-country skiers and controls. (Study III)

	Controls n = 332		Cross-country skiers n = 345		p
	n	%	n	%	
Any current cough	105	32.0	61	17.7	<0.001
Acute cough (<3 wk)	73	21.9	47	13.6	0.006
Prolonged cough (≥3 wk)	32	9.6	14	4.1	0.004

P values were obtained with Chi-squared test.

Table 17. Characteristics of participants with and without current prolonged cough. (Study III)

	No current cough or cough < 3 weeks n = 640		Prolonged cough ≥ 3 weeks n = 46		
	Median/n	Q_1-Q_3/%	Median/n	Q_1-Q_3/%	p
Age	16.8	14.8–21.3	17.7	14.8–26.3	0.408
Cross-country skier	337	52.6	14	30.4	0.004
Females	407	63.5	30	65.2	0.815
Current asthma	110	17.2	12	26.1	0.126
Smoking	19	3.0	1	2.2	1.000
Cough at exercise	101	15.8	22	47.8	<0.001
Cough after exercise	258	40.2	31	67.4	<0.001
Cold air provokes respiratory symptoms	176	27.5	22	47.8	0.003
Strong odours provoke respiratory symptoms	100	15.6	18	39.1	<0.001

P values were obtained with a Mann-Whitney U test for continuous variables and a Chi-squared test or Fisher's test for categorical variables.

5.10 Acute respiratory infections

The majority of skiers had refrained at least once from training (85.8%) or competing (66.0%) due to ARinfs during the season. A higher proportion of asthmatics (76.9%) than non-asthmatics (62.2%, p=0.011) had refrained from competing (Table 18). The odds ratio, with asthma as a risk factor for having to refrain from training, was 2.00 (CI 95% 0.90–4.43, p = 0.089), and from competition, it was 2.03 (CI 95% 1.17–3.51, p = 0.011). About half of the skiers trained, and one-fifth competed during ARinf, with no difference in relation to asthma.

Table 18. Number and proportion of cross-country skiers who reported refraining from training and competing because of acute respiratory infections at least once and who reported training or competing during acute respiratory infections at least once during the 2018/2019 season. The results were grouped by current asthma. (Study IV)

	Response	"Yes" in all skiers		"Yes" in skiers with asthma		"Yes" in skiers without asthma		
	n	n	%	n	%	n	%	p*
Refrained at least once from								
training because of ARinf	351	301	85.8	83	91.2	218	83.8	0.084
competition due ARinf	350	231	66.0	70	76.9	161	62.2	0.011
During ARinf at least once								
training	309	168	54.4	44	58.7	124	53.0	0.391
competing	351	79	22.5	25	27.5	54	20.8	0.188

*between skiers with and without asthma. P values were obtained with Chi-squared test.

There were no notable differences between the sexes, between juniors and seniors (cut-off age 16 years) or between quartiles grouped by training volume or competition success (FIS points) in refraining from training or competition because of an ARinf or in training or competing during an ARinf. (Table 19)

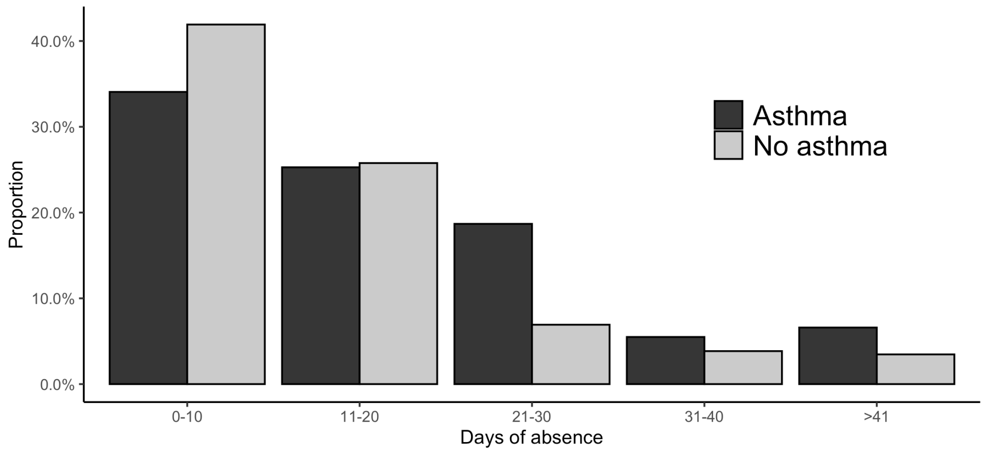
Table 19. Participant characteristics, training volume, prevalence of asthma, use of asthma medication and asthma control in cross-country skiers divided by performance level according to FIS points. (Study IV)

	Refrained from training due to ARinf			Refrained from competition due to ARinf		
	n	%	p	n	%	p
Male (147)	120	81.6		100	68.0	
Female (204)	181	88.7	0.061	131	64.5	0.496
Under 16 years of age (130)	108	83.1		85	65.4	
Over 16 years of age (221)	190	86.0	0.464	143	64.7	0.898
FIS points range (points)						
The best quartile (0–120.54)	37	90.2		30	73.2	
2nd quartile (120.25–185.13)	35	85.4		28	68.3	
3rd quartile (185.14–247.52)	33	80.5		22	53.7	
4th quartile (247.53–999)	35	87.5	0.632	27	67.5	0.280
Weekly training (hours)						
1st quartile (12.5–25.0)	75	85.2		61	69.3	
2nd quartile (10–12.5)	74	84.1		50	56.8	
3rd quartile (8.0–10.0)	78	88.6		58	65.9	
4th quartile (1.9–8.0)	74	85.1	0.837	62	72.1	0.160

P values were obtained with Chi-squared test.

Cross-country skiers with asthma had more days of absence from training because of an ARinf during the season compared with skiers with no asthma (median 15 days (IQR 8–28) vs. 10 days (IQR 6–18), $p = 0.006$, (Figure 12)). There were no differences in the days of absence because of an ARinf between quartiles when grouped by training volume (11, 11.5, 10 and 14.5 days in descending order, $p = 0.105$) or by FIS points (competition success) (10, 13, 10 and 10 days in descending order, $p = 0.893$). Skiers with asthma had a higher number of ARinf episodes than skiers with no asthma (3 (IQR 2–4) vs. 3 episodes (IQR 2–3), $p = 0.028$), but no difference was found between quartiles grouped by training volume (3, 3, 3, 3 events in descending order, $p = 0.846$) or by FIS points (3, 3, 3, 3 episodes, $p = 0.418$). The median duration of a single ARinf episode was longer in skiers with asthma (5.0 days, IQR 3.8–6.8 vs. 4.0 days, IQR 3.0–6.7, p = 0.017).

Figure 12. Days of absence from training because of ARinf in cross-country skiers as grouped by asthma status (median 15 days (IQR 8–28) in those with asthma vs. 10 days (IQR 6–18) in those without asthma, p = 0.006). Reproduced from Study IV.



5.11 Non-responder analysis

The non-responder analysis is presented in Table 20. Females responded more often in both groups, but in neither of the groups were there an age difference between the responders and non-responders. The FIS point distribution representing success in races was similar in the responders and non-responders among the cross-country skiers.

Table 20. Non-responder analysis in cross-country skiers and controls. (Study I)

	Cross-country skiers				Controls			
	Responders n=351		Non-responders n=931		Responders n=338		Non-responders n=1395	
	mean/ n	SD/%	mean/n	SD/%	mean/n	SD/%	mean/n	SD/%
Age, yrs.	18.8	6.1	18.6	6.2	19.7	6.8	19.9	6.2
Females	204	58.1	419	45.0	235	69.5	779	55.8
FIS points	198.02	163	195.55	430	N/A	N/A	N/A	N/A

The results are presented as mean (SD) or n (%).

6 DISCUSSION

6.1 Prevalence of asthma in cross-country skiers

In this thesis using a cross-sectional survey, the prevalence of asthma in competitive cross-country skiers was 25.9%. This was slightly higher than the 21% (CI 95% 14–28%) in a recent meta-analysis (Mäki-Heikkilä et al., 2020). However, the present study is in line with the most recent studies from Sweden, where the prevalence of asthma was 23%, 27%, and 31% (Eklund et al., 2018; Lennelöv et al., 2019; Norqvist et al., 2015).

This thesis reports for the first time the asthma prevalence in cross-country skiers based on success in competitions. Interestingly, the prevalence of asthma was the highest among the most successful skiers (56.0%, table 9). This may be related to several factors. First, the most successful skiers also trained the most. If a high volume of training in cold air causes asthma, this might be the reason for the higher prevalence of asthma in the most successful skiers. To support this finding, athletes using β2-agonists in the Olympic games from 2002 through 2010 won approximately twice as many medals as their proportion of all athletes across all disciplines (Fitch, 2012).

Another possible explanation for the high prevalence of asthma in the most successful skiers is related to the propensity to seek medical attention. This is likely because they are more invested in their careers and any symptoms could potentially hinder their performance. This is supported by the high rate of suspicion for asthma in this group, as 85.3% of the most successful skiers and 53.8% of all skiers have either been diagnosed with asthma or investigated for it.

Moreover, given their high level of training and competition, these successful skiers may be more aware of their bodily symptoms, including those related to respiratory health. This heightened awareness could make them more proactive in seeking medical evaluation and treatment. Additionally, the level of competition and training would add higher demands on the respiratory system among the most successful skiers.

The comparative prevalence of asthma in skiers and the general population prompts an examination of the underlying causes of this disparity. In recent epidemiological surveys on respiratory health, a decline in response rates has been observed, which often leads to the consideration that non-responded individuals, who may have fewer health issues, would less likely participate. This opens the possibility that the actual prevalence of asthma in the non-responder group of skiers could be lower. An estimation of a 10% prevalence among non-responders would lead to an adjusted overall prevalence estimate of 14.2%.

Furthermore, another consideration of whether the reported lower prevalence of asthma in the general population might be attributed to a lack of rigorous testing. In the studied population, 53.8% of skiers underwent lung function testing to investigate asthma whereas only 20.4% of controls had any testing. If the control group were subjected to the same lung function testing including exercise tests, as the skiers, it is conceivable that the prevalence rate in the general population might align more closely with that observed in skiers.

The high prevalence of lower airway dysfunction in athletes has remained consistent over the past three decades (Price et al., 2022). In 64 studies compiled to a meta-analysis the prevalence of lower airway dysfunction was 21% and was higher in certain subgroups such as winter athletes, endurance athletes and swimmers, 29.5%, 25.1% and 39.9%, respectively (Price et al., 2022). Asthma was considered a subterm of lower airway dysfunction in compilation with EIB and airway hyperresponsiveness (AHR).

However, the methodologies employed to determine lower airway function are crucial in presenting these figures. When studies were filtered by the type of lung function test used, the lowest prevalences were reported in actual exercise tests (16.8 %) which would represent real-life conditions (Price et al., 2022). Bronchial provocation tests, for example, tend to yield the highest percentages of dysfunction, often exceeding 30 % depending on the study (Price et al., 2022). In the meta-analysis by the author and others, the prevalence of asthma in cross-country skiers varied by method: Questionnaires report 21%, questionnaires with lung function testing 28% and one study with lung function testing only reported 20% (Mäki-Heikkilä et al., 2020; Turmel, Poirier, et al., 2012).

This evidence underscores the importance of methodology in studies measuring the prevalence of asthma/lower airway dysfunction, highlighting why the observed excess prevalence should be further and more carefully investigated in an unselected population, including asymptomatic individuals.

This speculation introduces a critical discussion point: is the apparent higher prevalence of asthma in skiers merely a consequence of more thorough testing and not necessarily a direct result of engaging in the sport? Many studies have pointed towards the underdiagnosing of asthma in cross-country skiers (Chapter 2.4.3), indicating that asthma in skiers, which would be mild in nature, may be asymptomatic and merely subjectively detectable.

The question of whether cross-country skiing is inherently harmful or if a high prevalence of asthma simply reflects a more thorough detection process remains open. The apparent overrepresentation of asthma and especially non-allergic asthma in skiers may indeed partly result from careful testing. However, it seems it is not fully explained by this reason alone. Future research aimed at understanding the excess prevalence of asthma should seek to disentangle the complex interplay of factors, including the extent of medical testing, environmental influences of the sport, actual pathophysiological mechanisms and potential underdiagnosis in the general population. Overreporting of asthma is also possible as the diagnoses are not always based on lung function testing and are only symptom-based.

6.2 Types of asthma and asthma-related risk factors

This thesis is the first to report the relative proportions of allergic and non-allergic asthma in competitive cross-country skiers and controls and assess the risk factors for different types of asthma in skiers. Interestingly, the difference in the prevalence of asthma in skiers and controls seems to be mainly because of the excess prevalence of non-allergic asthma in skiers (Figure 7). The current findings suggest that intensive training in cold air is the trigger for inducing the excess of non-allergic asthma in skiers. The increase in the prevalence of asthma in skiers after their career started was mainly because of an increase in the prevalence of non-allergic asthma. During this time, young athletes also start increasing training volume and intensive training in the cold and participating in competitions over longer distances. Increased training volume was a risk factor for non-allergic, but not for allergic asthma.

This relation between intensive training and non-allergic asthma might be related to airway damage caused by cold air because airway damage has been suggested as one of the risk factors for non-allergic asthma (Janson et al., 2007; Rennie et al., 2020; Vandenplas et al., 2014). The inflammatory mechanisms of non-allergic asthma can be non-allergic eosinophilic, neutrophilic, mixed or pauci-granulocytic (Wenzel, 2012). In biopsy studies, skier's asthma is more neutrophilic than asthma in controls (Karjalainen et al., 2000; Sue-Chu et al., 1998; Sue-Chu, Larsson, et al., 1999). Non-allergic eosinophilic asthma is more often severe with onset in late adulthood (Wenzel, 2012) and, therefore, is not very likely among young competitive athletes with extremely good physical performance. In the 2015 study by Couto and others, the phenotypes of asthma in athletes were categorised into atopic asthma and sports asthma (Couto et al., 2015). In this study, the categorisation was quite similar when using allergic and non-allergic asthma.

The categorisation of asthma as allergic and non-allergic asthma in this thesis was based on a questionnaire rather than direct measurement of allergic sensitisation or allergen challenge tests. However, the prevalences of allergic asthma were similar with three different definitions of allergic asthma, supporting the robustness of the results (Supplemental file 1 of Study II). Relevant aeroallergens in Finland are pollens and pets, covered in the questionnaire. Because of dry indoor air during the cold winter, house dust mite is rarely a clinically relevant allergen in Finland (Pennanen et al., 2007).

6.3 Onset age of asthma

The age at first asthma-related symptoms was higher in skiers than in the controls and was similar as in the latest studies in the 2010s (Eklund et al., 2018; Norqvist et al., 2015) However, in those studies, the criteria of onset of asthma were first asthma attack, while in the current study, we report also the median age at diagnosis and the median time difference between age at first asthma-related symptoms and age at diagnosis.

The prevalence of asthma starts to differ between skiers and non-skiers in early adolescence (Figure 6) and is statistically different from 14 years of age onwards. Sixteen cross-country skiers reported having asthma before they started cross-country skiing. This represents 4.5% of all cross-country skiers in the current study. and this subgroup of skiers has not been reported before. Thus, asthma may not be a major hurdle to start competitive cross-country skiing because there was no difference in asthma prevalence between the skiers and controls before the typical age of starting a skiing career. Based on these data, the difference in the prevalence of asthma starts to occur in adolescence after having started a skiing career. In skiers whose asthma was diagnosed later after they had started competitive cross-country skiing, the mean time to first asthma-related symptoms and to asthma diagnosis from career start was 6.2 and 8.6 years, respectively.

New cases of asthma in the Finnish population are mostly allergic until the age of 40, and in participants of similar age to the current population, about 65% of asthma is allergic (Pakkasela et al., 2020). This is well in line with 61% of the control participants with asthma in the current study reporting allergic asthma. The risk factors for allergic asthma in childhood are allergic sensitisation of the participant and parental asthma or allergy (Janson et al., 2007). This is in line with a family history of asthma and doctor-diagnosed allergy being risk factors for allergic asthma among competitive skiers.

6.4 Use of asthma medication

The use of asthma medication was significantly higher in cross-country skiers compared with the controls. Skiers with asthma used ICS more regularly. The indication for the use of bronchodilators has not been previously reported in cross-country skiers other than the use of asthma medication on a regular basis or occasionally (Heir & Oseid, 1994). ICS was used in combination with LABA in 47.3% of the skiers and 22.6% of the controls with asthma. In one study performed on cross-country skiers with “ski asthma” and controls with asthma, the effect of regular ICS was limited in skiers (Sue-Chu et al., 2000), and this may explain the frequent use of LABA in skiers.

However, it's also crucial to note that among skiers without a confirmed asthma diagnosis, 12.7% (n = 33) reported using asthma medication, primarily bronchodilators before exercise. Of these skiers with no asthma using asthma medication, 88% had been suspected of having asthma, but the diagnosis had not been confirmed. The reasons behind it warrant careful examination. In cases where the diagnosis has not been confirmed, but symptoms persist, a thorough reassessment of the athlete's condition would be recommended. The use of asthma medication without a confirmed diagnosis raises questions about possible over-prescription or self-medication in response to respiratory symptoms that may not stem from asthma, such as exercise-induced laryngeal obstruction or dysfunctional breathing.

The ergogenic effects of β2-agonists have been extensively studied. Meta-analyses by Riiser et al. have shown that while these substances enhance strength and power, they do not improve endurance performance or maximal oxygen uptake (Riiser et al., 2020a, 2020b). As knowledge about the effects of β2-agonists has advanced, the regulatory landscape concerning their use in sports has similarly progressed. Over the past decade, rules have been relaxed to better accommodate the health needs of athletes with asthma, striving for a balance between health and fair competition (*2010 Prohibited List Summary of Major Modifications*, 2009; *2023 Prohibited List*, 2022).

As the supra-therapeutic doses have been proved to be performance-enhancing and thus prohibited, the latest research have focused on the effects of the highest permissible therapeutic doses of β2-agonists on exercise performance, such as formoterol at maximum allowed daily dose with improvements in 6-second power and a slight improvement in 4-minute time trial on cycle ergometer (Jeppesen et al., 2023).

The primary aim of adjusting these rules was to prevent asthmatic athletes from being placed at a disadvantage. The prevailing evidence indicates that these medications do not boost performance in longer endurance events, yet further investigation into possible unrecognised effects is warranted. Continued research and strict oversight of asthma medication misuse are imperative. The ethical use of these medications in sports must be maintained, and any potential shift towards performance enhancement prevented. It is vital that guidelines and regulations are regularly updated, reflecting the latest scientific findings, to ensure the integrity of competitive sports and the health and safety of all athletes.

Anticholinergic agents, noted for their usage by 7.1% of the skiers but by none of the controls and often in combination with β2-agonists, present an intriguing aspect of asthma management in these athletes. Typically, anticholinergics are not considered a first-line therapy for asthma. They are usually introduced as a third line of treatment, following the standard progression from inhaled corticosteroids (ICS) to ICS+LABA and then adding LAMA (long-acting muscarinic antagonists) (*Global Initiative for Asthma. Global Strategy for Asthma Management and Prevention*, 2022).

6.5 Respiratory symptoms

A high prevalence of respiratory symptoms in cross-country skiers was found during and after exercise. Skiers are more symptomatic than controls, even when the participants are grouped by asthma status. Asthmatic participants had more symptoms than non-asthmatics in both skiers and controls. Even though cough after exercise was highly prevalent in skiers compared with the controls, prolonged cough over three weeks was more prevalent in the controls.

Different respiratory symptoms may have different causes. Cough and phlegm may be triggered by irritation of the airways, which activates sensory nerves and mucous glands, while wheezing and shortness of breath may be signs of obstruction, possibly due to smooth muscle contraction or mucosal oedema. (Cruz & Togias, 2008; Silvers, 1991) Also, dysfunctional breathing or exercise-induced laryngeal obstruction (EILO) may case dyspnoea and wheezing, mimicking asthma. Gastro-oesophageal reflux, although not extensively studied in skiers regarding cough (Boulet & Turmel, 2019), may also play a role. Furthermore, cold air hyperpnea can increase airway lining fluid osmolarity by evaporating water, activating certain sensory endings and causing coughing (Koskela et al., 2020). Exercise-induced bronchoconstriction (EIB) could trigger coughing; however, bronchoconstriction is a relatively weak stimulus for cough (Koskela et al., 2005).

Although asthma was highly prevalent in skiers, prolonged cough was not. The mechanisms behind asthma and cough reflex hypersensitivity are at least partly different (Koskela et al., 2021). High ventilation rate in cold air may trigger epithelial damage, induce inflammatory response and lead to hyper-reactivity of airway smooth muscle and asthma (Anderson & Kippelen, 2005). Once hyper-reactivity has developed, EIB is thought to be caused by water loss, resulting in heat loss and hyperosmolality of the airway surface liquid during exercise, leading to activation of mast cells releasing substances contracting smooth muscle (Anderson & Kippelen, 2005).

The most common respiratory symptom in skiers was cough, especially after exercise. Prolonged cough for over 8 weeks was very rare in skiers (2.0%). In both groups, current cough had mainly lasted less than 3 weeks, but prolonged cough was two times as prevalent in controls as in skiers. This does not support our hypothesis that repeated exposure through high-volume endurance training causes long-term cough reflex hypersensitivity. This may be partly explained by the survey taking place outside the competition season during which skiers may be less symptomatic than in the training season. A study to support this was reported in Scandinavia in the 90s, where in the winter, 42% of Norwegian skiers and 64% of Swedish skiers ($p<0.001$) reported coughing during training while during the summer, the respective percentages were 10% in Norwegian and 9% in Swedish skiers (Sue-Chu et al., 1996). To support this, in another Norwegian study in cross-country skiers, the airways were found to be more hyperreactive to methacholine challenge during competition season in skiers (Heir, 1994; Heir & Larsen, 1995).

Cough after exercise and prolonged cough may be related to different mechanisms. Airway mucosa irritation due to intense ventilation in cold air is a physiological response, as suggested by the high prevalence of rhinorrhoea in healthy participants exposed to cold air (Cruz & Togias, 2008; Silvers, 1991). This may also trigger short-term cough after intense exercise in cold air. On the other hand, prolonged cough is often related to cough reflex hypersensitivity, which may involve altered function in peripheral sensory neurons or altered central processing of the urge to cough (Chung et al., 2022). Turmel et al. discussed that cough receptors could be desensitised due to long-term exposure to cold and dry air (Turmel, Bougault, et al., 2012). This would explain why exercise may still trigger a short-term cough right after exercise but decreases the tendency to have prolonged cough. Moreover, capsaicin, another hypertussive irritant in addition to cold air, triggers cough after a single exposure but has been suggested to decrease cough sensitivity and to treat chronic cough as repeated dosing (Slovarp et al., 2022; Ternesten-Hasséus et al., 2015). This similarity between capsaicin and repeated exposure to cold air further supports the idea that different mechanisms are involved in cough after exercise and prolonged cough. Exposure to a trigger like cold air or capsaicin provokes cough, but repeated long-term exposure to the same trigger may desensitise cough reflex and protect from chronic cough.

Among participants of this study, we found that 39.1% of all participants and 35.7% (5 with prolonged cough vs 44 with no cough, $p<0.035$) of skiers with prolonged cough were sensitive to strong odours. This feature, known to be associated with cough reflex hypersensitivity in the general population (Millqvist, 2011; Morice et al., 2014), has not been reported in athletes previously. Furthermore, participants with asthma were more sensitive to strong odours, and this may be related to asthmatic inflammation sensitising cough reflex (Diver et al., 2019).

To interpret these high prevalence rates of respiratory symptoms in skiers, it should be highlighted that cross-country skiing puts an exceptionally high strain on airways through high sustained ventilation and cold subfreezing air in the winter (Holmberg et al., 2007; Sandbakk & Holmberg, 2014). Although respiratory symptoms may be a sign of respiratory illness, such as asthma, the airway response in the form of cough and increased sputum production may also be a physiological response to exercise (Cruz & Togias, 2008; Silvers, 1991). Although skiers are symptomatic, asthma is well controlled overall and across different performance levels (Study I and Study II). However, it is possible that skiers with respiratory health issues may have retired from their athletic career and, thus, not affecting the results. Skiers may also present with different conditions affecting the airways simultaneously, such as EILO or dysfunctional breathing (Schwellnus et al., 2022b). The presence of other respiratory conditions may further confound the results, as not all symptoms are due to asthma and different respiratory conditions may exist simultaneously, as shown by Irewall et al. (Irewall et al., 2021)

In this thesis, the focus was placed on quantifying the prevalence of five primary respiratory symptoms: cough, wheezing, chest tightness, phlegm production, and shortness of breath and their prevalence at rest, at exercise and after exercise. These symptoms should not be exclusively attributed to asthma, as there are often co-existing respiratory conditions that can manifest similarly. Therefore, while cough was identified as the most commonly reported symptom among skiers within the scope of these five, this finding does not preclude the existence, or the importance of other respiratory symptoms induced by exercise in cold environments.

Future research should consider a more general and open approach to symptom collection. This could involve qualitative surveys that allow athletes to report a wider range of symptoms in their own words, providing a richer and more nuanced understanding of the respiratory impacts of cross-country skiing. However, there is a delicate balance to be struck between the richness of open-ended questions and the clarity and comparability provided by specific, predefined symptoms. In moving forward, it will be important to find ways to capture the full complexity of athletes' respiratory health while still producing clear and actionable findings.

6.6 The burden of acute respiratory infections on training and competition

In the present study, we found that the majority of skiers had to refrain from training because of an ARinf during the season, and two-thirds of skiers had to refrain from competition because of an ARinf. Despite this, about half of the skiers trained and about one-fifth had competed during an ARinf. Skiers with asthma had more and longer episodes of ARinf, leading to increased days off from training and a higher rate of withdrawal from competitions.

Considering the high prevalence of asthma among cross-country skiers (20–30%) (Mäki-Heikkilä et al., 2020), its potential association with ARinfs could have a significant impact on a considerable number of athletes. Higher proportion of asthmatic skiers missed competition because of an ARinf and had more days with ARinf symptoms, which could be due to longer recovery times with chronic inflammation of the airways (Heir, 1994; Heir et al., 1995). The literature is scarce in investigating the effects of asthma on acute respiratory infections in athletes. In a recent study by Hull et al., 63% of 122 athletes were classified as susceptible to RTI (respiratory tract infection, equivalent to ARinf in the current study) if they had at least two or more RTI episodes in the past 18 months (Hull et al., 2021). In their analysis, all athletes with asthma were classified as RTI (ARinf) susceptible (n = 9) (Hull et al., 2021). Because of the moderate sample size, no significant difference was found between the groups (Hull et al., 2021). Notably, we found no difference in days of absence because of an ARinf or ARinf episodes when skiers were grouped by training volume or competition success contrasting with findings in competitive swimmers, where international-level swimmers had fewer days of absence than national-level swimmers (Hellard et al., 2015).

We did not investigate whether the athletes in the current study started training in the late stage of the infection with mild symptoms before becoming fully asymptomatic and, thus, reporting training during and ARinf. In a recent meta-analysis, the mean duration of ARinf in athletes was seven days, but only 20% of ARinf prevented training for more than one day (Snyders et al., 2022). Since ARinfs are among the most common conditions in athletes and there is no knowledge when it is safe to return to training, well documented studies on safe return to sports are required.

The link between asthma and airway infections in athletes remains an under-explored area. Potential connections between asthma and airway infections have been suggested, but conclusive evidence is lacking (Kisiel et al., 2021). This gap underscores the need for more focused research to understand the implications for athlete health and training. In this study, asthma was associated with more days of absence due to infections, indicating a potential impact on athletic performance. To fully understand this relationship, longitudinal studies utilising data from training diaries are essential for more definitive insights.

6.7 Strengths and limitations of the study

Methodological considerations. This study, inherently cross-sectional, captures observations at a specific point in time, limiting the ability to infer causality between asthma, training volume, use of asthma medication and respiratory symptoms. In cross-sectional research, while correlations can be identified, the direction of these relationships remains unclear, leaving room for speculation and further investigation.

With response rates of 27.3% and 19.5% for skiers and controls respectively, the current study's participation was relatively low. Nevertheless, it stands as the largest survey of competitive cross-country skiers, with 351 respondents. The non-responder analysis suggests that the age and performance levels (based on FIS points) are similar between responders and non-responders. A higher response rate among females aligns with previous research on respiratory health in a similar age group (Kotaniemi et al., 2001).

While self-reported physician-diagnosed asthma is the most common method for assessing asthma prevalence, the specific diagnostic methods employed for each skier could not be verified. In Finland, asthma diagnoses is most often based on objective lung function measures due to drug reimbursement criteria. The validity of self-reported asthma has been explored in a similar demographic population, yielding a specificity of 99% for physician-diagnosed current asthma among Finnish university students aged 18 to 25 (Kilpeläinen et al., 2001). However, we did not validate the asthma diagnosis from patient records or by lung function measures, which is a weakness of the current study.

The statistical methods employed in this cross-sectional study were selected appropriately. Most of the statistical analyses were comparing unpaired groups, which often were non-normally distributed. Given the study's design, risk ratios were not applicable, leading to the use of odds ratios, a common practice in cross-sectional analyses. While odds ratios effectively estimate the likelihood of outcomes, they have limitations, particularly in potentially overestimating effects in common outcomes.

Strengths and limitations. The observed correlations might also be skewed by survivor bias, particularly in athletes who continue their careers despite asthma. Athletes with severe respiratory symptoms or uncontrolled asthma, which might obstruct training and competing, may not be able to maintain a successful athletic career. This phenomenon could inadvertently lead to an overrepresentation of athletes who have either managed their asthma effectively or have milder forms of the condition. Furthermore, the most successful skiers might possess certain traits or strategies to cope with or manage asthma, which introduces a form of selection bias. Such biases highlight the complexity in understanding the true relationship between asthma and athletic performance.

The study only recorded the presence of symptoms rather than their intensity, leaving room for variability in the impact and severity of symptoms. Mild symptoms, for instance, might be non-disturbing and manageable, although this is speculative due to data limitations. Given the high prevalence of respiratory symptoms among skiers, one might speculate that these symptoms are generally manageable, allowing for continued participation in the sport. However, this remains an area for further investigation.

Skiers and controls responded to the study at slightly different times (May/June and March/April respectively). This discrepancy could confound results given Finland's intensive tree-pollen season that typically occurs from March to June. Additionally, the skiers' survey took place in the early training season outside competitions, potentially leading to a lower prevalence of respiratory symptoms and current cough at this point in the season. Nevertheless, truly prolonged cough (over eight weeks) was rare among skiers, indicating its lower prevalence regardless of the season.

Due to the nature of the study, most of the questions covered are subject to recall bias. This is especially relevant to training volume, days of absence from training or competition and age at asthma diagnosis. The responses were not verified from patient records or training diaries. As for absence from training and days of illness, we could not verify whether training during an ARinf affected symptom severity and duration.

The present study was conducted in a single country, and a similar study in another country and under different training cultures and considerations for training under ARinf could have produced different results, but the results are likely generalisable to all competitive cross-country skiers in other countries.

Responder bias could have led to an overrepresentation of participants with present respiratory symptoms or respiratory-related conditions, potentially inflating the asthma prevalence in both groups. Further, respiratory health issues might have deterred some adolescents from engaging in cross-country skiing. This cross-sectional study design limits the investigation of time effects.

While the study has its limitations, it provides empirical data on the prevalence of asthma in competitive cross-country skiers and underscores the need for future research, particularly longitudinal studies, to clarify the causality in these associations. The sample size is currently the largest study on this level of athletes and the similarity in age and performance levels between responders and non-responders contribute to the internal validity of the study.

6.8 Future perspectives

Investigating the mechanisms behind the elevated asthma incidence and prevalence in competitive cross-country skiers necessitates longitudinal studies involving younger participants. To explore a potential causal relationship between high-volume cold-air training and asthma, measurements of training volume, intensity, and estimated ventilation of cold air could be useful. If a connection is observed, this could open possibilities for developing strategies to prevent asthma in active skiers. Furthermore, it could elucidate the path to further investigate the airway injury and osmotic theories as the pathogenesis of asthma in this field.

Additionally, diagnosing asthma during the study and directly measuring the type and level of airway inflammation might provide further insights into the relationship between training volume and asthma characteristics such as type, severity, and prognosis. Given these considerations and the early onset of symptoms and asthma, the inclusion of young skiers in these studies is crucial.

The modest response rates observed in this thesis underscore an issue in contemporary research: the era of high-response surveys, particularly those conducted through postal services, may be approaching its end. This shift reflects a significant methodological challenge that extends beyond the scope of this study.

The factors contributing to this trend are complex and multifaceted. The rapid evolution of communication technology, combined with a growing sense of survey fatigue among the public, has created an environment where traditional methods of data collection are increasingly untenable. The saturation of surveys in everyday life has led to a general disinterest and a marked decline in participation, raising questions about the future viability of these research practices.

For the field of sports medicine research, where the demographic is often highly mobile and time-constrained, the implications are clear: a departure from conventional survey techniques is necessary, favoring the adoption of innovative data gathering strategies that align with the changing lifestyles of athletes. The focus should be on utilising and organising data derived from regular activities, such as training logs and the analytical output from athlete performance monitoring systems.

Asthma is just one factor contributing to the high prevalence of respiratory symptoms. Some symptoms could be benign, representing merely physiological responses to exercise. Therefore, future studies should consider ranking respiratory symptoms by severity and burden, which would provide a more comprehensive understanding of their impact on training and competition, rather than just measuring symptom presence. The burden of illness also warrants assessment, considering the commonality of training and competing under illness and how often this would result in more severe illnesses and complications.

To develop evidence-based protocols, randomised controlled trials alongside prospective observational studies of training and absence from training are needed. These protocols would aim to facilitate safe and efficient return to sports after infection, thus minimising detraining.

Moreover, future research should focus on understanding the reasons behind possible prolonged absences due to ARinfs among asthmatic skiers and the potential consequences of such absences, including early retirement. This could contribute to a more comprehensive understanding of how asthma affects winter athletes.

SUMMARY AND CONCLUSIONS

The main findings and conclusions are as follows:

1. The prevalence of asthma in cross-country skiers was about 2.5 times that in the general population. The prevalence of asthma was similar in early childhood but a rapid increase in the prevalence of asthma occurs at about 12 years of age in the cross-country skiers. Asthma control was similar in skiers and controls with asthma, but skiers with asthma used regular ICS and fixed combination of ICS + LABA more often, and they also more often used bronchodilators preventively before exercise rather than on demand.
2. The prevalence of asthma was the highest in the most successful cross-country skiers. The asthma in skiers was mostly non-allergic compared with the general population of the same age. The most important risk factor for non-allergic asthma in skiers was high training volume while family history and allergic rhinitis was associated with allergic asthma.
3. Cross-country skiers had more exercise-related respiratory symptoms than the controls, and the burden of symptoms was especially high in participants with asthma. Both groups were mostly asymptomatic at rest, but symptoms increased in both groups during and after exercise. Although exercise often provoked cough in cross-country skiers, repeated hyperpnea of cold air did not seem to lead to long-standing hypersensitivity of the cough reflex arc.
4. Skiers with asthma had to refrain from training and competitions because of experiencing ARinfs more often than non-asthmatic skiers and had more days of absence because of ARinf during the season. One half of skiers trained during ARinf one fourth competed during ARinf.

Cross-country skiing is one of the most demanding endurance sports for athletes' airways due to the exposure to dry cold air. The high volume of endurance training carried out for years in dry and cold air places an exceptional strain on the airways. Although skiers have a high prevalence of asthma and high prevalence of respiratory symptoms, it seems it does not prevent a successful and triumphant athletic career in skiers still pursuing athletic endeavours.

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Appendix 1. The full questionnaire used in this thesis including questions that are not included in the thesis. Questions used from other studies are cited if applicable. Other questions are freely translated from Finnish and are not validated for use in English.

1. Personal information
    a. Name and signature
    b. Personal identity code
    c. Address, postalcode and city
    d. email address

Training and background

2. Height (cm)
3. Weight (kg)
4. Competition class
    a. men
    b. women

5. What is your current status and/or occupation?
    a. primary school
    b. junior high school
    c. high school
    d. conscript service
    e. university or university of applied sciences
    f. full-time job (38,5 hours per week or more)
    g. part-time job (less than 38,5 hours per week)
    h. full-time athlete
    i. other

6. What is your primary competitive sport?
    a. cross-country skiing
    b. biathlon
    c. other, ______

7. In which other sports do you compete?
    a. I don't compete in other sports
    b. Biathlon
    c. Ballet
    d. Ski orienteering
    e. Football (soccer)
    f. Ice hockey
    g. Combat sports (wrestling, judo, karate, taekwondo)
    h. Volleyball

i. Cross-country skiing
j. Cycling
k. Floorball
l. Orienteering
m. Dancing
n. Gymnastics
o. Swimming
p. Nordic combined
q. Athletics, track disciplines
r. Athletics, field disciplines
s. Other, ____

8. What other sports do you engage in?
   a. I don't engage in other sports
   b. Biathlon
   c. Ballet
   d. Ski orienteering
   e. Football (soccer)
   f. Ice hockey
   g. Combat sports (wrestling, judo, karate, taekwondo)
   h. Volleyball
   i. Cross-country skiing
   j. Cycling
   k. Floorball
   l. Orienteering
   m. Dancing
   n. Gymnastics
   o. Swimming
   p. Nordic combined
   q. Athletics, track disciplines
   r. Athletics, field disciplines
   s. Other, ____

9. Do you use a training diary?
   a. Yes, electronic
   b. Yes, paperform
   c. No

10. How old were you, when you started your primary discipline?
   a. years

11. How many hours did you train in the last season 2018/2019? If you don't know the exact amount by ten hours, answer to the question 13 and 14.
    a. hours

The following question is only for skiers responding to question 12.

12. How many percent of the training is conducted in different intensity zones including strength training? The sum of percentages must be 100%.

Base endurance training, under aerobic threshold	%
Endurance training, over aerobic threshold	%
Strength training (gym, circle training)	%
Other training modalities (other sports)	%

13. Evaluate your weekly training hours during the summer (May–October)

Cross-country skiing, roller skiing or Nordic walking	hours
Other forms of endurance training (for example running and cycling)	hours
Other forms of training (ball sports, other sports)	hours

14. Evaluate your weekly training hours during the winter (November–April)

Cross-country skiing, roller skiing or Nordic walking	hours
Other forms of endurance training (for example running and cycling)	hours
Other forms of training (ball sports, other sports)	hours

Training: ski waxing and temperature limits

15. Do you prepare skis to
    a. training
    b. competition
    c. I don't prepare skis at all

If answer to question 15 is a and/or b, the following two questions appear.

16. Who mostly prepares skiing for competitions?
    a. myself
    b. someone else

17. Do you use a protective mask when you prepare skis?
    a. Yes, always
    b. Yes, sometimes, for example when applying ski glide powder
    c. No

Additional information for questions 18 and 19:

Temperature limits in competition
Cross-country skiing
Seniors: –20°C
Juniors under 16 years of age: –17°C[1]

Biathlon
Seniors: –20°C
Juniors under 17 years of age: –15°C

18. In cold weather, do you always compete if a competition will take place?
    a. Yes
    b. No

19. If you could decide, what would be a suitable temperature limit in competition in you respective age category?
    a. degrees Celsius

[1] Later, a higher temperature limit of –15°C have been introduced for season 2021/2022.

Training: sleep

20. On average, how many hours per day do you sleep in one day including naps?
    a. hours
21. On average, how many hours per night do you sleep?
    a. hours
22. On average, how many hours do you sleep the night before competition?
    a. hours

Respiratory illnesses

Questions 23–25 are from FinEsS-study, which have been validated in Finnish and Swedish (Pallasaho et al., 1999). Below are the English translations from the study appendix 1 by Pallasaho and others.

23. Have any of your parents, brothers or sisters had:
    a. asthma
    b. allergic eye-/nose catarrh (hay-fever)
    c. chronic bronchitis or emphysema

24. Have you now or have you had any of the following diseases:
    a. asthma

25. Have you been diagnosed by a doctor as having asthma?
    a. Yes
    b. No

The following three questions appeared only for responders who reported to have asthma in both questions 24. and 25.

26. How old were you when you were diagnosed with asthma?
    a. years

27. Where is your asthma diagnosed?
    a. primary care
    b. hospital
    c. medicine center in private sector
    d. other
    e. I don't remember

28. Oftentimes asthma diagnosis is set long after symptom onset. Now, do you remember how old you were when first asthma symptoms appeared?
    a. years

The following three questions appeared only for responders who did not have asthma according to 24. and 25.

29. Have you been suspected or examined with asthma, but no diagnosis was set?
    a. Yes, I have been suspected and examined with asthma, but diagnosis was not confirmed or there was no asthma.
    b. No, I have not been suspected or examined with asthma.

Asthma Control Test

The five following questions are licensed by GSK to use as Asthma Test. The test score ranges between 5 and 25 points. The first alternative awards one point, the last answer five points. If the score is ≥ 20 points, asthma is considered well-controlled. The following is presented in the UK dialect. Questions for athletes were in Finnish or Swedish, which have also been validated.

30. During the last 4 weeks, how much of the time has your asthma kept you from getting as much done at work, school or home?
    a. All of the time
    b. Most of the time
    c. Some of the time
    d. A little of the time
    e. None of the time

31. During the last 4 weeks, how often have you had shortness of breath?
    a. More than once a day
    b. Once a day
    c. 3 to 6 times a week
    d. Once or twice a week
    e. Not at all

32. During the last 4 weeks, how often have your asthma symptoms (wheezing, coughing, shortness of breath, chest tightness or pain) woken you up at night or earlier than usual in the morning?
    a. 4 or more nights a week
    b. 2 to 3 nights a week
    c. Once a week
    d. Once or twice
    e. Not at all

33. During the last 4 weeks, how often have you used your rescue inhaler or nebuliser medication (such as Salbutamol)?
    a. 3 or more times per day
    b. Once or twice per day
    c. 2 or 3 times per week
    d. Once a week or less
    e. Not at all

34. How would you rate your asthma control during the last 4 weeks?
    a. Not Controlled at all
    b. Poorly Controlled
    c. Somewhat Controlled
    d. Well Controlled
    e. Completely Controlled

35. Do you use asthma medication? If you use regularly and occasionally, choose both alternatives.
    a. I don't
    b. Yes, regularly
    c. Yes, occasionally

Use of asthma medication

The questions 36. and 37. appeared only if 35. b. or c. was selected.

36. What kind of asthma medication do you use regularly? Please write the names of the medications used and how often do you use them.
    a. open text field

37. What kind of asthma medication do you use occasionally? Please write the names of the medications used and how often do you use them.
    a. open text field

The following question is from Pallasaho et al. 1999.

38. Have you now or have you had any of the following diseases:
    a. allergic eye-/nose catarrh (hay-fever)

39. Do you have allergy diagnosed by a physician?
    a. Pollen allergy
    b. Animal allergy
    c. Other allergy
    d. No allergy

40. Do you use allergy medication?
    a. Yes, year-round
    b. Yes, seasonally
    c. No

41. How old were you when the allergy was diagnosed?
    a. years

Respiratory tract infections: Infections and days of absence

Introductory text in the questionnaire: The following questions consider respiratory tract infections in the last 12 months.

42. Did you have respiratory tract infections (for example the common cold, cough, sore throat, sinusitis) in the last 12 months that prevented training? The respiratory tract consists of nose, throat/larynx and lungs.
    a. Yes
    b. No / I don't know

43. If yes, how many episodes and days in total? One episode counts as one occurrence and the days are the sum of days during one season, when you could not train.
    a. episodes
    b. days

44. For which reasons did you have to refrain from training in the last 12 months? You can choose multiple.
    a. fever
    b. sore throat
    c. flu
    d. blocked nose
    e. pneumonia
    f. mycoplasma infection
    g. other reason

45. Have you trained during acute respiratory infection during the last 12 months?
    a. Yes
    b. No / I don't know

46. Have you competed during acute respiratory infection during the last 12 months?
    a. Yes
    b. No / I don't know

47. Did you have to abstain from competition due to acute respiratory infection in the last 12 months?
    a. Yes
    b. No / I don't know

48. Have you had a flu with fever in the last 12 months?

a. Yes
b. No / I don't know

49. Have you had a sinusitis in the last 12 months?
    a. Yes
    b. No / I don't know

Follow-up:

50. If yes, how many times?

51. Have you been prescribed antibiotics in the last 12 months?
    a. Yes
    b. No / I don't know

Follow-up:

52. If yes, how many times?

53. Have you taken the season influenza vaccine in the last 12 months?
    a. Yes
    b. No / I don't know

54. Have you ever taken the vaccine for pneumococcus? It has not been included in the national vaccination program when you were a child. (It was included 1.6.2010)
    a. Yes
    b. No / I don't know

55. Did you have to abstain from training and competition due to injury, for example back pain, muscle cramps or sprained ankle?
    a. Yes
    b. No / I don't know

56. If you have, how many episodes and days in total?
    a. episodes
    b. days

57. Were you able to train in alternative training modalities even when injured?
    a. yes, I trained during the injury
    b. yes, part of the time, days
    c. not at all

58. Did you have to abstain from training and competition due to overreaching or insufficient recovery? One episode counts as one occurrence and the days are the sum of days during one season, when you could not train.
    a. Yes
    b. No / I don't know

59. If you have, how many episodes and days in total?
    a. episodes
    b. days

60. Have you now or have you had any of the following diseases:
    a. atrial fibrilliation or other form of arrythmia
    b. panic disorder, anxiety disorder

If yes to question 60.a. or 60.b, then follow-up:

61. How old were you when it was diagnosed?
    a. atrial fibrilliation or other form of arrythmia, years
    b. panic disorder, anxiety disorder, years

62. In the first five years of my life
    a. I had recurrent otitis
    b. I had eartubes
    c. my adenoid was removed

63. How many children under 18 years of age live in you household? If you are underage yourself, don't count yourself in.
    a. children
    b. none

If yes to question 63.a, then follow-up 64 and 65:

64. Write down the ages of underage children. If you are underage yourself, don't count yourself in.

65. How many of those children are currently in daycare?

Respiratory diseases: mycoplasma infections

Introductory text in the questionnaire: The following questions consider mycoplasma pneumoniae -infections.

66. Have you been suspected or examined with mycoplasma infection?
    a. Yes
    b. No / I don't know

If yes to question 66.a, then follow-up 67 through 72.

67. Have you been diagnosed by a doctor as having mycoplasma infection?
    a. Yes
    b. No / I don't know

68. Was the diagnosis based on a blood test?
    a. Yes
    b. No / I don't know

69. If you have been diagnosed with mycoplasma infection, how many times have you had it?
    a. times

70. How many weeks did the symptoms last in each infection in total?
    a. weeks, 1st infection
    b. weeks, 2nd infection
    c. (number of lines as many there have been infections)

71. If mycoplasma infection was treated, how many weeks did the treatments last in total?
    a. weeks, 1st infection
    b. weeks, 2nd infection
    c. (number of lines as many there have been infections)

72. How old were you, then the first mycoplasma infection was diagnosed?
    a. years

Gastric reflux symptoms

Introductory text in the questionnaire: The following questions consider oftentimes related gastric reflux and heartburn symptoms with respiratory symptoms.

73. Have you had reflux disease related symptoms, for example burning pain under sternum, pain under sternum, acid reflux in mouth or heartburn?
    a. Yes
    b. No / I don't know

If yes to question 73.a, then follow-up 74.

74. Do these symptoms interfere with training and competing?
    a. Yes
    b. No / I don't know

75. Do you have a gastric reflux disease diagnosed by a physician?
    a. Yes
    b. No / I don't know

76. Do you use medication to treat gastric reflux disease or heartburn?
    a. Yes
    b. No / I don't know

Respiratory symptoms

77. Do you have symptoms in following situations:

	at rest		at exercise		after exercise	
	yes	no	yes	no	yes	no
cough						
chest tightness						
shortness of breath						
wheezing						
sputum production						
symptoms related to reflux disease such as burning pain under sternum, pain under sternum, acid reflux in mouth or heartburn						

The following question is from Pallasaho et al. 1999, except for the last two rows (humid air and gunpowder).

78. Do you usually have breathlessness, wheeze or severe cough:

	yes	no
in cold weather		
in dusty places, tobacco smoke, car exhaust fumes		
from pollens		
from animal with fur (cat, dog, horse, cow)		
from strong smelling scents (perfumes, spices, printing ink, cleaner, strong smelling flowers)		
foggy, very humid air		
gunpowder		

79. Yskäkysymykset
80. 2

81. 3

82. Do you any of these devices? Select the devices used.
    a. I don't use any of these devices

WellO₂ Sarvikuono Airtrim Lungplus

83. Do you some other devices, treatments or remedies to treat respiratory symptoms? If you use, what kind?
    a. open text field

The following table is from Vertigan and others. The questionnaire is validated in Finnish and Swedish and is available upon request. (Vertigan et al., 2014)

84. The Newcastle Laryngeal Hypersensitivity Questionnaire

	All of the time	Most of the time	A good bit of the time	Some of the time	A little of the time	Hardly any of the time	None of the time
There is an abnormal sensation in my throat	1	2	3	4	5	6	7
I feel phlegm and mucous in my throat	1	2	3	4	5	6	7
I have pain in my throat	1	2	3	4	5	6	7
I have a sensation of something stuck in my throat	1	2	3	4	5	6	7
My throat is blocked	1	2	3	4	5	6	7
My throat feels tight	1	2	3	4	5	6	7
There is an irritation in my throat	1	2	3	4	5	6	7
I have a sensation of something pushing on my chest	1	2	3	4	5	6	7
I have a sensation of something pressing on my throat	1	2	3	4	5	6	7
There is a feeling of constriction as though needing to inhale a large amount of air	1	2	3	4	5	6	7
Food catches when I eat or drink	1	2	3	4	5	6	7
There is a tickle in my throat	1	2	3	4	5	6	7
There is an itch in my throat	1	2	3	4	5	6	7
I have a hot or burning sensation in my throat	1	2	3	4	5	6	7

85. Do you smoke cigarettes, cigarillos, pipe or cigars?
    a. Yes (over 100 times)
    b. No (less than 100 times)
    c. I have quit smoking, year

86. Do you use snus?
    a. Yes, regularly
    b. Yes, occasionally
    c. No

87. I filled the questionnaire
    a. alone
    b. with a guardian
    c. with a coach
    d. with someone else, who?

88. Free text related to the study. In any question of request to contact, please send email to the following address (address does not exist anymore)
    a. open text field

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PUBLICATION I

Higher prevalence but later age at onset of asthma in cross-country skiers compared with general population

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ORIGINAL ARTICLE

WILEY

Higher prevalence but later age at onset of asthma in cross-country skiers compared with general population

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Cross-country skiing causes strain in the airways because skiers train and compete in cold air. The aim of this survey was to investigate the prevalence and age at onset of asthma, asthma control, and use of asthma medication in Finnish competitive cross-country skiers. All cross-country skiers who were enrolled in the largest national competitions in winter 2019 (n = 1282) were invited to the study via the Finnish Ski Association. A control group (n = 1733) was matched for the responding skiers by age, gender, and region. The response rate was 27.4% (n = 351) for skiers and 19.5% (n = 338) for the controls. The prevalence of asthma was 25.9% in skiers and 9.2% in the controls ($p < 0.001$). Median (IQR) age at first asthma-related symptoms was higher in skiers than in the controls (13.0 (8.25–16.0) vs. 8.0 (2.25–11.75) years, $p < 0.001$), and the difference in asthma prevalence was evident only after the start of skiing career. Median (IQR) Asthma Control Test (ACT) score in skiers and controls with asthma was 22.0 (21–24) vs. 22.0 (19–24) ($p = 0.611$), and 89.0% of skiers and 77.4% of controls had well-controlled asthma (ACT score ≥20). In skiers with asthma, 82.4% used regular inhaled corticosteroids (ICS), and 80.2% used bronchodilators. A fixed combination of ICS +long-acting β2-agonist was regularly used by 47.3% of the skiers and 22.6% of the controls with asthma ($p = 0.016$). In conclusion, asthma prevalence is about 2.5 times higher, and age at onset of asthma is later in skiers compared with the controls. Asthma in cross-country skiers is mostly well controlled and on regular maintenance treatment.

KEYWORDS
asthma, asthma control, cross-country skiing, onset age of asthma, respiratory health

1 | INTRODUCTION

Asthma is a heterogeneous disease characterized by variable airway obstruction and is usually associated with chronic airway inflammation.[1] Asthma is common in cross-country skiers, with a prevalence of approximately 21%.[2] This may be related to years of endurance training and high ventilation rates. During winter, cross-country skiers expose themselves to cold and dry air conditions, which strains the airways. The asthma endotype in cross-country skiers is reported to be found more often as neutrophilic than eosinophilic compared with asthma in the general population,[2] suggesting a difference in the underlying causes of asthma in these populations.

There are three previous studies reporting age at onset of asthma in cross-country skiers. The usual age at onset of asthma in cross-country skiers is reported in early adolescence between 10 and 20 years of age, while the typical age at onset of asthma in the non-skier population of the same age is in early childhood.[3-5] However, it is not known whether asthma onset in early childhood prevents competitive cross-country skiing in the first place and what the relation is between age at onset of asthma and age at starting skiing career.

Asthma control in skiers has been recently studied in two Swedish studies.[5,6] The first study included elite cross-country skiers and orienteers and found that 82% of the athletes had well-controlled asthma,[6] but the results were not divided based on the sport. Among adolescent cross-country skiers aged 12–15 years (n = 20), the median Asthma Control Test (ACT) score was 21, suggesting well-controlled asthma.[5] However, studies on asthma control including exclusively cross-country skiers over 15 years of age have not been reported.

The prevalence of the use of asthma medication in cross-country skiers has varied between 18% and 36% and was approximately 21% in our recent meta-analysis.[2] However, there is lack of knowledge on how the use of asthma medication compares between skiers and non-skiers and whether the typical use of bronchodilators in skiers is on demand for symptoms or pre-emptively before exercise.

The main purpose of the current study was to compare the prevalence and age at onset of asthma, use of asthma medication and asthma control in Finnish cross-country skiers with the general population of the same age, gender, and region. We hypothesized that asthma is more prevalent among cross-country skiers that in the general population, and that skiers have better asthma control but later onset of asthma.

2 | MATERIALS AND METHODS

A postal invitation with a password to an online questionnaire was sent to cross-country skiers in May 2019 and to controls in February 2020. All Finnish cross-country skiers who had enrolled in either national championships or the largest national junior skiing competition when they were 13–16 years of age (Hopeasompa competition) were invited to participate in the study (n = 1282). The Finnish Ski Association participated in the study by sending invitations to the athletes. Later, a similar questionnaire was sent to a control group collected from the Finnish Digital and Population Data Services Agency, here matching the control population to the skiers who had responded regarding age, gender, and region of the country in which they lived. The invitation letter for the controls also included the questionnaire in paper form. Cross-country skiers received one reminder, and the controls received two reminders. Written informed consent was obtained from each respondent and from guardians for subjects under 18 years of age. The study was approved by the Ethics Committee of Pirkanmaa Health Care District (R18108).

Three questions in the current study included questions from FinEsS questionnaire[7] regarding self-reported physician-diagnosed asthma, asthma in parents or siblings and age at asthma diagnosis. In addition, the subjects with asthma were asked an additional question regarding at which age they experienced their first asthma-related symptoms. Current asthma was defined as self-reported physician-diagnosed asthma and at least one of the following criteria: current three asthma-related symptoms (cough, chest pain, shortness of breath, wheezing or sputum production), active use of any asthma medication or ACT score of less than 25 points. The ACT was used to evaluate asthma control.[8] Other questions included the use and indication for asthma medication, weekly training volume in skiers and amount of exercise in the controls. After data collection, the Finnish Ski Association provided data on non-responder skiers, and the FIS points for skiers were obtained from the International Ski Associations 8th FIS points list from season 2018/2019, which was in effect at the time of the study[9]; then, an analysis was performed to compare the responders and non-responders.

The sample size was calculated based on the expected difference in asthma prevalence between the skiers and controls. We assumed an asthma prevalence of 10% in the controls[10] and at least 20% in competitive skiers.[2] To have a statistical power of 90% (correct negatives) with alpha-error of <5% (wrong positives), we needed at least 263 subjects in both groups to find such a difference in asthma prevalence. Therefore, we decided to invite all the competitive skiers of at least 13 years of age (n = 1282) and six healthy controls for each responded skier to get a sample of sufficient size. Because we could not identify from the population registry up to six controls for each skier fulfilling these criteria, the invited number of controls was 1,733 (on average 5.1 invited controls for each skier).

Statistical analyses were performed using SPSS version 27.0 (IBM Corp, Armonk, NY). The continuous variables were tested for normality (Kolmogorov-Smirnov). Unpaired t tests and Mann-Whitney U tests were used for the comparisons between the groups, as appropriate, and the results are presented as median (IQR) or mean (SD). Pearson's chi-square test or Fisher's exact test was used for comparisons of the categorical variables. A P value of <0.05 was considered statistically significant.

3 | RESULTS

The total response rate in the current study was 27.4% (n = 351) in skiers and 19.5% (n = 338) in controls. Twenty-five percent (n = 88) of the controls engaged in some competitive sports but not in cross-country skiing. The most common sports were team sports (n = 54, 61.3%), high ventilation sports (orienteering or aerobic gymnastics, n = 7, 7.9%), moderate ventilation sports (eg, combat sports or gymnastics, n = 19, 21.6%), and low-ventilation sports (eg, shooting or horseback riding, n = 5, 5.7%). All skiers were non-smokers, and 5.9% (n = 20) of the controls reported smoking.

The characteristics of the subjects are presented in Table 1. The skiers were somewhat younger and had a lower median Body Mass Index (BMI) compared with the controls, but the differences were small. The skiers also more often had a family history of asthma, and they had a considerably higher median number of hours of heavy exercise per week. The prevalence of self-reported physician-diagnosed asthma (ever asthma) was 26.2% (n = 92) in cross-country skiers and 10.6% (n = 36) in the controls ($p < 0.001$). There were 91 (25.9%) skiers and 31 controls (9.2%) ($p < 0.001$) with current asthma, and there were no differences in asthma prevalence between sexes in either of the groups. All analyses regarding asthma as a classifying variable have been grouped by current asthma from now on in this study.

In subjects with asthma, the median age at first asthma-related symptoms and median age at diagnosis of asthma were higher in skiers compared with the controls (13.0 (8.25–16.0) vs. 8.0 (2.25–11.75) years, p <0.001). There was no difference between the groups in the time from first asthma-related symptoms to diagnosis of asthma, and in 57.1% (n = 52) of the skiers and 41.9% (n = 13) of the controls, asthma was diagnosed within one year after the first symptoms (p = 0.143). There were 16 cross-country skiers (4.6% of all skiers and 19.7% of skiers with asthma) who reported having been diagnosed with asthma before they started cross-country skiing. In skiers whose asthma was diagnosed after they had started competitive cross-country skiing, the mean (SD) times from starting a competitive skiing career to first asthma-related symptoms and asthma diagnosis were 6.1 (4.2) and 8.3 (4.5) years, respectively. In subjects with no asthma diagnosis, 38.0% (98/258) of skiers and 14.3% (39/273) of the controls reported as having been suspected and examined for asthma, but no diagnosis had been made. The prevalence of asthma according to age in skiers and the controls is presented in Figure 1.

In the subgroup analysis between genders for the cross-country skiers, there were no differences in age, presence of asthma in parents or siblings, use of asthma medication, prevalence of self-reported physician-diagnosed asthma, age at diagnosis of asthma, age at first asthma-related symptoms or ACT score. Median (IQR) BMI and weekly training hours were higher in males compared with females (21.7 (19.7–23.2) vs. 20.5 (19.1–22.3) kg/m^2, p < 0.001 and 10.6 (8.5–13.5) vs. 10.0 (8.0–12.1) hours, p = 0.04).

Asthma was well-controlled (ACT score ≥20) in 89.0% (n = 81) of the skiers and 77.4% (n = 24) of the controls

TABLE 1 Subjects' characteristics and asthma-related results in cross-country skiers and controls

	Cross-country skiers		Controls		
	Median/n	Q_1–Q_3/%	Median/n	Q_1–Q_3/%	p
Age, yrs.	16.5	14.3–21.5	17.0	15–22.5	**0.033**
Body mass index, kg/m^2	21.0	3.6	21.8	5.4	**<0.001**
Asthma in parents or siblings	137	39.0	100	29.6	**0.007**
Training or heavy exercise/week, h	10.0	4.5	2.4	3.5	**<0.001**
Use of any asthma medication	123	35.0	39	11.5	**<0.001**
Current asthma	91	25.9	31	9.2	**<0.001**
Age of first asthma-related symptoms in subjects with asthma, yrs.	13.0	8.25–16.0	8.0	2.25–11.75	**<0.001**
Diagnosis age of asthma, yrs.	15.0	12.0–17.8	10.0	3.0–12.0	**<0.001**
Time to asthma diagnosis from onset of asthma-related symptoms, yrs.	1.0	1.0–3.0	1.0	0–4.0	0.789
Asthma Control Test score	22.0	21–24	22.0	19–24	0.611

Note: The bold values indicate P<0.05.

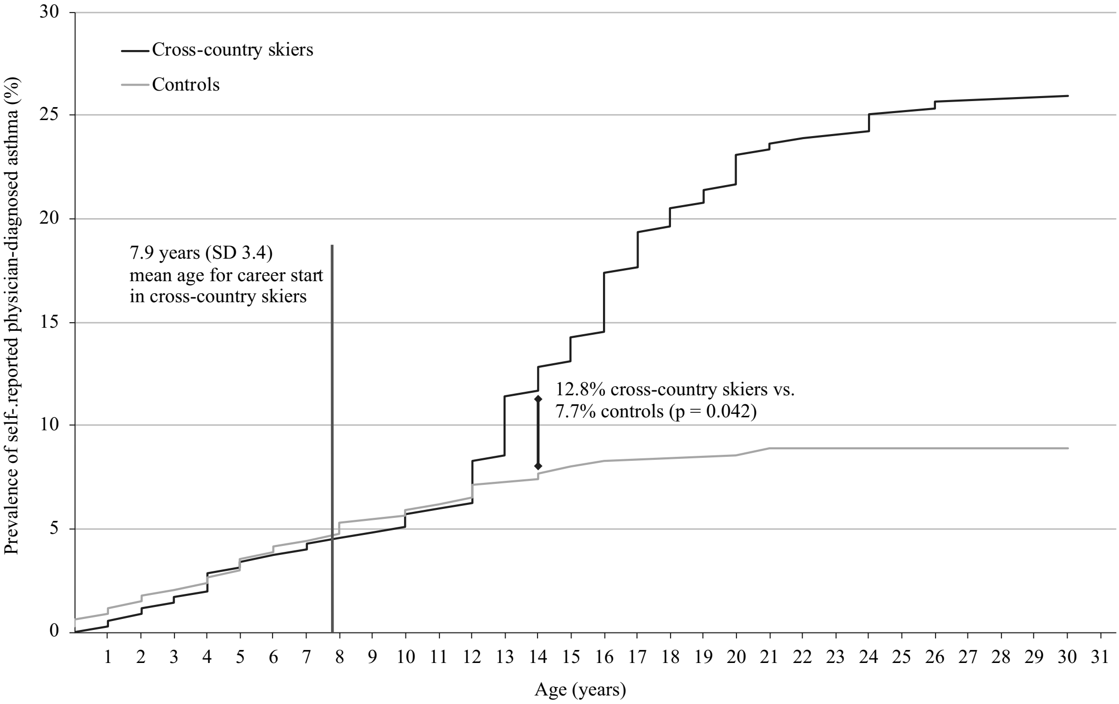

FIGURE 1 Prevalence of self-reported physician-diagnosed asthma according to age calculated based on reported age at diagnosis among the subjects with asthma. The median age at asthma diagnosis was 15.0 (IQR 12.0–17.8) years in cross-country skiers and 10.0 (IQR 3.0–12.0) years in the controls ($p = 0.001$). A rapid increase in the prevalence occurs at 12 years of age in the cross-country skiers. The difference in the prevalence of asthma between the groups was statistically significant ($p < 0.05$) from 14 years of age onwards

with asthma ($p = 0.045$). Asthma was poorly controlled (ACT score ≤15) in none of the skiers but in 16.1% (n = 5) of the controls with asthma and the lowest scores reported were 17 and 12 in skiers and controls, respectively.

The use of asthma medication based on asthma status is presented in Table 2. The prevalence of the use of asthma medication in cross-country skiers was 98.9% (90/91) in those with asthma and 12.7% (33/260) in those without a diagnosis of asthma. The respective percentages were 87.1% (27/31) and 3.9% (12/307) in the controls. The use of inhaled corticosteroids (ICS) was more frequent among skiers than in the controls with asthma, and skiers with asthma used ICS more often regularly than seasonally when compared with the controls with asthma. A fixed combination of ICS +long-acting β2-agonist (LABA) was regularly used by 47.3% (n = 43) of the skiers and 22.6% (n = 7) of the controls with asthma ($p = 0.016$). None of the athletes or the controls used LABA as monotherapy. No controls used anticholinergic agents as asthma medication. The median (IQR) ACT score in skiers with ICS +LABA treatment was slightly worse compared with skiers without combination therapy (22 (20–24) vs. 23 (22–24) points, $p = 0.018$).

The question considering the use of asthma medication was an open text field. Based on the responses in 60.9% (n = 75) of the skiers and 33.3% (n = 13) of the controls who were using asthma medication, the indication for the use of bronchodilators could be identified. With skiers reporting any indication, all of them reported using bronchodilators pre-emptively before exercise. Four controls (10.3%) reported pre-emptive use.

The non-responder analysis is presented in Table 3. Females responded more often in both groups, but in neither of the groups was there age difference between the responders and non-responders. The FIS point distribution representing success in races was similar in the responders and non-responders among the cross-country skiers.

4 | DISCUSSION

We found that asthma was more prevalent and started later in skiers than in the non-skiing population, and a higher prevalence of asthma in skiers was found only after the onset of one's skiing career. Asthma control was

TABLE 2 The use of asthma medication by asthma status

	Cross-country skiers (n = 351)					Controls (n = 338)					
	Asthma n = 91		No asthma n = 260			Asthma n = 31		No asthma n = 307			
	n	%	n	%	p	n	%	n	%	*p*	Difference between groups with asthma
Regular use of any ICS	75	82.4	6	2.3	**<0.001**	14	45.2	0	0	**<0.001**	**<0.001**
Seasonal use of any ICS	6	7.7	6	2.3	0.053	7	22.6	2	0.7	**<0.001**	**0.02**
Any use of β2-agonist or anticholinergic agent	73	80.2	28	10.8	**<0.001**	24	77.4	11	3.6	**<0.001**	0.739
Use of short-acting β2-agonist or anticholinergic agent	73	80.2	28	10.8	**<0.001**	24	77.4	10	3.3	**<0.001**	0.739
Use of long-acting β2-agonist or anticholinergic agent	14	15.4	1	0.4	**<0.001**	2	6.5	0	0	**<0.001**	0.203

Note: The bold values indicate P<0.05.

TABLE 3 Nonresponder analysis in cross-country skiers and controls

	Cross-country skiers				Controls			
	Responders n = 351		Nonresponders n = 931		Responders n = 338		Nonresponders n = 1395	
	Mean/n	SD/%	mean/n	SD/%	mean/n	SD/%	mean/n	SD/%
Age, yrs.	18.8	6.1	18.6	6.2	19.7	6.8	19.9	6.2
Females	204	58.1	419	45.0	235	69.5	779	55.8
FIS points	198.02	163	195.55	430	N/A	N/A	N/A	N/A

Note: The results are presented as mean (SD) or n (%).

similar in skiers and controls with asthma, but skiers with asthma used regular ICS and fixed combination of ICS +LABA more often, and they also more often used bronchodilators preventively before exercise rather than on demand.

In the present cross-sectional survey, the prevalence of asthma in competitive cross-country skiers was 25.9%. This was slightly higher than the 21% (CI 95% 14–28%) in a recent meta-analysis.[2] However, the present study is in line with the most recent studies from Sweden, where the prevalence of asthma was 23%, 27%, and 31%.[3-5]

The age at first asthma-related symptoms was higher in skiers than in the controls and was similar to those skiers analyzed the latest studies in the 2010s by Norqvist et al. and Eklund et al.[3,4] However, in those studies, the criteria of onset of asthma were first asthma attack, while in the current study, we report also the median age at diagnosis (15 vs. 10 years, $p < 0.001$) and the median time difference between age at first asthma-related symptoms and age at diagnosis (1.0 vs. 1.0 years, $p = 0.789$). The prevalence of asthma starts to differ between skiers and non-skiers in early adolescence (Figure 1) and is statistically different from 14 years of age onwards. Sixteen cross-country skiers reported having asthma before they started cross-country skiing. This represents 4.5% of all cross-country skiers in the current study. This has not been reported before in any study. Thus, asthma may not be a major hurdle to start competitive cross-country skiing because there was no difference in asthma prevalence between the skiers and controls before the typical age of starting a skiing career. Based on these data, the difference in the prevalence of asthma starts to occur in adolescence after having started a skiing career. In skiers whose asthma was diagnosed later after they had started competitive cross-country skiing, the mean time to first asthma-related symptoms and to asthma diagnosis from career start was 6.2 and 8.6 years, respectively.

One of the key differences between skiers and controls is that skiers more frequently expose themselves to cold, dry air. It is supposed that athlete's asthma may be induced by airway remodeling and hyperresponsiveness triggered by long-term high ventilation rates.[11] Since cross-country skiers train and compete in dry and cold air, they may be exceptionally prone to developing sport-induced asthma. Although the median onset age of asthma in the current study was higher in skiers than in controls, it seemed to be earlier than in a previous study reporting winter sports athletes participating in the Olympic Games in Torino 2006 where the majority of athletes reported asthma onset later than 20 years of age.[12] However, the studies included different populations, and therefore, further studies are needed to assess whether sport-related asthma starts earlier in cross-country skiing in comparison with other endurance sports.

In 37.6% of non-asthmatic skiers and 12.4% of non-asthmatic controls, the subjects had been investigated for asthma, with no diagnosis as a result. In total, 53.8% of skiers and 20.4% of controls have been either diagnosed with or investigated for asthma. This almost threefold difference between skiers and controls may be explained by the requirements for airways that come with cross-country skiing. Airflow limitation impairs exercise performance, and the ventilatory demands in heavy exercise compared with everyday life may refer symptomatic skiers more often to the doctor's office. In our recent meta-analysis, we found that in several studies, previously healthy skiers undergoing lung function testing fulfilled the diagnostic criteria for asthma.[2] Although 53.8% of skiers were diagnosed with or investigated for asthma, almost a half were not. This subgroup of skiers may have undiagnosed asthma as several studies in skiers and in other sports have shown that athletes may have no prior history of asthma but still objective criteria for asthma in lung function measurements.[13-17] However, because the prevalence of asthma in skiers increases notably by age, asthma may still appear later in their careers.

Asthma control in elite endurance athletes is reported to be better compared with controls (ACT score 22.2 vs. 21.0, $p = 0.004$) in one Swedish study.[6] In the current study, we found no significant difference in asthma control between the groups (median ACT score 22.0 vs. 22.0, $p = 0.611$), but the ACT scores were similar, as in the earlier study.[6] The fourth question in the ACT (*During the last 4 weeks, how often have you used your rescue inhaler or nebuliser medication (such as Salbutamol)?)* had the lowest mean score compared with the other questions (3.68 points). This question may be impractical for skiers because the majority of the skiers using short-acting beta-agonists used them as a preventive measure before exercising rather than reactively after having asthma-related symptoms (60.9% vs. 35.0%). Most skiers (86.8%) used short-acting beta-agonists two or three times per week or less, which is similar to the frequency of high-intensity exercises in a regular training regimen.[18] A better clinical tool for evaluating asthma control in athletes is warranted because asthma is well controlled as per the ACT in almost all athletes, and most of the decrease in points emerges from using B_2-agonists regularly before exercise (Question 4). Questions assessing asthma control better suited for athletic life may be a more useful tool in assessing asthma control in athletes.

The proportion of subjects having parents or siblings with asthma is higher in cross-country skiers compared with controls (39.0% vs. 29.6%, $p = 0.007$). This is almost identical to the study by Eklund et al.,[3] which reported a 40% prevalence of asthma in skiers' parents or siblings and 29% in the controls' siblings. This may suggest a similar lifestyle because the skiers' parents may also have been endurance athletes and, thus, possibly more prone to asthma.

The use of asthma medication was significantly higher in cross-country skiers compared with the controls. Skiers with asthma used ICS more regularly. The indication for the use of bronchodilators has not been previously reported in cross-country skiers other than the use of asthma medication on a regular basis or occasionally.[19] ICS was used in combination with LABA in 47.3% of the skiers and 22.6% of the controls with asthma. In one study performed on cross-country skiers with "ski asthma" and controls with asthma, the effect of regular ICS was limited in skiers, and this may explain the frequent use of LABA in skiers.[20]

In skiers with no asthma diagnosis, 12.7% (n = 33) used asthma medication, and most of these athletes reported the use of bronchodilators before exercise. Of these skiers with no asthma using asthma medication, 88% had been suspected of having asthma, but the diagnosis had not been confirmed. This indicates that asthma medication had been prescribed based on their symptoms rather than diagnostic asthma findings. Anticholinergic agents were used by 7.1% of the skiers but by none of the controls, and anticholinergic agents were often combined with beta-agonists. Use of asthma medication without a diagnosis of asthma may be explained by skiers having another underlying condition (eg, exercise-induced laryngeal obstruction, dysfunctional breathing, or rhinitis)[21] mimicking asthma. They may be prone to overuse of SABA in trying to control their symptoms even though the mechanism causing their symptoms might not be smooth muscle contraction and asthma.

Asthma in Finnish elite athletes was previously studied in 2012 in Olympic athletes.[22] In the subgroup of 81 endurance athletes, the prevalence of self-reported physician-diagnosed asthma was 28.8%, and the prevalence of use of asthma medication was 31.1%.[22] The proportions are similar compared with the present larger study focusing on cross-country skiers.

The response rate in the current study was relatively low (27.3% in skiers and 19.5% in controls). However, the present study is the largest survey in competitive cross-country skiers by number of responders (n = 351). The non-responder analysis indicates that the responders and non-responders are the same age and that the performance level in the skiers is similar based on FIS points. Females responded more often, which has also been reported earlier in a similar age group investigating respiratory health.[23] Self-reported physician-diagnosed asthma is the most commonly used method to evaluate the prevalence of asthma. The methods used in each skier's diagnostic work out could not be verified, but in Finland, asthma diagnosis is most often based on objective lung function measures because of the criteria for drug reimbursement. Validation of self-reported asthma by lung function measures has been studied in a similar demographic population compared with the subjects in the present study, finding that among Finnish university students 18 to 25 years of age, the specificity of physician-diagnosed current asthma was 99%.[24] However, we did not validate the asthma diagnosis from patient records or by lung function measures, which is a weakness of the current study, and furthermore, responses may be subject to recall bias. Responder bias may lead to subjects with present respiratory symptoms or a respiratory-related condition to be over presented among the responders possibly increasing asthma prevalence in both groups. The amount of exercise was asked differently for the skiers and controls because the questions were adjusted to the known difference in intensity and volume of exercise training between the groups. Asthma was well controlled in almost all cross-country skiers. However, skiers with poorly controlled asthma may already have quit, and the responses in the current study may thereby be subject to survivor bias. This type of a cross-sectional study is limited in investigating time effects.

5 | PERSPECTIVE

Cross-country skiing is one of the most demanding endurance sports for athletes' airways due to the exposure to dry cold air. The high volume of endurance training carried out for years in dry and cold air places exceptional strain on the airways. The prevalence of asthma has been on the rise among competitive skiers during the last decades, and the current study showing a prevalence of 25.9% is in line with others conducted in the 2010s.[2-5] The incidence and prevalence of asthma between skiers and the controls were similar in early childhood before the typical age of starting a skiing career and started to differ from 12 years of age onwards. This highlights the need for early interventions and possible regular screening of asthma in young skiers. To understand the mechanisms by which active cross-country skiing is associated with a higher incidence and prevalence of asthma, a longitudinal study including the youngest cross-country skiers is needed. This would allow for estimating if measures to prevent asthma in active skiers are possible.

The majority of skiers had well-controlled asthma. However, the questions in the ACT do not reflect the athletes' daily lives, and thus, tools and questions to monitor and evaluate the effects of asthma on training and competing are needed.

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CONFLICTS OF INTEREST

The authors declare no conflicts of interest.

AUTHOR CONTRIBUTIONS

RM-H, JK, JP, MV, and LL designed the study. RM-H wrote the first draft of the manuscript. RM-H and HH analyzed the data. All authors approved the final version of the manuscript.

DATA AVAILABILITY STATEMENT

The data that support the findings of this study are available on request from the corresponding author. The data are not publicly available due to privacy or ethical restrictions.

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PUBLICATION
II

High training volume is associated with increased prevalence of nonallergic asthma in competitive cross-country skiers

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High training volume is associated with increased prevalence of non-allergic asthma in competitive cross-country skiers

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ABSTRACT

Background Cross-country skiers have a high prevalence of asthma, but its phenotypes and association with success in competitions are not known.

Objective To investigate, by means of a postal survey, the relative proportions of allergic and non-allergic asthma in competitive cross-country skiers compared with the general population, to study how performance level and training volume are related to asthma and its type and to assess the possible risk factors for allergic and non-allergic asthma in competitive skiers.

Methods All Finnish cross-country skiers enrolled in the largest national competitions in winter 2019 (n=1282), and a random sample (n=1754) of the general population of the same age were sent a postal questionnaire. The response rate was 27.4% (n=351) for skiers and 19.5% (n=338) for the controls. International Ski Federation (FIS) ranking points measured the level of success in skiers. Asthma was defined as self-reported, physician-diagnosed asthma. Asthma was considered allergic if associated with doctor-diagnosed allergy, and exposure to allergens provoked asthma symptoms.

Results The prevalence of asthma was higher in skiers than in the controls (25.9% vs 9.2%, p<0.001), and it was the highest (56.1%) in the most successful quartile of skiers. Asthma was more often non-allergic in skiers than in the controls (60.1% vs 38.7%, p=0.036). Being a skier came with a higher risk for non-allergic (OR 5.05, 95% CI 2.65 to 9.61) than allergic asthma (OR 1.92, 1.08–3.42). Using multivariable regression analysis, training volume was associated with non-allergic asthma, while age, family history of asthma and allergic rhinitis were associated with allergic asthma.

Conclusion The prevalence of asthma is the highest in the most successful cross-country skiers. The asthma in skiers is mostly non-allergic compared with the general population of the same age. The most important risk factor for non-allergic asthma in skiers is high training volume.

Key messages

What is already known on this topic

⇒ Asthma is highly prevalent in cross-country skiers, and the age of onset of asthma is in early adolescence.

What this study adds

⇒ The prevalence of asthma is the highest in the most successful skiers—up to 56.1%.
⇒ Cross-country skiers mainly have non-allergic asthma. The excess prevalence of asthma compared with the general population is largely because non-allergic asthma emerges a couple of years after the onset of an active skiing career.
⇒ High training volume is associated with non-allergic asthma, while older age, family history of asthma and allergic rhinitis are associated with allergic asthma.

How this study might affect research, practice and/ or policy

⇒ Asthma does not prevent competition success in cross-country skiing. High prevalence of non-allergic asthma should be taken into account when diagnosing and treating asthma in skiers.

INTRODUCTION

Asthma is a heterogeneous disease characterised by variable airway obstruction and is usually associated with chronic airway inflammation.[1] Different phenotypes of asthma can be identified based on patient characteristics and the type of airway inflammation. The onset of allergic asthma usually occurs in childhood or early adulthood and is associated with a family history of asthma and IgE-mediated airway allergies, and eosinophilic inflammation.[2] Airway inflammation in non-allergic asthma can be eosinophilic, neutrophilic, mixed or pauci-granulocytic.[3] The risk factors for different types of non-allergic asthma are not known in detail. Non-allergic asthma has been associated with airway infections, long-term exposure to irritants and airway damage.[4–6] The incidence of non-allergic asthma is relatively low in childhood and early adulthood and increases in older age.[7]

Asthma is at least twice as common in cross-country skiers as in the general population, with a prevalence of approximately 21%.[8] This may be related to years of endurance training and high ventilation rates in cold and dry air, which strain the airways. Airway allergies and allergic asthma are common in children, whether or not they take part in competitive sports such as cross-country skiing.[9–11] The total burden of asthma among competitive skiers can be speculated as consisting of a 'background' prevalence of asthma that these individuals would have anyway, even without competitive sports, and an 'excess' of asthma prevalence triggered by competitive skiing. The mechanisms of asthma triggered by skiing may differ from the most common form of asthma in children and young adults—namely, allergic asthma. The type of airway inflammation in cross-country skiers with asthma is reported to more often be neutrophilic than eosinophilic in comparison with asthma in the general population.[12–14] The prevalence of asthma has not been thoroughly assessed by performance level in cross-country skiers, but one might speculate that asthma is most common among those who train the most. Indeed, in the Winter Olympics from 2002 through 2010, athletes using inhaled β_2-agonists won approximately twice as many medals as their proportion of all the athletes across all disciplines.[15] However, their asthma status was not explicitly reported.

The purpose of this study was to investigate the relative proportions of allergic and non-allergic asthma in competitive cross-country skiers compared with the general population, to study how performance level and training volume are related to asthma and its type and to assess the possible risk factors for allergic and non-allergic asthma in competitive skiers. We hypothesised that asthma is associated with training volume and is more often non-allergic in competitive cross-country skiers.

METHODS

Study design and recruitment

The present study has been described in detail previously.[16] In short, all Finnish cross-country skiers who had enrolled in either national championships (from 17 years of age onwards to seniors) or the largest national junior skiing competition (13–16 years of age, Hopeasompa competition) were invited to participate in this cross-sectional questionnaire survey (n=1282). The control group was collected from the Finnish Digital and Population Data Services Agency, matching the control population to the skiers who had responded by age, gender and region of the country in which they lived. The controls were allowed to participate in competitive sports, but none competed in cross-country skiing.[16] The total response rate was 27.4% (n=351) in skiers and 19.5% (n=338) in the controls. Written informed consent was obtained from each respondent and guardian for subjects under 18. The study was approved by the ethics committee of Pirkanmaa Healthcare District (R18108).

The questionnaire included three questions from the FinEsS questionnaire[17] regarding self-reported physician-diagnosed asthma, asthma in parents or siblings and age at asthma diagnosis. In addition, the subjects with asthma were asked at which age they experienced their first asthma-related symptoms. Current asthma was defined as self-reported physician-diagnosed asthma and at least one of the following: currently having three asthma-related symptoms (cough, chest pain, shortness of breath, wheezing or sputum production), active use of any asthma medication or an Asthma Control Test (ACT) score of fewer than 25 points. ACT was used to evaluate asthma control.[18]

Asthma was defined as allergic if the subject reported a doctor-diagnosed allergy and asthma-related symptoms when exposed to furry animals or pollens. Otherwise, asthma was defined as non-allergic. As a sensitivity analysis, two additional definitions of allergic asthma (doctor-diagnosed asthma and doctor-diagnosed allergy to pollens or animals or doctor-diagnosed asthma and asthmatic symptoms when exposed to furry animals or pollens) were used.

International Ski Federation (FIS) points for skiers were obtained from the International Ski Association's 8th FIS points list from the 2018/2019 season, which was in effect at the time of the study.[19] FIS points are awarded in competitions and calculated based on the level of competition, the level of the top five finishing athletes and the relative loss of the athlete compared with the winner. In World Cup competitions, the winner is awarded zero points (the lower the FIS points, the better the performance). FIS points were used to divide skiers into subgroups by performance level.

Statistical analysis

Statistical analyses were performed using SPSS version 27.0 (IBM Corp, Armonk, New York, USA). The continuous variables were tested for normality (Kolmogorov-Smirnov). Unpaired t-test, Mann Whitney U test and one-way analysis of variance were used to compare the groups, as appropriate. A X^2 test or Fisher's exact test was used to compare the categorical variables. Binary logistic regression was used to calculate the risk factors for current asthma, allergic asthma and non-allergic asthma. Variables were included in the multivariable analysis if the p value was <0.1 in the univariate analyses. A p value of <0.05 was considered statistically significant.

Patient and public involvement

Patients and/or the public were not involved in this research's design, conduct, reporting or dissemination plans.

RESULTS

Prevalence and type of asthma

The characteristics of the skiers and controls are presented in table 1. The controls were slightly older,

Table 1 Subjects' characteristics and asthma-related results in cross-country skiers and controls

	Cross-country skiers		Controls		
	Median/n	Q_1–Q_3/%	Median/n	Q_1–Q_3/%	P value
Age, years.	16.5	14.3–21.5	17.0	15–22.5	**0.033**
Body mass index, kg/m^{2-}	21.0	3.6	21.8	5.4	**<0.001**
Female subjects	204	58.1	235	69.5	**0.002**
Engaged in competitive sports other than cross-country skiing	223	63.5	88	26.0	**<0.001**
Team sports	36	16.1	54	61.3	**<0.001**
High ventilation sports (cycling, running, triathlon, orienteering, aerobic gymnastics)	195	87.6	7	7.9	**<0.001**
Moderate ventilation sports (combat sports, gymnastics, dancing)	0	0	19	21.6	**<0.001**
Low ventilation sports (shooting, horseback riding, weightlifting)	34	15.2	5	5.7	**0.022**
Smoking	0	0	20	5.9	**<0.001**
Physician-diagnosed allergy to pollens or animals	113	32.2	82	24.5	**0.025**
Self-reported allergic rhinitis	160	45.7	122	36.9	**0.019**
Asthma in parents or siblings	137	39.0	100	29.6	**0.007**
Training or heavy exercise/week, hours	10.0	8.0–10	2.4	1.0–4.5	**<0.001**
Use of any asthma medication	123	35.0	39	11.5	**<0.001**
Has been diagnosed with, or been investigated for, asthma	189	53.8	69	20.4	**<0.001**
Current asthma	91	25.9	31	9.2	**<0.001**
Allergic asthma (% of current asthma)	36	39.6	19	61.3	**0.036**
Non-allergic asthma (% of current asthma)	55	60.4	12	38.7	
Age at first asthma-related symptoms in subjects with asthma, years*	13.0	8.25–16.0	8.0	2.25–11.75	**<0.001**
Age at diagnosis of asthma, years*	15.0	12.0–17.8	10.0	3.0–12.0	**<0.001**
Time from onset of asthma-related symptoms to diagnosis of asthma, years*	1.0	1.0–3.0	1.0	0–4.0	0.789
Asthma Control Test score*	22.0	21–24	22.0	19–24	0.611

*In subjects with current asthma.

and a larger proportion of the controls than skiers were female. Cross-country skiers trained more, had asthma more often and were older at the onset of asthma symptoms and diagnosed asthma. Although skiers reported allergies to pollen or animals and allergic rhinitis more often, their asthma was more often regarded as non-allergic.

To illustrate the relation between age at asthma diagnosis and type of asthma, we calculated the prevalence of allergic and non-allergic asthma in skiers and controls based on their reported age at asthma diagnosis (figure 1). A rapid increase in the prevalence of non-allergic asthma occurs at 10 years of age in cross-country skiers. The difference in the prevalence of asthma between skiers and controls with non-allergic asthma was significant ($p<0.05$) starting from 14 years of age onwards. The difference in allergic asthma between skiers and controls was not statistically significant.

Asthma in relation to performance level

In total, 163 (46.4%) skiers had participated in FIS competitions to earn FIS points. The prevalence of asthma and other asthma-related factors among these skiers are presented according to their performance level (table 2). In the most successful subgroup of skiers, as measured by the lowest FIS points, the prevalence of asthma was the highest (56.1%). This group was also the oldest and trained the most. The use of asthma medication differed between the groups, with more successful skiers using asthma medication. Asthma was well controlled in all subgroups. In skiers who did not report current asthma, 37.7% (98/260) reported that asthma had been suspected and investigated but not confirmed. In the subgroup analysis and based on the performance level, 85% of the skiers in the most successful quartile had been either investigated for, or diagnosed with, asthma. Skiers with asthma had lower (better) FIS points (SD) than skiers without asthma (173.22 (117.46) vs 213.65 (108.83), p=0.026).

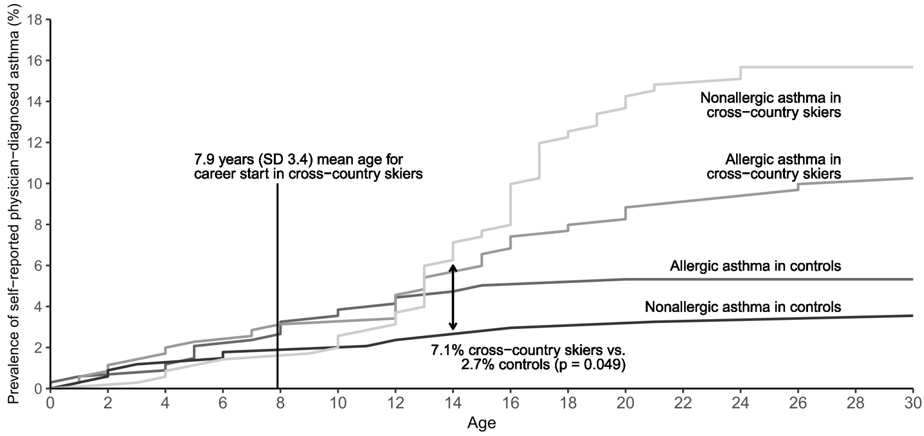

Figure 1 Prevalence of self-reported physician-diagnosed asthma categorised as non-allergic and allergic in relation to age in competitive cross-country skiers and controls. The median (IQR) age at diagnosis of non-allergic asthma was 16.0 (13.0–17.0) years in cross-country skiers and 8.5 (2.3–15.5) years in controls (p=0.022). Age at diagnosis of allergic asthma was 13.0 (7.0–18.0) years in skiers and 8.0 (4.8–12.0) years in controls (p=0.018). A rapid increase in the prevalence of non-allergic asthma occurred at 13 years of age in the cross-country skiers. The difference in the prevalence of non-allergic asthma between the groups was statistically significant (p<0.05) from 14 years of age onwards but no difference in allergic asthma was significant.

Skiers who did not have FIS points consisted mostly of juniors under 16 years of age (n=132) who did not yet participate in FIS competitions and, to some extent, also of athletes over 16 years of age but who, for some reason, had not yet participated in FIS competitions to earn FIS points (n=56). In this population (n=188), 62.8% were female (n=118), 37.8% had a known family history of asthma (n=71), 62.2% were suspected of having or diagnosed with asthma (n=117), 14.9% had current asthma (n=28), 6.4% had allergic asthma (n=12), 8.5% had non-allergic asthma (n=16), and the median (IQR) ACT score was 23 (21–24). Median (IQR) age was 14.4 (13.6–15.7), and the median weekly training hours was 8.6 (7.0–10.5) hours. In addition, in juniors under 16 years of age, the prevalence of asthma was 16.7% (n=22).

Table 2 Subject characteristics, training volume, prevalence of asthma, use of asthma medication and asthma control in cross-country skiers divided by performance level according to FIS points

	Skiers with FIS points n=163								
	Best quartile n=41		2nd quartile n=41		3rd quartile n=41		Poorest quartile n=40		P value between the quartiles
	0–120.54		120.55–185.13		185.14–247.52		247.53–999		
FIS points range	**Median/n**	**Q_1–Q_3/%**	**Median/n**	**Q_1–Q_3/%**	**Median/n**	**Q_1–Q_3/%**	**Median/n**	**Q_1–Q_3/%**	
Female subjects	16	39.0	22	53.7	25	61.0	23	57.5	0.205
Age, years	24.1	22.2–27.3	21.2	18.0–27.9	19.8	18.6–24.9	19.1	17.4–24.4	**<0.001**
Parents or siblings with asthma	13	31.7	18	43.9	20	48.8	15	37.5	0.419
Weekly training, hours	14.4	12.5–15.4	12.3	10.7–13.4	11.5	10–13.1	9.7	7.8–11.3	**<0.001**
Has been diagnosed with, or been investigated for, asthma	35	85.3	29	70.7	28	68.3	26	65.0	**<0.001**
Use of any asthma medication	25	61.0	22	53.7	16	39.0	17	42.5	0.171
Current asthma	23	56.1	17	41.5	11	26.8	12	30.0	**0.028**
Allergic asthma (% of current asthma)	8	34.8	8	47.1	3	27.2	5	41.7	0.730
Non-allergic asthma (% of current asthma)	15	65.2	9	52.9	8	72.8	7	58.3	
Asthma Control Test score among subjects with current asthma	23.0	18–25*	22.0	18–25*	21.8	19–25*	21.8	17–25	0.522

*Range
FIS, International Ski Federation.

Table 3 Univariate analysis of the risk factors for current asthma in cross-country skiers and controls represented as ORs with 95% CIs

	All			Skiers			Controls		
	OR	95% CI	P value	OR	95% CI	P value	OR	95% CI	P value
Being a cross-country skier	3.47	2.23 to 5.38	**<0.001**	NA			NA		
Age (per year)	1.05	1.02 to 1.08	**0.001**	1.07	1.03 to 1.12	**<0.001**	1.04	0.99 to 1.09	0.112
100 hours more training or heavy exercise per year	1.30	1.20 to 1.40	**<0.001**	1.36	1.19 to 1.56	**<0.001**	1.01	0.82 to 1.25	0.919
Parents or siblings with asthma	2.76	1.85 to 4.11	**<0.001**	2.15	1.32 to 3.48	**0.002**	3.88	1.82 to 8.27	**<0.001**
Female gender	1.01	0.67 to 1.52	0.956	1.14	0.7 to 1.85	0.602	0.78	0.34 to 1.80	0.554
Allergic rhinitis	2.83	1.89 to 4.24	**<0.001**	2.11	1.3 to 3.43	**0.003**	4.89	2.17 to 11.01	**<0.001**
50 FIS points less	NA			1.19	1.02 to 1.39	**0.03**	NA		

FIS, International Ski Federation.

Risk factors for asthma and its different phenotypes

The risk factors for current asthma in cross-country skiers and the controls are presented in table 3. In both groups, asthma in parents or siblings and allergic rhinitis were associated with current asthma. In cross-country skiers, older age, higher training volume and success—here as measured by FIS points—were also associated with current asthma. Being a cross-country skier was associated with OR of 3.47 (95% CI 2.23 to 5.38, p<0.001) for having asthma, 1.92 (1.08 to 3.42, p<0.027) for having allergic asthma and 5.05 (2.65 to 9.61, p<0.001) for having non-allergic asthma.

Skiers' risk factors for allergic and non-allergic asthma are presented according to the univariate and multivariate analyses in tables 4 and 5, respectively. We found that older age and higher training volume were associated with non-allergic asthma, while older age, family history of asthma and allergic rhinitis were associated with allergic asthma (table 4). In the multivariable analyses, the association between larger training volume and non-allergic asthma persisted, while older age, family history of asthma and allergic rhinitis were independently associated with allergic asthma (table 5).

Two additional definitions of allergic asthma were used as a sensitivity analysis, and the results remained similar. See online supplemental file 1 for the full analysis.

DISCUSSION

From the same population, we have previously reported that there is more than a 2.7 times higher prevalence of physician-diagnosed asthma in competitive cross-country skiers than in the general population, along with a rapid increase in asthma prevalence about 5 years after starting a skiing career.[16] In the current study, we found that asthma in skiers was mainly non-allergic compared with the general population of the same age. We also found that the rapid increase in asthma prevalence in skiers after the start of their careers is mainly because of non-allergic asthma. In skiers, higher training volume was associated with non-allergic asthma, while older age, family history of asthma and allergic rhinitis were independently associated with allergic asthma. In line with this, asthma was most prevalent among the most successful skiers who trained the most.

Prevalence and type of asthma

This is the first study to report the relative proportions of allergic and non-allergic asthma in competitive cross-country skiers and controls and assess the risk factors for different types of asthma in skiers. Our finding of higher asthma prevalence in competitive skiers aligns with many previous studies presented in our recent meta-analysis.[8] Interestingly, the difference in the prevalence of asthma in skiers and controls seems to be mainly because of the excess prevalence of non-allergic asthma in skiers. The current findings suggest that intensive training in cold air is the trigger for inducing the excess of non-allergic asthma in skiers. The increase in the prevalence of asthma in skiers after their career started was mainly because of an increase in the prevalence of non-allergic asthma. During this time, young athletes also start increasing training volume and intensive training in the cold and participating in competitions over longer distances. Increased training volume was a risk factor for non-allergic, but not allergic, asthma. This relation between intensive training and non-allergic asthma might be related to airway damage caused by cold air because airway damage has been suggested as one of the risk factors for non-allergic asthma.[4–6] The inflammatory mechanisms of non-allergic asthma can be non-allergic eosinophilic, neutrophilic, mixed or pauci-granulocytic.[2] In biopsy studies, skier's asthma is more neutrophilic than asthma in controls.[12–14] Non-allergic eosinophilic asthma is more often severe with onset in late adulthood[2] and, therefore, is not very likely among young competitive athletes with extremely good physical performance. The phenotypes of asthma in athletes have been previously categorised into atopic asthma and sports asthma by Couto *et al*,[20] which were

Table 4 Univariate analysis of the risk factors for allergic and non-allergic asthma in cross-country skiers represented as ORs with 95% CIs

	Non-allergic asthma n=55			Allergic asthma n=36		
	OR	95% CI	P value	OR	95% CI	P value
Age	1.05	1.00 to 1.09	**0.032**	1.07	1.02 to 1.12	**0.05**
100 hours more training per year	1.35	1.16 to 1.58	**<0.001**	1.18	0.99 to 1.41	0.064
Parents or siblings with asthma	1.63	0.91 to 2.91	0.098	2.40	1.19 to 4.84	**0.014**
Female gender	1.00	0.56 to 1.79	0.992	0.76	0.37 to 1.56	0.46
Allergic rhinitis	0.69	0.38 to 1.25	0.224	16.20	4.86 to 53.95	**<0.001**
50 FIS points less	0.87	0.73 to 1.04	0.137	1.15	0.92 to 1.43	0.217

FIS, International Ski Federation.

defined quite similarly as allergic and non-allergic asthma in this study.

Another key finding in our study was that before starting their skiing career, there was no difference in asthma prevalence between cross-country skiers and the controls and the controls mainly had allergic asthma. New cases of asthma in the Finnish population are mostly allergic until the age of 40, and in subjects of similar age to the current population, about 65% of asthma is allergic.[7] This is in line with 61% of the control subjects with asthma in the current study reporting allergic asthma. The risk factors for allergic asthma in childhood are allergic sensitisation of the subject and parental asthma or allergy.[4] This is in accordance with a family history of asthma and doctor-diagnosed allergy being risk factors for allergic asthma among competitive skiers in the current study.

Prevalence of asthma and competition success

To the best of our knowledge, this is the first study reporting asthma prevalence in cross-country skiers based on success in competitions. Interestingly, the prevalence of asthma was highest among the most successful skiers. This might be related to several factors. First, the most successful skiers also trained the most. If a high volume of training in cold air causes asthma, this might be the reason for the higher prevalence of asthma in the most successful skiers. To support this finding, athletes using β_2-agonists in the Olympic games from 2002 through 2010 won approximately twice as many medals as their proportion of all athletes across all disciplines.[15] Skiers also reported a high burden of respiratory symptoms.[8] Another possible explanation for the high prevalence of asthma in the most successful skiers is related to the propensity to seek medical attention. The most successful skiers also invest the most in their careers so that they might seek medical help for any symptoms more often than the general population. This is supported by the high rate of suspicion for asthma in this group in the current study. Although the prevalence of asthma is very high among the most successful competitive cross-country skiers, they also seemed to have the best symptom control, even though the difference was not statistically significant. This suggests that asthma in skiers is often well controlled and mostly does not prevent success in skiing careers. On the contrary, it has also been discussed whether asthma could provide a training stimulus not available to non-asthmatic athletes.[21]

The current study's categorisation of asthma as allergic and non-allergic asthma was based on a questionnaire rather than direct measurement of allergic sensitisation or allergen challenge tests. However, the results were similar with three different definitions of allergic asthma, supporting the robustness of our results. Relevant aeroallergens in Finland are pollens and pets, covered in our questionnaire. Because of dry indoor air during the cold winter, house dust mite is rarely a clinically relevant allergen in Finland.[22]

Table 5 Multivariable analysis for the risk of current asthma in cross-country skiers represented as ORs with 95% CIs

	Current asthma			Non-allergic asthma n=55			Allergic asthma n=36		
	OR	95% CI	P value	OR	95% CI	P value	OR	95% CI	P value
Age	1.06	1.01 to 1.11	**0.011**	1.02	0.97 to 1.07	0.411	1.08	1.02 to 1.14	**0.011**
100 hours more training per year	1.29	1.11 to 1.50	**0.001**	1.33	1.12 to 1.58	**0.001**	1.10	0.89 to 1.36	0.379
Parents or siblings with asthma	2.41	1.42 to 4.08	**0.001**	1.81	0.98 to 3.33	0.057	2.47	1.15 to 5.30	**0.021**
Allergic rhinitis	2.14	1.27 to 3.60	**0.004**	0.64	0.34 to 1.19	0.642	16.38	4.82 to 55.67	**<0.001**

Limitations

The response rate in this study was relatively low (27.3% in skiers and 19.5% in the controls), but this is still the largest survey in competitive cross-country skiers based on the number of respondents (n=351). Self-reported, physician-diagnosed asthma is the most commonly used method to evaluate the prevalence of asthma. The tests used in each skier's diagnostic workout could not be verified. However, in Finland, diagnosis of asthma is based on objective lung function measures because of the criteria for drug reimbursement. Asthma medication is fully reimbursed only if the diagnosis is based on such measures. Validation of self-reported asthma by lung function measures has been studied in a similar demographic population compared with the subjects in this study, finding that among Finnish university students aged 18 to 25 years, the specificity of physician-diagnosed current asthma was 99%.[23] The present study was conducted in a single country, but the results are probably generalisable to all competitive cross-country skiers in other countries. Responses regarding age at onset of asthma symptoms and age at diagnosis of asthma might be subject to recall bias. However, the questions were similar for both skiers and the controls, so comparison of the groups should be reliable. In addition, skiers with poorly controlled asthma might already have quit, so the respondents in the study might be subject to survivor bias. Some adolescents might never have taken part in cross-country skiing because of respiratory health concerns. This type of cross-sectional study is also limited in investigating time effects.

CONCLUSION

We conclude that the excess prevalence of asthma among competitive cross-country skiers compared with that in the general population is mainly because of non-allergic asthma emerging a couple of years after the onset of an active skiing career. Among skiers, a high volume of training seems to be a risk factor for non-allergic asthma, which might be the reason for the highest prevalence of asthma in the most successful cross-country skiers. On average, asthma is well controlled in all success categories of competitive skiers and does not seem to prevent a successful career. However, the findings in this study are limited owing to the response rate. Prospective studies with direct measures of the type and level of airway inflammation would verify a causal relationship between training volume and the type, severity and prognosis of asthma in competitive cross-country skiers.

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Contributors All authors designed the study. RM-H collected data. RM-H and HH conducted analyses. RM-H wrote the first version of the manuscript. All authors approved the final version. RM-H was the guarantor of the study.

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Competing interests The ICMJE forms are filled by all authors and declare no conflicts or interest that are relevant to this study.

Patient and public involvement Patients and/or the public were not involved in the design, or conduct, or reporting, or dissemination plans of this research.

Patient consent for publication Not applicable.

Ethics approval This study involves human participants and was approved by the ethics committee of Pirkanmaa Health Care District (R18108). Participants gave informed consent to participate in the study before taking part.

Provenance and peer review Not commissioned; externally peer reviewed.

Data availability statement Data are available upon reasonable request. The data that support the findings of this study are available on request from the corresponding author. The data are not publicly available due to privacy or ethical restrictions.

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Supplemental file 1

Mäki-Heikkilä et al. High training volume is associated with increased prevalence of nonallergic asthma in competitive cross-country skiers

Sensitivity analysis

Definition of allergic asthma

Asthma was defined as allergic if the subject reported a doctor-diagnosed allergy and asthma-related symptoms when exposed to furry animals or pollens. Otherwise, asthma was defined as nonallergic. As a sensitivity analysis, two additional different definitions of allergic asthma (doctor-diagnosed asthma and doctor-diagnosed allergy to pollens or animals or doctor-diagnosed asthma and asthmatic symptoms when exposed to furry animals or pollens) were used and are presented below.

Doctor-diagnosed asthma and doctor-diagnosed allergy to pollens or animals

Table 4A. Risk factors for allergic and non-allergic asthma asthma in cross-country skiers, represented as odds ratios (OR) with 95 % confidence intervals

	Non-allergic asthma n = 43			Allergic asthma n = 48		
	OR	**95% CI**	***p***	**OR**	**95% CI**	***p***
Age	1.04	1.00–1.09	0.078	1.07	1.03–1.12	**<0.001**
100 hours more training per year	1.28	1.08–1.51	**0.004**	1.25	1.07–1.45	**0.005**
Parents or siblings with asthma	2.18	1.14–4.15	**0.018**	2.22	1.23–3.99	**0.008**
Female sex	0.64	0.32–1.25	0.189	1.04	0.58–1.86	0.908
Allergic rhinitis	0.42	0.21–0.84	**0.014**	***		
50 FIS-points less	1.02	0.86–1.22	0.801	1.18	0.98–1.42	0.087

*** All skiers with allergic asthma by this definition had allergic rhinitis.

Table 5A. Multivariable analysis for the risk on current asthma in cross-country skiers, represented as odds ratios (OR) with 95 % confidence intervals.

	Current asthma n = 91			Non-allergic asthma n = 43			Allergic asthma n = 48		
	OR	**95% CI**	***p***	**OR**	**95% CI**	***p***	**OR**	**95% CI**	***p***
Age	1.06	1.01–1.11	**0.011**	1.03	0.97–1.09	0.359	1.10	1.03–1.17	0.003
100 hours more training per year	1.29	1.11–1.50	**0.001**	1.26	1.05–1.53	**0.016**	1.22	0.99–1.50	0.062
Parents or siblings with asthma	2.41	1.42–4.08	**0.001**	2.59	1.30–5.16	0.007	2.46	1.19–5.05	**0.015**
Allergic rhinitis	2.14	1.27–3.60	**0.004**	0.37	0.18–0.76	0.007	***		

*** All skiers with allergic asthma by this definition had allergic rhinitis.

Doctor-diagnosed asthma and asthmatic symptoms when exposed to furry animals or pollens

Table 4B. Risk factors for allergic and non-allergic asthma asthma in cross-country skiers, represented as odds ratios (OR) with 95 % confidence intervals

	Non-allergic asthma n = 26			Allergic asthma n = 65		
	OR	**95% CI**	***p***	**OR**	**95% CI**	***p***
Age	1.05	1.00–1.11	0.062	1.06	1.02–1.11	**0.003**
100 hours more training per year	1.37	1.13–1.68	**0.002**	1.24	1.07–1.44	**0.003**
Parents or siblings with asthma	0.68	0.29–1.60	0.372	3.11	1.79–5.44	**<0.001**
Female sex	1.43	0.64–3.17	0.385	0.72	0.41–1.25	0.241
Allergic rhinitis	0.86	0.38–1.93	0.717	2.81	1.60–4.94	**<0.001**
50 FIS-points less	1.54	1.11–2.12	**0.009**	1.05	0.90–1.22	0.556

Table 5B. Multivariable analysis for the risk on current asthma in cross-country skiers, represented as odds ratios (OR) with 95 % confidence intervals.

	Current asthma n = 91			Non-allergic asthma n = 26			Allergic asthma n = 65		
	OR	**95% CI**	***p***	**OR**	**95% CI**	***p***	**OR**	**95% CI**	***p***
Age	1.06	1.01–1.11	**0.011**	1.02	0.95–1.09	0.588	1.06	1.01–1.11	0.016
100 hours more training per year	1.29	1.11–1.50	**0.001**	1.34	1.07–1.67	**0.009**	1.18	1.00–1.39	0.054
Parents or siblings with asthma	2.41	1.42–4.08	**0.001**	0.63	0.25–1.59	0.329	3.59	1.98–6.51	**<0.001**
Allergic rhinitis	2.14	1.27–3.60	**0.004**	0.92	0.31–2.72	0.873	2.71	1.49–4.91	**0.001**

PUBLICATION
III

Cross-country skiers often experience respiratory symptoms during and after exercise but have a low prevalence of prolonged cough

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Cross-country skiers often experience respiratory symptoms during and after exercise but have a low prevalence of prolonged cough

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ABSTRACT

Background Cross-country skiers train and compete during the winter for long periods of time in subfreezing conditions, which strains the airways and provokes respiratory symptoms. This study aimed to compare the prevalence of exercise-related symptoms and prolonged cough in competitive cross-country skiers versus the general population and to investigate the association between these symptoms and asthma.

Methods A questionnaire was sent to Finnish cross-country skiers (n=1282) and a random sample of the general population (n=1754), with response rates of 26.9% and 19.0%, respectively.

Results Both groups were mostly asymptomatic at rest, but symptoms were increased in both groups during and after exercise. Cough was more prevalent after exercise in skiers and phlegm production was more common during and after exercise in skiers. Asthma did not provoke specific symptoms, but symptom prevalence was higher in asthmatic individuals. Skiers had a higher prevalence of cough after exercise (60.6% vs 22.8%, $p<0.001$) compared with controls, but controls had a higher prevalence of prolonged cough (4.1% vs 9.6%, $p=0.004$). In participants without asthma, cold air triggered symptoms more often in skiers than controls, while strong odours triggered symptoms more often in asthmatic controls than skiers. Chronic cough lasting more than 8 weeks was rare, reported by 4.8% of controls and 2.0% of skiers.

Conclusion Cross-country skiers, especially those with asthma, experience a higher burden of exercise-related respiratory symptoms compared with controls. However, repeated exposure to cold air does not appear to result in long-term hypersensitivity of the cough reflex arc.

WHAT IS ALREADY KNOWN ON THIS TOPIC

⇒ Respiratory symptoms are very common in cross-country skiers.

WHAT THIS STUDY ADDS

⇒ Skiers and controls were mostly asymptomatic at rest, but symptoms were increased in both groups during and after exercise.
⇒ Asthmatic participants had more symptoms than non-asthmatics in both skiers and controls. Skiers were more symptomatic than the controls, even when grouped by asthma status.
⇒ Even though cough after exercise was more prevalent in skiers compared with the controls, prolonged cough was more prevalent in the controls.

HOW THIS STUDY MIGHT AFFECT RESEARCH, PRACTICE AND/ OR POLICY

⇒ High prevalence rates of respiratory symptoms should be graded with severity and burden to further evaluate their effect on training and competition.

INTRODUCTION

Cross-country skiing is a demanding Olympic winter sport that requires a high maximal oxygen uptake, anaerobic capacity and high levels of upper body power.[1] Minute ventilation in elite skiers may well exceed 200 L/min, and their forced vital capacity and forced expiratory volume in one second often exceed normal values.[2] During the winter season, most of the training and competition in cross-country skiing takes place in subfreezing temperatures and cold and dry air acts as an external irritant, which cools the airways and increases osmolarity of the respiratory lining fluid due to water loss. This increase in osmolarity stimulates sensory nerves and may activate inflammatory cells and smooth muscle, contributing to the provocation of symptoms.[3] Respiratory symptoms are very common among cross-country skiers and may sometimes even be normal reactions to intensive exercise and the environment, thus being completely benign and physiological.

Respiratory symptoms in skiers are often reported using point prevalence, which refers to the proportion of individuals experiencing specific symptoms at a given time.[4–8] Reported symptoms include cough, chest tightness, phlegm production, wheezing and shortness of breath. The first study on respiratory symptoms in cross-country skiers was by Heir and Oseid in 1994, who found that 58% out of 153 Norwegian skiers had two or more respiratory symptoms and that skiers with asthma had more symptoms than non-asthmatic skiers, except for cough.[4] Sue-Chu *et al* reported respiratory symptoms separately for Norwegian and Swedish cross-country skiers, finding in the winter that 42% of Norwegian skiers and 64% of Swedish skiers (p<0.001) reported coughing during training. During the summer, the respective percentages were only 10% in Norwegian and 9% in Swedish skiers.[5] Turmel *et al* found in a screening study that 50% of the tested Canadian skiers and biathletes had respiratory symptoms, but possible differences between genders were not reported.[6] In recent studies by Norqvist and Eklund, female skiers had significantly more symptoms than male skiers in Sweden.[7 8] Various factors, such as exposure to cold air, may contribute to the provocation of respiratory symptoms. The effect of cold air on symptoms in skiers has been reported in one study that showed cold air increased respiratory symptoms in 14% of adolescent cross-country skiers in Norway and 45% in Sweden, without providing a specific comparison point.[5]

Cough in winter athletes is highly prevalent during exercise and after exercise.[4 5 9 10] However, it is not clear whether this causes a decrease in performance or leads to prolonged cough. Although cough as a respiratory symptom during and after exercise has been studied in skiers, no studies have investigated prolonged cough in athletes of any sport.[11 12] It is uncertain whether repeated high-intensity exercise in cold air damages the airways and induces long-term cough reflex hypersensitivity. Among athletes training in cold air, cough reflex sensitivity to capsaicin remained unchanged during the season, but cough after training was observed to be more frequent up to 8 hours after training.[10] This suggests that training might not change sensitivity of the cough reflex but to act as a trigger of cough.

The primary aim of the current study was to investigate the prevalence of respiratory symptoms in Finnish cross-country skiers, with a focus on prolonged cough and asthma subgroups at rest, during exercise and after exercise. Additionally, we sought to compare these findings with the general population of the same age, gender and region. We hypothesised that respiratory symptoms are more common in skiers during and after exercise, as they frequently engage in high-intensity exercise and have a higher prevalence of asthma.[13 14] Both factors may contribute to an increased occurrence of acute and prolonged cough in skiers.

METHODS

The present study protocol has been described in detail previously.[14] In short, all Finnish cross-country skiers who had enrolled in either national championships (from 17 years of age onwards to seniors) or the largest national junior skiing competition (13–16 years of age, Hopeasompa competition) were invited to participate in this cross-sectional questionnaire survey (n=1282). The control group was collected from the Finnish Digital and Population Data Services Agency, matching the skiers who had responded regarding age, gender and region of the country in which they lived. The controls were allowed to participate in competitive sports, but none of the controls competed in cross-country skiing.[14] Engaging in competitive sports was divided into four categories: team sports and sports based on required ventilation rate (high, moderate, low). Written informed consent was obtained from each respondent and from their guardians for participants under 18 years of age.

Skiers participated in the study at the beginning of the training season in May and June, while the controls participated in March and April. The participants filled out a questionnaire where different respiratory symptoms (cough, wheezing, shortness of breath, phlegm production and chest tightness) were each inquired about separately for at rest, during exercise and after exercise. The common triggers for respiratory symptoms were enquired. The participants were also asked whether they suffered from a current cough and its duration (less than a week, over a week but under 3 weeks, over 3 weeks but under 2 months, over 2 months but under 1 year, over 1 year but under 5 years, over 5 years but under 10 years or over 10 years). Cough was defined as acute current cough if it had lasted less than 3 weeks, prolonged cough if it had lasted more than 3 weeks but under 8 weeks and chronic cough lasting over 8 weeks.[15]

Current asthma was defined as self-reported physician-diagnosed asthma and at least one of the following criteria: currently having three asthma-related symptoms (cough, chest tightness, shortness of breath, wheezing or sputum production), active use of any asthma medication or an asthma control test score less than 25 points.[16] Allergic rhinitis was defined as self-reported physician-diagnosed allergic rhinitis. Smoking was defined as never-smoking or current smoking.

Statistical analyses were performed using SPSS V.27.0 (IBM, Armonk, New York). The continuous variables were tested for normality (Kolmogorov–Smirnov). Unpaired t-test, Mann-Whitney U test and one-way analysis of variance (ANOVA) were used for the comparisons between the groups, as appropriate. A χ^2 test or Fisher's exact test was used for comparisons of the categorical variables. A p value of <0.05 was considered statistically significant.

RESULTS

The total response rate in the current study was 19.0% (n=334) in the controls and 26.9% (n=345) in the skiers. The participants' characteristics are presented in table 1. The controls were slightly older, and a larger proportion of the controls compared with the skiers were women. Skiers had asthma more often, and none of them was currently smoking.

Number of different respiratory symptoms in cross-country skiers and controls at different states are presented in figure 1, and all percentages from all figures

Table 1 Participants' characteristics in the cross-country skiers and controls

	Cross-country skiers n=345		Controls n=334		
	Median/n	Q_1-Q_3/%	Median/n	Q_1-Q_3/%	P
Age, years	16.5	14.3–21.5	17.0	15–22.5	**0.033**
Body mass index, kg/m^2	21.0	19.2–22.8	21.6	19.7–25.1	**<0.001**
Women	204	58.1	235	69.5	**0.002**
Engaged in competitive sports other than cross-country skiing	223	63.5	88	26.0	**<0.001**
Team sports	36	16.1	54	61.3	**<0.001**
High ventilation sports (cycling, running, triathlon, orienteering, aerobic gymnastics)	195	87.6	7	7.9	**<0.001**
Moderate ventilation sports (combat sports, gymnastics, dancing)	0	0	19	21.6	**<0.001**
Low ventilation sports (shooting, horseback riding, weightlifting)	34	15.2	5	5.7	**0.022**
Smoking	0	0	20	5.9	**<0.001**
Current asthma	91	25.9	31	9.2	**<0.001**
Physician-diagnosed allergy to pollens or animals	113	32.8	82	24.6	**0.018**
Self-reported allergic rhinitis	159	46.1	122	36.5	**0.011**

P values were obtained with a Mann-Whitney U test for continuous variables and a Chi-squared test or Fisher's test for categorical variables; statistical significance (p<0.05) is indicated in bold.

are presented in online supplemental file 1. Both groups were mostly asymptomatic at rest, but symptoms were increased in both groups during and after exercise. Skiers had more exercise-related respiratory symptoms than the controls (figure 1). Moreover, skiers tended to have more symptoms after exercise than during exercise (p<0.001).

The most common respiratory symptoms in cross-country skiers were cough, phlegm production, wheezing and shortness of breath. Only chest tightness was uncommon in cross-country skiers. In controls, there were fewer symptoms overall compared with skiers and there was no clear difference in prevalence between different types of symptoms in controls themselves (figure 2). There were significant differences between the groups regarding respiratory symptoms. Cough was more prevalent after exercise in skiers. Phlegm production was more common in skiers both during and after exercise. In the controls, wheezing was more common at rest than in skiers, but during exercise and after exercise, skiers experienced wheezing significantly more (figure 2)

As asthma was more prevalent among skiers, the prevalence of respiratory symptoms in different physical activity categories according to asthma status is shown in figure 3. Skiers and controls with asthma reported a similar number of respiratory symptoms at rest and during exercise, but cross-country skiers with asthma had more symptoms after exercise than the asthmatic controls. In participants with no asthma, cross-country skiers had more symptoms during and after exercise compared with the controls.

When respiratory symptoms were grouped by category and asthma status, a higher prevalence in all symptoms was found in participants with asthma. The relative proportions of different symptoms between asthmatic

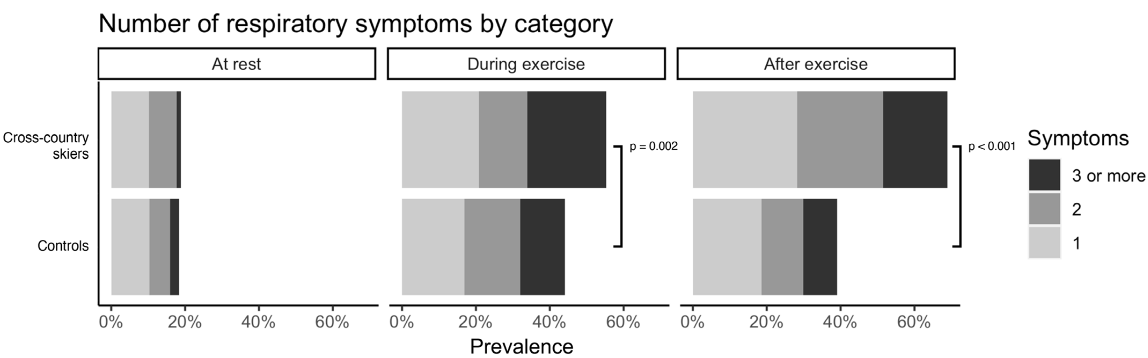

Figure 1 Number of different respiratory symptoms in cross-country skiers and controls at rest, during exercise and after exercise.

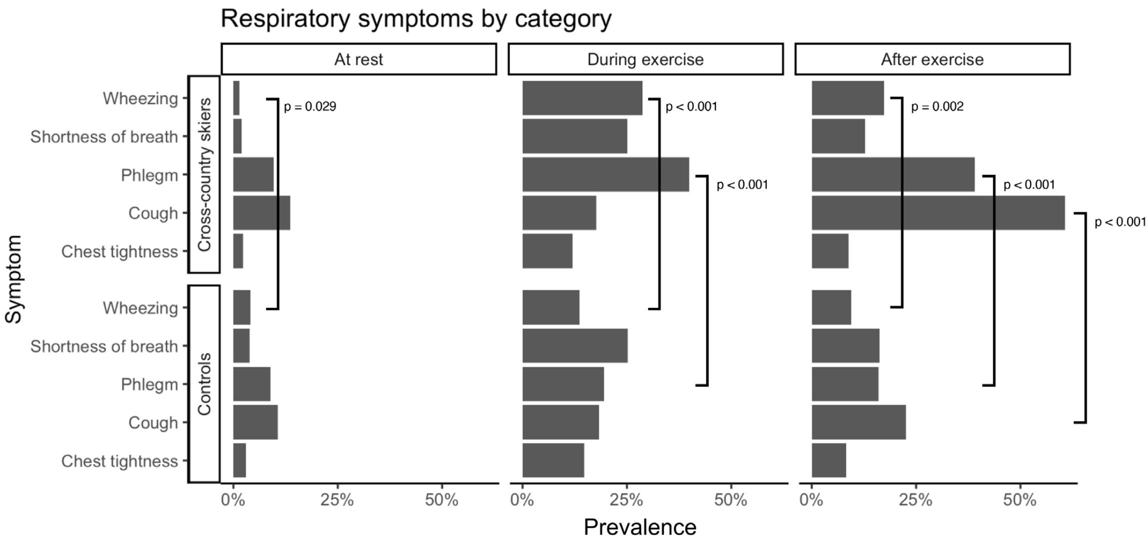

Figure 2 Prevalence of different respiratory symptoms in cross-country skiers and controls at rest, during exercise and after exercise.

and non-asthmatic participants were similar (ie, asthma did not provoke specific symptoms), but the prevalence of symptoms in general was higher in participants with asthma (figure 4).

The most common triggers causing respiratory symptoms were dust, tobacco smoke, exhaust gases, cold air, pollen and strong odours. All triggers caused more respiratory symptoms in participants with asthma than in non-asthmatic participants. In participants without asthma, cold air triggered symptoms more often in skiers than in the controls. On the other hand, strong odours triggered symptoms more often in asthmatic controls than in asthmatic skiers. The data are presented in table 2.

Current cough, both acute and prolonged, was more prevalent in controls compared with skiers (table 3). When skiers and controls were pooled together, participants with prolonged coughs also reported coughs more

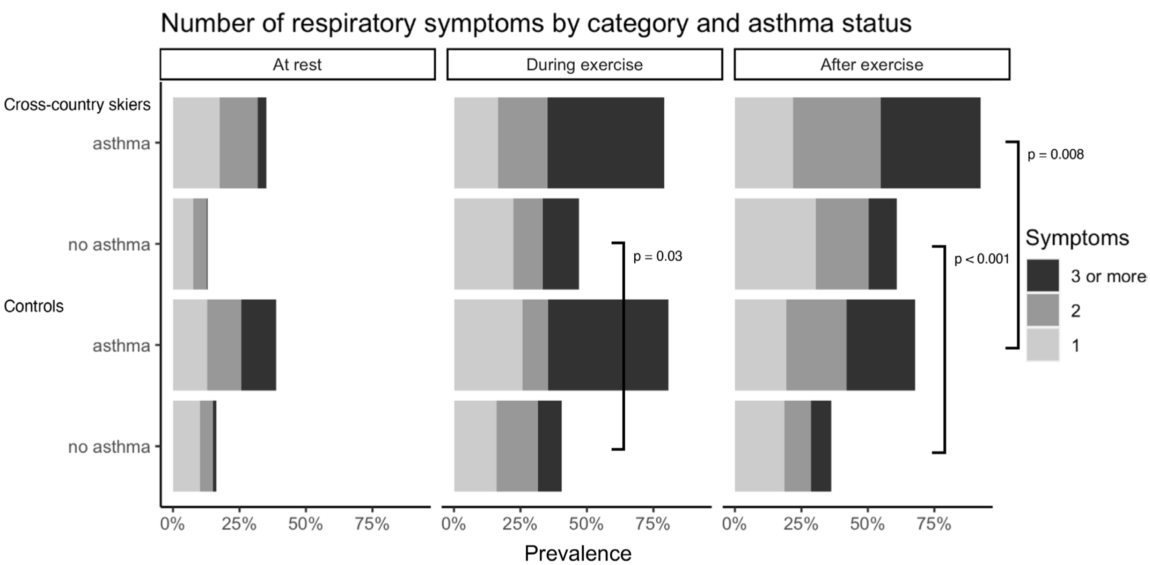

Figure 3 Number of respiratory symptoms in cross-country skiers and controls at rest, during exercise and after exercise according to the asthma status.

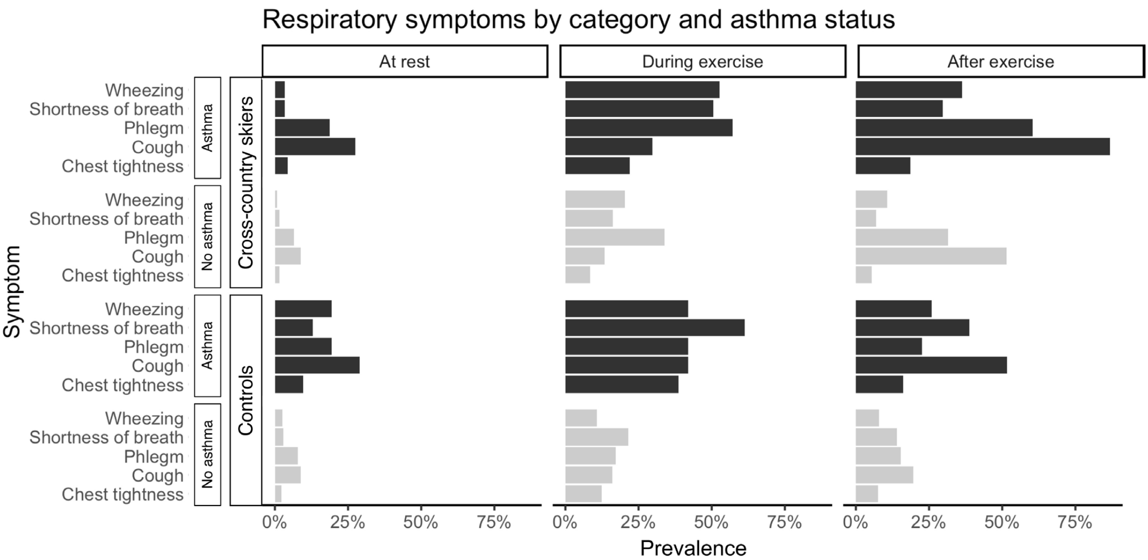

Figure 4 Prevalence of different respiratory symptoms in cross-country skiers and controls at rest, during exercise and after exercise according to asthma status.

frequently at exercise and after exercise (table 4). Furthermore, participants with prolonged cough reported cold air and strong odours as triggers for their respiratory symptoms more frequently.

DISCUSSION

In the current study that was conducted among competitive cross-country skiers, we have reported a high prevalence of respiratory symptoms during and after exercise. Skiers are more symptomatic than controls, even when the participants are grouped by asthma status. Asthmatic participants had more symptoms than non-asthmatics in both skiers and controls. Even though cough after exercise was more prevalent in skiers compared with the controls, prolonged cough (>3 weeks) and chronic cough (>8 weeks) were less prevalent in skiers than in controls.

Different respiratory symptoms may have different causes. Cough and phlegm may be triggered by irritation of the airways, which activates sensory nerves and mucous glands, while wheezing and shortness of breath may be signs of obstruction, possibly due to smooth muscle contraction or mucosal oedema.[17 18] Also, dysfunctional breathing or exercise-induced laryngeal obstruction (EILO) may case dyspnoea and wheezing, mimicking asthma. Gastro-oesophageal reflux, although not extensively studied in skiers regarding cough,[19] may also play a role. Furthermore, cold air hyperpnea can increase airway lining fluid osmolarity by evaporating water, activating certain sensory endings and causing coughing.[20]

Table 2 Triggers causing respiratory symptoms

	No asthma n=567				P between groups with no asthma	Asthma n=122				P between groups with asthma
	Controls n=307		Cross-country skiers n=260			Controls n=31		Cross-country skiers n=91		
	n	%	n	%		n	%	n	%	
Cold air	55	18.0	68	26.1	**0.025**	19	61.3	56	62.2	1.000
Dust, tobacco smoke, exhaust gases	100	32.7	89	34.4	0.739	22	71.0	55	60.4	0.404
Pollen	46	15.0	56	21.6	0.055	17	54.8	42	46.7	0.564
Hairy animals	21	6.9	18	7.0	1.000	11	36.7	18	19.8	0.103
Strong odours	51	16.7	28	10.7	0.058	16	51.6	23	25.3	**0.013**
Humid, misty air	15	4.9	10	3.8	0.693	3	9.7	17	18.7	0.399

P values were obtained with Chi-squared test; statistical significance (p<0.05) is indicated in bold.

Table 3 Current cough in cross-country skiers and controls

	Controls n=332		Cross-country skiers n=345		
	n	%	n	%	P
Any current cough	105	32.0	61	17.7	**<0.001**
Acute cough (<3 weeks)	73	21.9	47	13.6	**0.006**
Prolonged cough (≥3 weeks)	32	9.6	14	4.1	**0.004**
Chronic cough (>8 week)	16	4.8	7	2.0	**0.047**

P values were obtained with Chi-squared test; statistical significance (p<0.05) is indicated in bold.

Exercise-induced bronchoconstriction (EIB) could trigger coughing; however, bronchoconstriction is a relatively weak stimulus for cough.[21]

Although asthma has been reported to be highly prevalent according to earlier articles in this current population,[14 22] prolonged cough was not prevalent in skiers in the current study. The mechanisms behind asthma and cough reflex hypersensitivity are at least partly different.[23] High ventilation rate in cold air may trigger epithelial damage, induce inflammatory response and lead to hyper-reactivity of airway smooth muscle and asthma.[24] Once hyper-reactivity has developed, EIB is thought to be caused by water loss, resulting in heat loss and hyperosmolality of the airway surface liquid during exercise, leading to activation of mast cells releasing substances contracting smooth muscle.[24]

The most common respiratory symptom in skiers was cough, especially after exercise. Prolonged cough for over 8 weeks was very rare in skiers (2.0%). In both groups, current cough had mainly lasted less than 3 weeks, but prolonged cough was two times as prevalent in controls as in skiers. This does not support our hypothesis that repeated exposure through high-volume endurance training causes long-term cough reflex hypersensitivity. This may be partly explained by the survey taking place outside the competition season during which skiers may be less symptomatic in the training season. A study to support this was reported by Sue-Chu *et al*,[5] where in the winter, 42% of Norwegian skiers and 64% of Swedish skiers (p<0.001) reported coughing during training and while during the summer, the respective percentages were 10% in Norwegian and 9% in Swedish skiers. To support this, in another Norwegian study in cross-country skiers, the airways were found to be more hyperreactive to methacholine challenge during competition season in skiers.[25 26]

Cough after exercise and prolonged cough may be related to different mechanisms. Airway mucosa irritation due to intense ventilation in cold air is a physiological response, as suggested by the high prevalence of rhinorrhoea in healthy participants exposed to cold air.[17 18] This may also trigger short-term cough after intense exercise in cold air. On the other hand, prolonged cough is often related to cough reflex hypersensitivity, which may involve altered function in peripheral sensory neurons or altered central processing of the urge to cough.[27] Turmel *et al* discussed that cough receptors could be desensitised due to long-term exposure to cold and dry air.[10] This would explain why exercise may still trigger a short-term cough right after exercise but decreases the tendency to have prolonged cough. Moreover, capsaicin, another hypertussive irritant in addition to cold air, triggers

Table 4 Characteristics of participants with and without current prolonged cough among the total population

	No current cough or cough <3 weeks n=640		Prolonged cough ≥ 3 weeks n=46		
	n	%	n	%	P
Cross-country skier	337	52.6	14	30.4	**0.004**
Women	407	63.5	30	65.2	0.815
Current asthma	110	17.2	12	26.1	0.126
Smoking	19	3.0	1	2.2	1.000
Cough at exercise	101	15.8	22	47.8	**<0.001**
Cough after exercise	258	40.2	31	67.4	**<0.001**
Cold air provokes respiratory symptoms	176	27.5	22	47.8	**0.003**
Strong odours provoke respiratory symptoms	100	15.6	18	39.1	**<0.001**

P values were obtained with χ^2 test or Fisher's test; statistical significance (p<0.05) is indicated in bold.

cough after a single exposure but has been suggested to decrease cough sensitivity and to treat chronic cough as repeated dosing.[28 29] This similarity between capsaicin and repeated exposure to cold air further supports the idea that different mechanisms are involved in cough after exercise and prolonged cough. Exposure to a trigger like cold air or capsaicin provokes cough, but repeated long-term exposure to the same trigger may desensitise cough reflex and protect from chronic cough.

In the current study, we found that 39.1% of all participants and 35.7% (5 with prolonged cough vs 44 with no cough, p<0.035) of skiers with prolonged cough were sensitive to strong odours. This feature, known to be associated with cough reflex hypersensitivity in the general population,[30 31] has not been reported in athletes previously. Furthermore, participants with asthma were more sensitive to strong odours, and this may be related to asthmatic inflammation sensitising cough reflex.[32]

To interpret these high prevalence rates of respiratory symptoms in skiers, it should be highlighted that cross-country skiing puts an exceptionally high strain on airways through high sustained ventilation and cold subfreezing air in the winter.[1 2] Although respiratory symptoms may be a sign of respiratory illness, such as asthma, the airway response in the form of cough and increased sputum production may also be a physiological response to exercise.[17 18] Although skiers are symptomatic, asthma is well controlled overall and across different performance levels.[14 22] However, it is possible that skiers with respiratory health issues may have retired their athletic career and, thus, not affecting the results. Skiers may also present with different conditions affecting the airways simultaneously, such as EILO or dysfunctional breathing.[33] The presence of other respiratory conditions may further confound the results, as not all symptoms are due to asthma and different respiratory conditions may exist simultaneously, as shown by Irewall *et al*.[34]

Strengths and weaknesses

In the present study, we did not measure the intensity of symptoms, only the mere presence of symptoms in different situations and the time frame presented (at rest, at exercise, after exercise) was not strictly defined. The intensity and effect of symptoms may differ, and mild symptoms may not be disturbing. Survivor bias may also affect the results because skiers with difficult symptoms may not continue a successful athletic career for long. However, respiratory symptoms in skiers may be in general mild in nature as most skiers report respiratory symptoms.

The survey times were slightly different in skiers and controls. Skiers mainly responded to the study during May/June and the controls in March/April. This may confound the results because the most intensive tree-pollen season in Finland is in May (usually from March to June). Moreover, the survey in skiers was conducted in early training season outside of competitions, so the prevalence of respiratory symptoms and current cough might have been lower at this of year. Again, as discussed earlier, truly prolonged cough over 8 weeks was rare in skiers and supports the argument that prolonged cough is less prevalent in skiers, irrespective of the time of the year.

The methods used in each skier's diagnostic work out could not be verified, but in Finland, asthma diagnosis is most often based on objective lung function measures because of the criteria for drug reimbursement. Validation of self-reported asthma by lung function measures has been studied in a similar demographic population as the participants in the present study, finding that among Finnish university students, 18 to 25 years of age, the specificity of physician-diagnosed current asthma was 99%.[35]

The response rate in the current study was relatively low (19.0% (n=334) in the controls and 26.9% (n=345) in the skiers). Women responded more often, which has also been reported earlier in a similar age group investigating respiratory health.[36] Low response rate is a common issue when surveying young and healthy populations, and it is particularly challenging to obtain responses from young men living in rural areas,[37 38] who constituted the majority of participants in this study. Responses may be subjected to recall bias, and this type of cross-sectional study is limited in investigating time effects.

CONCLUSION

We conclude that cross-country skiers have more exercise-associated respiratory symptoms than controls and that the prevalence of symptoms is especially high in participants with asthma. Although exercise often provokes cough in cross-country skiers, repeated hyperpnea of cold air does not seem to lead to long-standing hypersensitivity of the cough reflex and prolonged cough. This is in contrast to the high prevalence of asthma in skiers. Thus, the results suggest that the high prevalence of symptoms does not cause a major burden to prevent a successful athletic career. In the future, research on respiratory symptoms should be graded with symptom severity and burden to further evaluate their effect on training and competition and explore whether long-time exposure to high ventilation of dry and cold air actually desensitises cough receptors and prevents prolonged cough.

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Competing interests None declared.

Patient and public involvement Patients and/or the public were not involved in the design, or conduct, or reporting, or dissemination plans of this research.

Patient consent for publication Consent obtained directly from patient(s).

Ethics approval This study involves human participants and was approved by the Ethics Committee of Pirkanmaa Health Care District (R18108). Participants gave informed consent to participate in the study before taking part.

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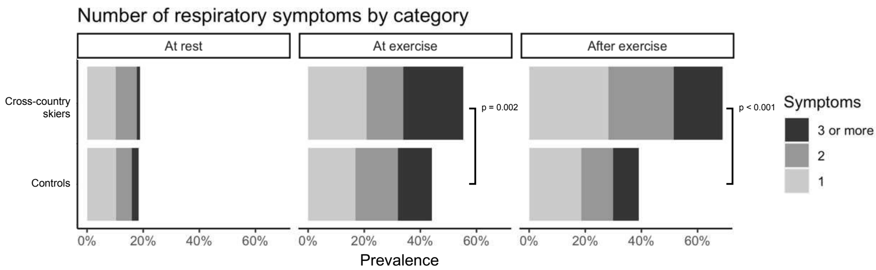
Supplement 1

Cross-country skiers often experience respiratory symptoms during and after exercise but have a low prevalence of prolonged cough

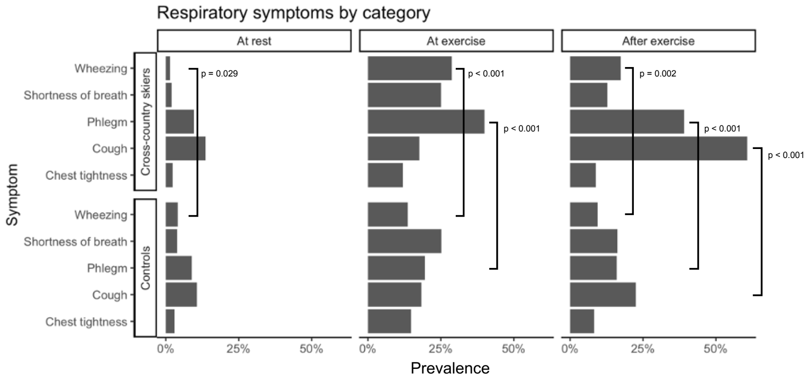
Mäki-Heikkilä Rikhard, Koskela Heikki, Karjalainen Jussi, Parkkari Jari, Huhtala Heini, Valtonen, Maarit, Lehtimäki Lauri

Figure 1 with percentages.



	At rest				At exercise				After exercise			
symptoms	Skiers		Controls		Skiers		Controls		Skiers		Controls	
	n	%	n	%	n	%	n	%	n	%	n	%
1	36	10.3	35	10.4	73	20.8	57	16.9	99	28.2	63	18.6
2	26	7.4	19	5.6	46	13.1	51	15.1	82	23.4	38	11.2
3 or more	4	1.1	8	2.4	75	21.4	41	12.1	61	17.3	31	9.2
	p = 0.969				p = 0.002				p<0.001			

Figure 2 with percentages.

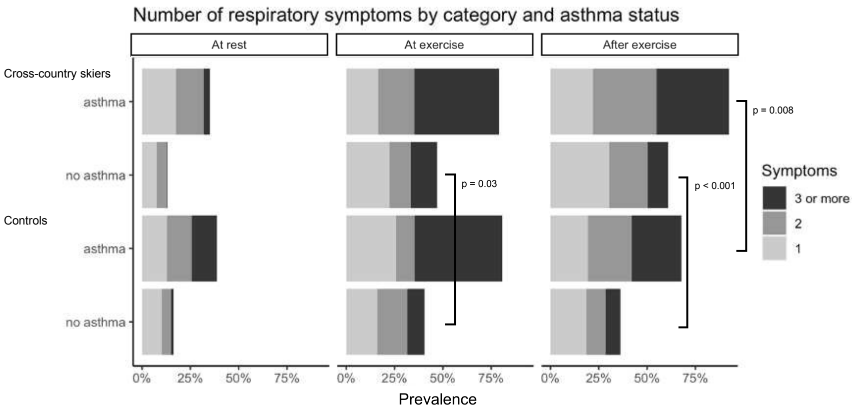


At rest					
symptoms	Skiers		Controls		p
	n	%	n	%	
Wheezing	5	1.4	14	4.2	0.029
Shortness of breath	7	2.0	12	3.6	0.217
Phlegm	34	9.9	30	9.0	0.697
Cough	47	13.6	35	10.5	0.209
Chest tightness	8	2.3	10	3.0	0.584

At exercise					
symptoms	Skiers		Controls		p
	n	%	n	%	
Wheezing	101	29.3	46	13.8	<0.001
Shortness of breath	88	25.5	85	25.4	0.986
Phlegm	137	39.7	66	19.8	<0.001
Cough	62	18.0	62	18.6	0.842
Chest tightness	42	12.2	50	15.0	0.287

After exercise					
symptoms	Skiers		Controls		p
	n	%	n	%	
Wheezing	61	17.7	32	9.6	0.002
Shortness of breath	45	13.0	55	16.5	0.208
Phlegm	134	38.8	54	16.2	<0.001
Cough	209	60.6	76	22.8	<0.001
Chest tightness	30	8.7	28	8.4	0.884

Figure 3 with percentages.

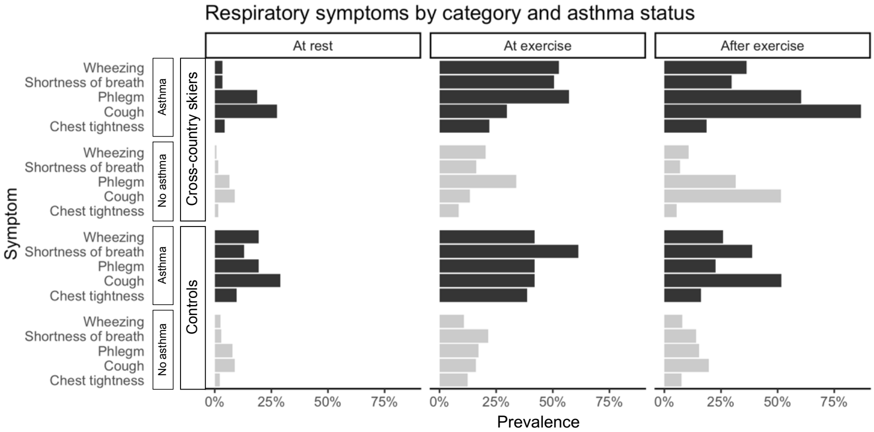


At rest					
	Skiers		Controls		p
	n	%	n	%	
Asthma					
1 symptom	15	16.9	4	12.9	
2 symptoms	13	14.6	4	12.9	0.271
3 or more symptoms	3	3.4	4	12.9	
No asthma					
1 symptom	20	7.8	31	10.2	
2 symptoms	13	5.1	14	4.6	0.489
3 or more symptoms	1	0.4	4	1.3	

At exercise					
	Skiers		Controls		p
	n	%	n	%	
Asthma					
1 symptom	14	15.7	8	25.8	
2 symptoms	17	19.1	3	9.7	0.474
3 or more symptoms	40	44.9	14	45.2	
No asthma					
1 symptom	56	21.9	49	16.2	
2 symptoms	29	11.3	48	15.8	0.03
3 or more symptoms	35	13.7	27	8.9	

	After exercise				
	Skiers		Controls		p
	n	%	n	%	
Asthma					
1 symptom	18	20.2	6	19.4	
2 symptoms	30	33.7	7	22.6	0.008
3 or more symptoms	34	38.2	8	25.8	
No asthma					
1 symptom	78	30.5	57	18.8	
2 symptoms	51	19.9	31	10.2	<0.001
3 or more symptoms	26	10.2	23	7.6	

Figure 4 with percentages.



	At rest				
	Skiers		Controls		p
	n	%	n	%	
Asthma					
Wheezing	3	3.4	6	19.4	0.009*
Shortness of breath	3	3.4	4	12.9	0.072*
Phlegm	17	19.1	6	19.4	0.975
Cough	24	27.0	9	29.0	0.824
Chest tightness	4	4.5	3	9.7	0.373*
No asthma					
Wheezing	2	0.8	8	2.6	0.119*
Shortness of breath	4	1.6	8	2.6	0.560*
Phlegm	17	6.6	24	7.9	0.563
Cough	23	9.0	26	8.6	0.867
Chest tightness	4	1.6	7	2.3	0.561*

*Fisher's test

	At exercise				
	Skiers		Controls		p
	n	%	n	%	
Asthma					
Wheezing	48	53.9	13	41.9	0.250
Shortness of breath	46	51.7	19	61.3	0.355
Phlegm	51	57.3	13	41.9	0.140
Cough	27	30.3	13	41.9	0.238
Chest tightness	20	22.5	12	38.7	0.078
No asthma					
Wheezing	53	20.7	33	10.9	0.001
Shortness of breath	42	16.4	66	21.8	0.109
Phlegm	86	33.6	53	17.5	<0.001
Cough	35	13.7	49	16.2	0.410
Chest tightness	22	8.6	38	12.5	0.133

	After exercise				
	Skiers		Controls		p
	n	%	n	%	
Asthma					
Wheezing	33	37.1	8	25.8	0.254
Shortness of breath	27	30.3	12	38.7	0.391
Phlegm	54	60.7	7	22.6	<0.001
Cough	78	87.6	16	51.6	<0.001
Chest tightness	17	19.1	5	16.1	0.713
No asthma					
Wheezing	28	10.9	24	7.9	0.221
Shortness of breath	18	7.0	43	14.2	0.007
Phlegm	80	31.3	47	15.5	<0.001
Cough	131	51.2	60	19.8	<0.001
Chest tightness	13	5.1	23	7.6	0.228

PUBLICATION IV

Acute respiratory infections hamper training and competition in cross-country skiers, especially in those with asthma

Mäki-Heikkilä Rikhard, Karjalainen Jussi, Parkkari Jari,
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SHORT COMMUNICATION

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Acute respiratory infections hamper training and competition in cross-country skiers, especially in those with asthma

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ABSTRACT
Acute respiratory infections (ARinf) are one of the leading causes that prevent athletes from training and competing. The aim of this study was to investigate the burden of ARinfs during one season among cross-country skiers. All Finnish cross-country skiers enrolled in the largest national competitions in winter 2019 ($n = 1282$) were sent a postal questionnaire. A higher proportion of skiers with than without asthma had to refrain from competitions because of ARinf (76.9% vs. 62.2%, $p = 0.011$) but there was no significant difference in refraining from training (91.2% vs. 83.8%, $p = 0.084$). In skiers with asthma, the median duration of a single ARinf episode was longer (5.0 days, IQR 3.8–6.8 vs. 4.0 days, IQR 3.0–6.7, $p = 0.017$), and they had more days of absence because of ARinf throughout the season (median 15 days (IQR 8–28) vs. 10 days (IQR 6–18), $p = 0.006$) in comparison to non-asthmatics. However, many of the skiers either trained (54.4%) or competed (22.5%) during an ARinf.

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Introduction

Acute respiratory infections (ARinfs) are one of the main causes that prevent athletes from training [1]. Previously, the burden of ARinfs has been assessed in cross-country skiers only in a few studies with different designs. A retrospective study by Svendsen et al. [2] investigated 7000 weeks of training diaries from 37 skiers and found that, on average, skiers suffered from ARinf three times a year and that the median duration of symptoms was 19 days (range 6–43 days). After intense competition periods, such as the Tour de Ski, the participating athletes were at three times higher risk of ARinf compared to athletes not participating in the Tour de Ski [3]. Furthermore, during the Nordic Ski World Championships, skiers were at a seven times higher risk of ARinf than the controls of the general population [4]. The prevalence of asthma among cross-country skiers is high, ranging between 20% and 30% [5] and we have also previously reported higher prevalence of asthma in skiers compared to general population in Finland (25.9% vs. 9.6%) [6]. Given the potential relationship between asthma and ARinfs [7], the current study aimed to investigate the burden of ARinfs during one season among cross-country skiers within the same study sample and whether asthma is related to the burden.

Methods

The present study protocol has been described in detail previously [6]. In short, all Finnish cross-country skiers who had enrolled in either national championships in spring 2019 (from 17 years of age onwards to seniors) or the largest national junior skiing competition (13–16 years of age, Hopeasompa competition) were invited to participate in this cross-sectional questionnaire survey. The Finnish Ski Association participated in the study by sending questionnaires to the athletes ($n = 1282$). Written informed consent was obtained from each respondent and from guardians for subjects under 18 years old. The study was approved by the Ethics Committee of Pirkanmaa Health Care District (R18108).

Current asthma was defined as self-reported physician-diagnosed asthma and at least one of the following: currently having three asthma-related symptoms (cough, chest pain, shortness of breath, wheezing or

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sputum production), active use of any asthma medication or asthma control test (ACT) score of less than 25 points.

Refraining from training or competition was defined with answering “yes” to the following questions: “Did you have acute respiratory infections (e.g. flu, common cold, cough, sinusitis) during the last 12 months that prevented you from training?” or “Did you have to abstain from competition because of an acute respiratory infection in the last 12 months?”, respectively.

Engaging in sports during an ARinf was defined with answering “yes” to the following questions: “Have you trained during an acute respiratory infection during the last 12 months?” and “Have you competed during an acute respiratory infection during the last 12 months?”.

Further data collection included weekly training volume, and FIS points for skiers to measure competition success were obtained from the International Ski Associations (FIS) 8th FIS points list from season 2018/2019, which was in effect at the time of the study [8]. In total, 163 skiers had collected FIS points.

Statistical analyses were performed using SPSS version 27.0 (IBM Corp., Armonk, NY). The continuous variables were skewed (Kolmogorov – Smirnov), and Mann Whitney U-test was used for the comparisons between the groups. A chi-square test or Fisher’s exact test was used for comparisons of the categorical variables. A *P* value of <0.05 was considered statistically significant.

Results

Details of the study sample have been previously published [6]. The response rate was 27.3% ($n = 351$), 58% of the responders were women, and 25.9% ($n = 91$) had current asthma. The median age was 16.6 years (IQR 14.3–21.4), and the weekly median training volume was 10.0 hours (IQR 8.0–12.5). The majority of skiers had refrained at least once from training (85.8%) or competing (66.0%) due to ARinfs during the season. A higher proportion of asthmatics (76.9%) than non-asthmatics (62.2%, $p = 0.011$) had refrained from competing (Table 1). The odds ratio, with asthma as a risk factor for having to refrain from training, was 2.00 (CI 95% 0.90–4.43, $p = 0.089$), and from competition, it was 2.03 (CI 95% 1.17–3.51, $p = 0.011$). About half of the skiers trained, and one-fifth competed during ARinf, with no difference in relation to asthma.

There were no notable differences between the sexes, between juniors and seniors (cut-off age 16 years) or between quartiles grouped by training volume or competition success (FIS points) in refraining from training or competition because of an ARinf or in training or competing during an ARinf (Table 2).

Cross-country skiers with asthma had more days of absence from training because of an ARinf during the season compared with skiers with no asthma (median 15 days (IQR 8–28) vs. 10 days (IQR 6–18), $p = 0.006$ (Figure 1)). There were no differences in the days of absence because of an ARinf between quartiles when grouped by training volume (11, 11.5, 10 and 14.5 days in descending order, p = 0.105) or by FIS points (competition success) (10, 13, 10 and 10 days in descending order, p = 0.893). Skiers with asthma had a higher number of ARinf episodes than skiers with no asthma (3 (IQR 2–4) vs. 3 episodes (IQR 2–3), $p = 0.028$), but no difference was found between quartiles grouped by training volume (3, 3, 3, 3 events in descending order, p = 0.846) or by FIS points (3, 3, 3, 3 episodes, p = 0.418). The median duration of a single ARinf episode was longer in skiers with asthma (5.0 days, IQR 3.8–6.8 vs. 4.0 days, IQR 3.0–6.7, $p = 0.017$).

Discussion

In the present study, we found that the majority of skiers had to refrain from training because of an ARinf during the season, and two-thirds of skiers had to refrain from competition because of an ARinf. Despite this, about half of the skiers trained and about one-fifth had competed during an ARinf. Skiers with asthma had more and longer episodes of ARinf, leading to increased

Table 1. Number and proportion of cross-country skiers who reported refraining from training and competing because of acute respiratory infections at least once, and who reported training or competing during acute respiratory infections at least once during the 2018/2019 season. The results were grouped by current asthma.

	Response	“Yes” in all skiers		“Yes” in skiers with asthma		“Yes” in skiers without asthma		
	n	n	%	n	%	n	%	p*
Refrained at least once from								
training because of ARinf	351	301	85.8	83	91.2	218	83.8	0.084
competition due ARinf	350	231	66.0	70	76.9	161	62.2	**0.011**
During ARinf at least once								
training	309	168	54.4	44	58.7	124	53.0	0.391
competing	351	79	22.5	25	27.5	54	20.8	0.188

*p-value between skier with and without asthma.

Table 2. Subject characteristics, training volume, prevalence of asthma, use of asthma medication and asthma control in cross-country skiers divided by performance level according to FIS points.

	Refrained from training due to ARinf			Refrained from competition due to ARinf		
	n	%	p	n	%	p
Male (147)	120	81.6		100	68.0	
Female (204)	181	88.7	0.061	131	64.5	0.496
Under 16 years of age (130)	108	83.1		85	65.4	
Over 16 years of age (221)	190	86.0	0.464	143	64.7	0.898
FIS points range (points)						
The best quartile (0–120.54)	37	90.2		30	73.2	
2nd quartile (120.25–185.13)	35	85.4		28	68.3	
3rd quartile (185.14–247.52)	33	80.5		22	53.7	
4th quartile (247.53–999)	35	87.5	0.632	27	67.5	0.280
Weekly training (hours)						
1st quartile (12.5–25.0)	75	85.2		61	69.3	
2nd quartile (10–12.5)	74	84.1		50	56.8	
3rd quartile (8.0–10.0)	78	88.6		58	65.9	
4th quartile (1.9–8.0)	74	85.1	0.837	62	72.1	0.160

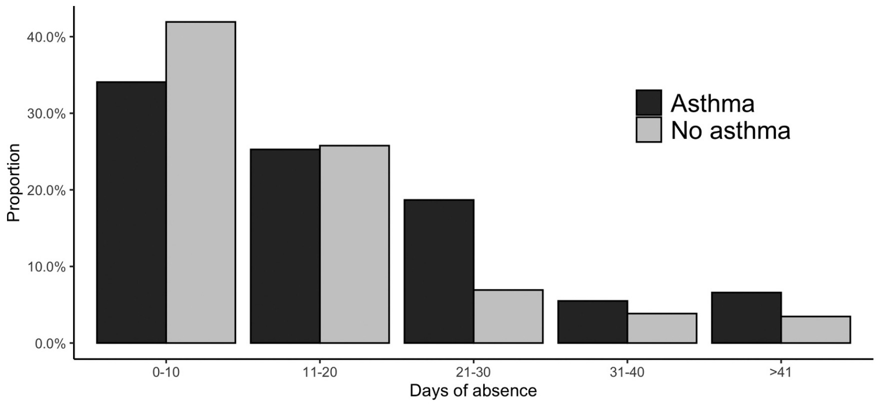

Figure 1. Days of absence from training because of ARinf in cross-country skiers as grouped by asthma status (median 15 days (IQR 8–28) in those with asthma vs. 10 days (IQR 6–18) in those without asthma, p = 0.006).

days off from training and a higher rate of withdrawal from competitions.

Considering the high prevalence of asthma among cross-country skiers (20–30%) [5], its potential association with ARinfs could have a significant impact on a considerable number of athletes. Higher proportion of asthmatic skiers missed competition because of an ARinf and had more days with ARinf symptoms, which could be due to longer recovery times with chronic inflammation of the airways [9,10]. The literature is scarce in investigating the effects of asthma on acute respiratory infections in athletes. In a recent study by Hull et al., 63% of 122 athletes were classified as susceptible to RTI (respiratory tract infection, equivalent to ARinf in the current study) if they had at least two or more RTI episodes in the past 18 months [11]. In their analysis, all athletes with asthma were classified as RTI (ARinf) susceptible ($n = 9$) [11]. Because of the moderate sample size, no significant difference was found between the groups [11]. Notably, we found no difference in days of absence because of an ARinf or ARinf episodes when skiers were grouped by training volume or competition success contrasting with findings in competitive swimmers, where international-level swimmers had fewer days of absence than national-level swimmers [12].

We did not investigate whether the athletes in the current study started training in the late stage of the infection with mild symptoms before becoming fully asymptomatic and, thus, reporting training during and ARinf. In a recent meta-analysis, the mean duration of ARinf in athletes was 7 days, but only 20% of ARinf prevented training for more than 1 day [13]. Since ARinfs are among the most common conditions in athletes and there is no knowledge of when it is safe to return to training, well-documented studies on safe return to sports are required.

Although this sample is the largest ever collected in competitive cross-country skiers, as measured by the number of participating skiers, the results are limited by factors such as the response rate, potential recall bias and lack of verification of training absences or ARinf periods from training diaries or similar records and whether training during an ARinf affected symptom severity and duration. The present study was conducted in a single country, and a similar study in another country and under different training cultures and considerations for training under ARinf could have produced different results. Future studies should investigate whether training and competing during an ARinf could increase the risk of developing asthma or major complications and whether this causes longer breaks from training and competitions.

Conclusion

We conclude that training and competing under an ARinf is very common in cross-country skiers. Notably, skiers with asthma, exhibit a higher propensity to abstain from competition, endure more frequent and longer ARinfs, and consequently, take more days off training due to ARinfs in a season compared to non-asthmatic skiers. Despite previous research suggesting a successful athletic career is achievable with asthma, our findings highlight a greater burden posed by ARinfs for asthmatic athletes. Thus, it is critical for asthmatic athletes and their coaches to understand the potential need for an extended recovery period following an ARinf.

In the future, prospective studies should focus on the objective verification of training absences, detailed symptom reporting, assessment of ARinf severity, its impact on training and performance while also exploring the incidence of possible major complications because of training during an ARinf. Moreover, randomised controlled trials are needed to establish evidence-based protocols for safe and as quick as possible returning to sports after the acute phase of an infection to avoid detraining. Further research should also explore the reasons behind extended absences due to ARinfs among asthmatic skiers and the potential consequences of such absences, including early retirement. This will help better comprehend the full impact of asthma on winter athletes.

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Disclosure statement

No potential conflict of interest was reported by the author(s).

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